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Interplanting of Three Lupine Cultivars with Orange Trees at Three Lupine Planting Densities in Sandy Soil

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ABSTRACT

Background and Objective: Interplanting legumes with orchards is a popular practice on newly reclaimed soils. A field trial was conducted at the newly reclaimed soils of East of Suez Canal Horticulture Research Station, Agricultural Research Center (ARC), North Sinai Governorate, Egypt. The study aimed to identify the optimal plant density for three lupine cultivars when interplanted with orange trees in sandy soil to enhance crop productivity, land use efficiency and profitability. **Materials and Methods:** The 18 treatments were formed by combining three lupine cultivars (Giza 1, Giza 2 and Giza 3) with three planting densities (50.0, 62.5 and 75.0% of the recommended sole lupine density) under interplanting and sole plantings. The treatments were arranged in a strip split-plot design with three replicates. The two cropping systems were assigned in the vertical strips, the three lupine plant densities were assigned in the horizontal strips and the three lupine cultivars were distributed in the sub-plots. **Results:** Interplanting negatively affected the seed yield and yield components of lupine compared with sole plantings. However, the seed yield/fad increased with increased lupine plant density. The Giza 3 showed higher productivity than the other two cultivars. The productivity of orange trees increased when the plant density was 75.0% of the recommended sole lupine. Additionally, there was an increase in the productivity of orange trees with Giza 3 compared to the other two cultivars. **Conclusion:** Interplanting 6 ridges of Giza 3 with orange trees achieved high productivity of both crops, efficient land usage and profitability under sandy soil conditions.

KEYWORDS

Interplanting, sandy soils, orange trees, lupine cultivars, lupine plant density, land usage

INTRODUCTION

In regions with limited land resources, interplanting is especially important. Lupines (*Lupinus albus* L.) are believed to have been cultivated for 2000 years, starting in Egypt. Nutritive and functional elements found in lupine seeds include lipids, proteins, carbohydrates, carotenoids, tocopherols, polyphenols and dietary fibres[1]. These components make lupine seeds a highly nutritious food source, providing essential macronutrients and micronutrients necessary for overall development. Egypt has a very small area under cultivation for lupine and the country's needs cannot be met by the amount produced locally. Egypt relies

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heavily on imports to meet the demand for lupine, primarily from countries with larger cultivation areas and higher production levels. It is well recognized that sandy soil frequently lacks important soil nutrients, which lowers output. Lupines can thrive in conditions where other crops struggle to survive. The symbiotic relationship between lupines and rhizobia sp., is well-known for its ability to withstand harsh environmental conditions and stresses[2]. Moreover, Rovedder *et al.*[3] claim that lupine improves soil structure and is adaptable to various farming methods.

In Egypt, interplanting legumes in orchards is a popular practice on newly reclaimed soils[4,5]. Research has shown that the overall advantages of legumes are comparable to applying 50-100 kg of nitrogen (N)/ha as fertilizer[6]. Biological N fixation (BNF) primarily occurs through the symbiotic association of legumes and some woody species with specific N_2-fixing microorganisms that convert elemental N into ammonia[7]. According to Abouziena *et al.*[4] and Srivastava *et al.*[8], legumes have been shown to improve fruit yield compared to solid orchards. Legumes are considered to have the highest contribution to BNF among seed producers, with reported rates of up to 450 kg N/ha[9]. This process helps to reduce the need for mineral N fertilizers, making the farming process more sustainable and environmentally friendly. Thus, Selim *et al.*[5] found that interplanting soybeans with mandarin increased the land equivalent ratio (LER), land equivalent coefficient (LEC), the total return of both species and monetary advantage index (MAI) in El-Kassaseen, Ismailia Governorate.

Producing lupine by interplanting in orange fields without affecting orange output would be very useful to orange farmers, especially on reclaimed soils, as it would offer significant potential to extend and improve lupine production. Interplanting with lupine cultivars and adjusting plant density can greatly impact the utilization of agricultural resources. In a study by Pospišil and Pospišil[10], it was found that white lupin cultivars had higher seed yields compared to narrow-leafed lupin cultivars-specifically, the cv. Energy had the highest 1000 seed weight, while the cv. Arabella had the highest number of pods and seeds per plant. However, the low 1000 seed weight of cv. Arabella limited its overall yield potential. An important factor in photosynthesis is the optimal plant density, which influences plant growth, seed yield and competitiveness with other plants.

Research conducted by Wassermann[11] showed that narrow rows significantly increased the pod density per unit area but had a negative impact on the weight of 100 seeds. Plant height increased with higher plant population densities from 33 to 55 plants/m^2, while seed yield/plant, number of branches and pods/plant and 100-seed weight decreased[12]. Additionally, the choice of cultivar and plant density can impact yield potential when interplanted with orchards. Therefore, the objective of this study was to identify the optimal plant density for three lupine cultivars when interplanted with orange trees in sandy soil to enhance crop productivity, land use efficiency and profitability.

MATERIALS AND METHODS

The study was conducted at the East of Suez Canal Horticulture Research Station, ARC, North Sinai Governorate, Egypt (30°53'09"N and 32°05'04"E). The 30 old Valencia orange trees were planted at a spacing of 4×6 m under drip irrigation during the 2021/2022 and 2022/2023 seasons. Each plot was 96 m^2 (12 m in length and 8 m in width). Lupine cultivars were sown on November 21st and 28th in 2021 and 2022 winter seasons, respectively. Mechanical and chemical analyses of the soil (0-20 and 20-70) were done by Water, Soil and Environment Research Institute, ARC. Mechanical and chemical properties of the soil (depth: 20-70 cm) were determined using the methods described by Bradford *et al.*[13]. The texture class was sandy (sand, silt and clay recorded 83.60, 11.8 0 and 4.60%, respectively.). While, EC (dS/m) recorded 0.65, pH recorded 8.30, Na^+ recorded 4.89 meq/L, Ca^{++} recorded 0.85 meq/L, N recorded 35.90 ppm, P recorded 3.05 ppm, K recorded 35.00 ppm and O.M. recorded 0.22%.

Three lupine cultivars (Giza 1, Giza 2 and Giza 3) were used in this study. The Giza 1 and 2 were improved from landraces, while Giza 3 was improved from Dijon 2 variety. Eighteen treatments were the combinations between three lupine cultivars (Giza 1, Giza 2 and Giza 3) and three planting densities (50.0, 62.5 and 75.0% of recommended sole lupine density) under interplanting and sole plantings. Three planting densities were cultivated within ridges as follows:

- **Low planting density under interplanting:** Planting two lupine plants/hill spaced at 15 cm on one side of four ridges (4.0 m in length and 0.75 m in width). There is a 1.50 m space between the orange trees and the lupine ridge next to the trees. This system was expressed as 50.0% plant density of recommended sole lupine
- **Low planting density under sole planting:** Planting two lupine plants/hill spaced at 15 cm on one side of four ridges (4.0 m in length and 0.75 m in width). This system was expressed as 50.0% plant density of recommended sole lupine
- **Medium planting density under interplanting:** Planting two lupine plants/hill spaced at 15 cm on one side of five ridges (4.0 m in length and 0.75 m in width). There is a 1.12 m space between the orange trees and the lupine ridge next to the trees. This system was expressed as 62.5% plant density of recommended sole lupine
- **Medium planting density under sole planting:** Planting two lupine plants/hill spaced at 15 cm on one side of five ridges (4.0 m in length and 0.75 m in width). This system was expressed as 62.5% plant density of recommended sole lupine
- **High planting density under interplanting:** Planting two lupine plants/hill spaced at 15 cm on one side of six ridges (4.0 m in length and 0.75 m in width). There is a 0.75 m space between the orange trees and the lupine ridge next to the trees. This system was expressed as 75.0% plant density of recommended sole lupine
- **High planting density under sole planting:** Planting two lupine plants/hill spaced at 15 cm on one side of six ridges (4.0 m in length and 0.75 m in width). This system was expressed as 75.0% plant density of recommended sole lupine

In addition to:

- **Recommended sole orange trees:** As a result of existing the alternate bearing in orange trees, three years old Valencia Orange trees (on-year bearing) were growing at a distance 4×6 m apart (175 trees/fad) and subjected to experiments in the first season, meanwhile another group of trees (in the same bearing status) were chosen in the second year
- **Recommended sole lupine:** It was conducted by planting two lupine plants/hill spaced at 15 cm on one side of eight ridges (4.0 m in length and 0.75 m in width). Recommended sole plantings of both species were used to estimate LER and LEC

The experiment was set up in a strip split-plot design with three replicates. The two cropping systems were arranged in the vertical strips, the three lupine plant densities were assigned in the horizontal strips and the three lupine cultivars were distributed in the sub-plots. For the orange crop, a split-plot design with three replicates was used. The three lupine planting densities were assigned in the main plots and the three lupine cultivars were distributed in the sub-plots.

All experimental treatments included a drip irrigation system that controlled the desired levels, timings and techniques of fertigation (fertilization) using individual nets for each crop. Each season, 0.5 kg of calcium superphosphate (15.5% P_2O_5) and 10 kg of organic manure were administered in rounded trenches at the root system around the tree canopy to the experimental trees that were either planted alone or interplanted. Furthermore, 125 kg N/fad of ammonium nitrate (33.5% N) was administered as N fertilizer in equal monthly dosages under interplanting or sole planting, respectively, from March to

October. Under interplanting or sole planting, 1.5 kg K/week of potassium (K) fertilizer was applied. Additionally, either sole planting or interplanting was used to apply phosphoric acid at a rate of 1 L/15 days.

With respect to lupine, calcium super phosphate (15.5% P_2O_5) was applied for lupine at a rate of 200 kg/fad during soil preparation in the two summer seasons. Lupine seeds were inoculated with rhizobia sp. and gum Arabic was used as a sticking agent. The N fertilizer was applied for lupine at a rate of 10, 12.5, or 15 kg N/fad for 50.0, 62.5, or 75.0% plant density of recommended sole lupine, respectively, under interplanting or sole planting as ammonium nitrate (33.5% N). The K fertilizer was applied for lupine at a rate of 25, 31.25, or 37.5 kg K/fad for 50.0, 62.5, or 75.0% plant density of recommended sole lupine, respectively, under interplanting or sole planting as potassium sulfate.

With respect to recommended sole lupine, calcium super phosphate (15.5% P_2O_5) was applied for lupine at a rate of 200 kg/fad during soil preparation in the two summer seasons. Lupine seeds were inoculated with rhizobia sp. and gum Arabic was used as a sticking agent. The N fertilizer was applied for lupine at a rate of 20 kg N/fad as ammonium nitrate (33.5% N). The K fertilizer was applied for lupine at a rate of 50 kg K/fad as potassium sulfate. The other prescribed cultural procedures for orange trees and lupine plants were followed. Interplanted Giza 1 and Giza 2 were harvested on April 11th and 16th in 2022 and 2023, respectively.

Interplanted Giza 3 was harvested on April 24th and 30th in 2022 and 2023, respectively. Sole Giza 1 and Giza 2 were harvested on April 14th and 20th in 2022 and 2023, respectively. Sole Giza 3 was harvested on April 28th and May 3rd in 2022 and 2023, respectively. Recommended sole Giza 1 and Giza 2 were harvested on April 14th and 20th in 2022 and 2023, respectively. Recommended sole Giza 3 was harvested on April 28th and May 3rd in 2022 and 2023, respectively. Interplanted orange was harvested on May 15th and 17th in 2022 and 2023, respectively. Recommended sole orange was harvested on May 11th and 12th in 2022 and 2023, respectively.

Studied traits were as follows:

- **Seed yield and its components:** At harvest, five lupine plants were randomly taken to estimate the following traits: Plant height (cm), numbers of branches and pods/plant, seed yield/plant (g) and 100-seed weight (g). Seed yield/fad was recorded based on the experimental plot (kg) and then converted to kg/fad [One ha is equivalent to 2.38 fad]. Orange yield/fad was recorded based on the experimental plot (kg) and then converted to ton/fad
- **Competitive relationships:**
    - **LER:** The LER is the ratio of area needed under sole cropping to one of interplanting at the same management level to produce an equivalent yield[14]. To calculate the Land Equivalent Ratio (LER), use the formula:

$$\text{LER} = \frac{Y_{ab}}{Y_{aa}} + \frac{Y_{ba}}{Y_{bb}}$$

where, Y_{aa} is the yield of crop a (orange) in a pure stand, Y_{bb} is the yield of crop b (lupine) in a pure stand, Y_{ab} is the yield of crop a (orange) in an interplanting system and Y_{ba} is the yield of crop b (lupine) in an interplanting system.

Using this formula, the Relative Yield (RY) can be determined as follows:

$$\text{RY of orange} = \frac{Y_{ab}}{Y_{aa}}$$

$$\text{RY of lupine} = \frac{Y_{ba}}{Y_{bb}}$$

LEC: The LEC is a measure of interaction concerned with the strength of relationship[15]. It is calculated as follows:

$$LEC = Ry_a \times RY_b$$

where, RY_a is relative yield of crop a (orange) and RY_b is relative yield of crop b (lupine).

Economic evaluation

Total return/fad: It was calculated by plus the income of orange fruits/fad (Egyptian pounds) with income of lupine seeds/fad (Egyptian pounds). Lupine seeds and orange fruit prices presented by market price (2023) were used. Market prices (2023) of crops are 8000 Egyptian pounds/ton for orange fruits and 45000 Egyptian pounds/ton for lupine seeds (One euro is equivalent to 33.41 Egyptian pounds).

MAI: The economic evaluation should focus on the value of the preserved land, which can be determined by assessing its rental value. Tripathi *et al.*[16] formula was used to calculate the MAI, which is derived as:

$$MAI = \frac{\text{Value of combined interplants} \times (LER - 1)}{LER}$$

Statistical analysis: Every season's collected findings were subjected to a variance analysis. Using the MSTAT-C statistical program, an ANOVA was performed on the observed variables. The least significant differences (LSD) test was used for mean comparisons, with a significance threshold of 5%[17].

RESULTS

Lupine crop

Effect of cropping systems: The cropping systems in both seasons had a substantial impact on number of branches and pods/plants in the first season, meanwhile, it significantly affected seed yield/plant and seed yield/fad in both seasons (Table 1). Numbers of branches and pods/plant, as well as seed yields per plant and per fad of interplanted lupine were reduced as compared with sole lupine.

Effect of plant densities of lupine: The plant densities of lupine in both seasons had a substantial impact on seed yield and yield components except seed yield/plant in the first season and plant height and 100-seed weight in both seasons (Table 1). The numbers of branches and pods/plant and seed yield/plant were reduced by increasing the plant density from 50.0 to 75.0% of recommended sole lupine in both seasons. Regarding seed yield/fad, the opposite was true. Conversely, seed yield/fad was increased when increased the plant density from 50.0 to 75.0% of recommended sole lupine.

Effect of lupine cultivars: Lupine cultivars showed significant differences in number of branches/plants and seed yield/fad in both seasons and number of pods/plants in the second season (Table 1). In terms of the numbers of branches and pods/plants, Giza 3 had more branches and fewer pods compared to the other two cultivars. With respect to seed yield/fad, Giza 3 had a higher seed yield/fad than the other two cultivars in both seasons.

Effect of the interaction between cropping systems and plant densities of lupine: Table 1 illustrates the interaction between cropping systems and lupine cultivars in terms of plant height in the first season and the number of pods/plant and seed yield/fad in the second season. In the interplanting system, plant

Table 1: Effect of cropping system, lupine plant density, lupine cultivar, and their interactions on seed yield and yield components in both seasons

		Plant height (cm)							
		First season				Second season			
Treatment		Giza 1	Giza 2	Giza 3	Mean	Giza 1	Giza 2	Giza 3	Mean
Inter	50.0%	110.57	113.83	114.62	113.01	102.35	101.89	103.29	102.51
	62.5%	117.60	118.73	119.81	118.71	105.26	105.12	107.30	105.89
	75.0%	119.40	120.32	121.14	120.28	105.82	104.00	107.50	105.77
	Mean	115.86	117.63	118.52	117.33	104.47	103.67	106.03	104.72
Sole	50.0%	106.06	109.41	113.53	109.67	96.470	96.760	95.350	96.190
	62.5%	113.95	114.51	117.41	115.29	99.320	98.550	100.77	99.550
	75.0%	115.24	118.47	115.42	116.37	100.03	100.01	101.28	100.44
	Mean	111.75	114.13	115.45	113.78	98.600	98.440	99.130	98.720
Average of lupine plant density	50.0%	108.32	111.62	114.07	111.34	99.410	99.320	99.320	99.350
	62.5%	115.77	116.62	118.61	117.00	102.29	101.83	104.03	102.72
	75.0%	117.32	119.39	118.28	118.33	102.92	102.00	104.39	103.10
Average of lupine cultivars		113.80	115.88	116.99	115.55	101.54	101.05	102.58	101.72
LSD 5% Cropping system S				ns					ns
LSD 5% Plant density PD				ns					ns
LSD 5% Cultivars C				ns					ns
LSD 5% S×PD				12.04					ns
LSD 5% S×C				ns					ns
LSD 5% PD×C				ns					7.50
LSD 5% S×PD×C				ns					ns

		Number of branches/plant							
		First season				Second season			
Treatment		Giza 1	Giza 2	Giza 3	Mean	Giza 1	Giza 2	Giza 3	Mean
Inter	50.0%	2.46	2.60	2.74	2.60	2.72	3.00	3.01	2.91
	62.5%	2.24	2.41	2.53	2.39	2.51	2.67	2.75	2.64
	75.0%	1.85	1.98	1.98	1.93	1.97	2.09	2.17	2.08
	Mean	2.18	2.33	2.41	2.31	2.40	2.59	2.64	2.54
Sole	50.0%	2.62	2.80	2.93	2.78	2.86	3.17	3.23	3.08
	62.5%	2.32	2.62	2.70	2.55	2.69	2.96	3.11	2.92
	75.0%	2.16	2.43	2.53	2.37	2.29	2.45	2.76	2.50
	Mean	2.37	2.62	2.72	2.57	2.61	2.86	3.03	2.83
Average of lupine plant density	50.0%	2.54	2.70	2.83	2.69	2.79	3.08	3.12	3.00
	62.5%	2.28	2.51	2.61	2.47	2.60	2.82	2.93	2.78
	75.0%	2.01	2.21	2.25	2.15	2.13	2.27	2.47	2.29
Average of lupine cultivars		2.27	2.47	2.57	2.44	2.50	2.72	2.84	2.65
LSD 5% Cropping system S					0.14				ns
LSD 5% Plant density PD					0.19				0.16
LSD 5% Cultivars C					0.25				0.19
LSD 5% S×PD					ns				ns
LSD 5% S×C					ns				ns
LSD 5% PD×C					0.44				ns
LSD 5% S×PD×C					0.62				0.47

		Number of pods/plant							
		First season				Second season			
Treatment		Giza 1	Giza 2	Giza 3	Mean	Giza 1	Giza 2	Giza 3	Mean
Inter	50.0%	19.21	19.42	20.34	19.65	26.81	24.14	24.43	25.12
	62.5%	18.21	18.91	19.33	18.82	24.58	24.68	22.50	23.92
	75.0%	17.29	17.64	18.44	17.79	24.57	22.94	21.12	22.87
	Mean	18.24	18.65	19.37	18.75	25.32	23.92	22.68	23.97
Sole	50.0%	24.81	24.94	21.12	23.62	30.70	27.26	26.62	28.19
	62.5%	24.17	22.07	20.89	22.38	28.60	25.65	26.42	26.89
	75.0%	20.39	19.83	18.37	19.53	26.01	22.95	19.41	22.79
	Mean	23.12	22.28	20.13	21.84	28.43	25.28	24.15	25.95

Table 1: Continued

Average of lupine plant density	50.0%	22.01	22.18	20.73	21.64	28.75	25.70	25.52	26.66
	62.5%	21.19	20.49	20.11	20.60	26.59	25.16	24.46	25.40
	75.0%	18.84	18.73	18.41	18.66	25.29	22.94	20.26	22.83
Average of lupine cultivars		20.68	20.47	19.75	20.30	26.88	24.60	23.41	24.96
LSD 5% Cropping system S					2.81				ns
LSD 5% Plant density PD					2.82				1.47
LSD 5% Cultivars C					ns				2.68
LSD 5% S×PD					ns				2.08
LSD 5% S×C					ns				ns
LSD 5% PD×C					4.64				ns
LSD 5% S×PD×C					ns				ns

		Seed yield/plant (g)							
		First season				Second season			
Treatment		Giza 1	Giza 2	Giza 3	Mean	Giza 1	Giza 2	Giza 3	Mean
Inter	50.0%	20.74	21.03	22.64	21.47	23.51	24.55	25.95	24.67
	62.5%	18.29	19.01	20.13	19.14	21.60	21.10	22.81	21.84
	75.0%	17.52	18.04	19.39	18.31	19.79	20.56	21.69	20.68
	Mean	18.85	19.36	20.72	19.64	21.63	22.07	23.48	22.39
Sole	50.0%	25.20	26.93	28.17	26.76	30.80	30.10	30.88	30.59
	62.5%	23.40	24.80	25.50	24.56	24.13	27.32	28.56	26.67
	75.0%	22.12	22.83	22.89	22.61	25.30	24.09	26.90	25.43
	Mean	23.57	24.85	25.52	24.65	26.74	27.17	28.78	27.56
Average of lupine plant density	50.0%	22.97	23.98	25.40	24.12	27.15	27.32	28.41	27.63
	62.5%	20.84	21.90	22.81	21.85	22.86	24.21	25.68	24.25
	75.0%	19.82	20.43	21.14	20.46	22.54	22.33	24.30	23.05
Average of lupine cultivars		21.21	22.10	23.12	22.14	24.19	24.62	26.13	24.98
LSD 5% Cropping system S					4.24				0.30
LSD 5% Plant density PD					ns				0.29
LSD 5% Cultivars C					ns				ns
LSD 5% S×PD					ns				ns
LSD 5% S×C					ns				5.62
LSD 5% PD×C					ns				ns
LSD 5% S×PD×C					ns				ns

		100-seed weight (g)							
		First season				Second season			
Treatment		Giza 1	Giza 2	Giza 3	Mean	Giza 1	Giza 2	Giza 3	Mean
Inter	50.0%	30.49	30.92	31.55	30.99	32.93	33.46	34.60	33.66
	62.5%	29.94	29.98	30.53	30.15	33.78	33.06	33.46	33.43
	75.0%	28.98	29.16	29.72	29.28	31.39	31.27	32.98	31.88
	Mean	29.80	30.02	30.60	30.14	32.70	32.59	33.68	32.99
Sole	50.0%	30.94	31.50	33.11	31.85	33.02	32.30	35.27	33.53
	62.5%	30.30	30.21	30.81	30.44	32.37	32.00	34.50	32.95
	75.0%	29.72	29.78	29.70	29.73	31.83	32.49	32.28	32.20
	Mean	30.32	30.49	31.20	30.67	32.40	32.26	34.01	32.89
Average of lupine plant density	50.0%	30.71	31.21	32.33	31.42	32.97	32.88	34.93	33.59
	62.5%	30.12	30.09	30.67	30.29	33.07	32.53	33.98	33.19
	75.0%	29.35	29.47	29.71	29.51	31.61	31.88	32.63	32.04
Average of lupine cultivars		30.06	30.25	30.90	30.40	32.55	32.43	33.85	32.94
LSD 5% Cropping system S					ns				ns
LSD 5% Plant density PD					ns				ns
LSD 5% Cultivars C					ns				ns
LSD 5% S×PD					ns				ns
LSD 5% S×C					ns				ns
LSD 5% PD×C					ns				4.15
LSD 5% S×PD×C					ns				ns

Table 1: Continued

Treatment		Seed yield/fad (kg) First season Giza 1	Giza 2	Giza 3	Mean	Second season Giza 1	Giza 2	Giza 3	Mean
Inter	50.0%	368.33	359.04	439.03	388.80	407.61	396.79	453.55	419.31
	62.5%	460.97	472.03	576.99	503.33	489.59	511.69	611.57	537.61
	75.0%	484.00	507.97	613.00	534.99	515.92	531.39	654.72	567.34
	Mean	437.76	446.34	543.00	475.70	471.04	479.95	573.28	508.09
Sole	50.0%	489.30	568.20	647.35	568.28	555.00	624.14	727.31	635.48
	62.5%	515.14	610.92	709.25	611.77	585.36	649.83	757.93	664.37
	75.0%	600.43	656.57	744.03	667.01	632.93	687.52	804.83	708.43
	Mean	534.95	611.89	700.21	615.68	591.09	653.83	763.35	669.43
Average of lupine plant density	50.0%	428.81	463.62	543.19	478.54	481.30	510.46	590.43	527.40
	62.5%	488.05	541.47	643.12	557.55	537.47	580.76	684.75	600.99
	75.0%	542.21	582.27	678.51	601.00	574.42	609.46	729.77	637.88
Average of lupine cultivars		486.36	529.12	621.60	545.69	531.07	566.89	668.32	588.76
LSD 5% Cropping system S					58.29				9.69
LSD 5% Plant density PD					34.62				23.60
LSD 5% Cultivars C					34.11				21.89
LSD 5% S×PD					ns				33.37
LSD 5% S×C					48.24				30.97
LSD 5% PD×C					ns				ns
LSD 5% S×PD×C					ns				ns

ns: Not significant

height was 113.01, 118.71 and 120.28 cm under 50.0, 62.5 and 75.0% of recommended sole lupine, respectively. In the sole planting system, plant height was 109.67, 115.29 and 116.37 cm under the same plant density conditions. For the number of pods/plant, it was 25.12, 23.92 and 22.87 under 50.0, 62.5 and 75.0% of recommended sole lupine, respectively, under interplanting. In the sole planting system, the number of pods/plants was 28.19, 26.89 and 22.79 under the same plant density conditions. Regarding seed yield/fad, it was 419.31, 537.61 and 567.34 kg under 50.0, 62.5 and 75.0% of recommended sole lupine, respectively, under interplanting. In the sole planting system, seed yield/fad was 635.48, 664.37 and 708.43 kg under the same plant density conditions.

Effect of the interaction between cropping systems and lupine cultivars: The interaction between cropping systems and lupine cultivars had a significant impact on seed yield/plant in the second season and seed yield/fad in both seasons (Table 1). In the second season, the seed yield/ plant was 21.63, 22.07 and 23.48 g for Giza 1, Giza 2 and Giza 3 when interplanted with orange trees, respectively. Meanwhile, these values were 26.74, 27.17 and 28.78 g for Giza 1, Giza 2 and Giza 3 under sole plantings, respectively. Additionally, the seed yield/fad was 437.76, 446.34 and 543.00 kg for Giza 1, Giza 2 and Giza 3 when interplanted with orange trees in the first season. In the second season, these values were 471.04, 479.95 and 573.28 kg for Giza 1, Giza 2 and Giza 3, respectively. For sole plantings, the seed yield/fad was 534.95, 611.89 and 700.21 kg for Giza 1, Giza 2 and Giza 3 in the first season. In the second season, these values were 591.09, 653.83 and 763.35 kg for Giza 1, Giza 2 and Giza 3, respectively.

Effect of the interaction between lupine plant densities and lupine cultivars: The interaction between lupine plant densities and lupine cultivars significantly affected plant height in the second season and number of branches and pods/plants in the first season (Table 1). Plant height of lupine cultivars was increased by increasing lupine plant density from 25.0 to 75.0% of recommended sole lupine. Conversely, numbers of branches and pods of lupine cultivars were decreased by increasing plant density from 25.0 to 75.0% of the recommended sole lupine.

Table 2: Fruit yield of orange trees as affected by plant densities of lupine, lupine cultivars and their interactions in both seasons.

	Fruit yield/fad (ton)							
	First season				Second season			
Treatment	Giza 1	Giza 2	Giza 3	Mean	Giza 1	Giza 2	Giza 3	Mean
50.0% of recommended sole lupine density	2.05	2.08	2.26	2.13	2.32	2.44	2.51	2.42
62.5% of recommended sole lupine density	2.19	2.29	2.42	2.30	2.43	2.58	2.73	2.58
75.0% of recommended sole lupine density	2.21	2.35	2.44	2.33	2.59	2.70	2.86	2.71
Mean	2.15	2.24	2.37	2.25	2.44	2.57	2.70	2.57
LSD 5% Plant density PD				0.19				0.27
LSD 5% Cultivars C				0.16				0.16
LSD 5% PD×C				ns				ns

Recommended sole orange yield: 1.94 ton/fad in 1st season and 2.15 ton/fad in 2nd season

Effect of the interaction among cropping systems, plant densities of lupine and lupine cultivars: Table 1 demonstrates that the interaction between cropping systems, plant densities of lupine and lupine cultivars had a significant impact on the number of branches/plants in both seasons. Sole Giza 3, grown at 50% plant density, exhibited the highest number of branches/plants in both seasons, with 2.93 in the first season and 3.23 in the second season.

Orange crop

Effect of plant densities of lupine: Table 2 illustrates that the productivity of orange trees increased as the plant density increased from 50.0 to 75.0% of the recommended sole lupine. The fruit yield also showed an increase from 2.13 to 2.33 ton/fad in the first season and from 2.42 to 2.71 ton/fad in the second season with the plant density increasing from 50.0 to 75.0% of the recommended sole lupine.

Effect of lupine cultivars: Table 2 shows the notable variations in orange tree fruit output between lupine cultivars in both seasons. When comparing Giza 3 to the other two cultivars, orange trees of this cultivar are more productive, yielding 2.37 and 2.70 ton/fad in the first and second seasons, respectively.

Effect of the interaction between lupine plant densities and lupine cultivars: Table 2 shows that productivity of orange trees was not affected by the interaction between lupine plant densities and lupine cultivars in both seasons.

Competitive relationships

LER: Based on the recommended sole plantings of both crops, the LER values were estimated to determine yield advantages. An LER greater than 1.00 indicates a yield advantage, while an LER less than 1.00 indicates a yield loss. An LER equal to 1.00 indicates no gain or loss. The LER can be applied in an additive or replacement series of interplanting. The results obtained were in strong agreement with the definition of LER. When interplanting orange trees in both seasons, LER values were greater than one for all lupine cultivars (Table 3). The LER ranged from 1.52 to 1.94 in the first season and from 1.57 to 1.95 in the second season, depending on the lupine cultivar and plant density.

EC: The LEC is a measure of the strength of a relationship. According to LEC, a two-crop mixture must have a minimum predicted productivity coefficient (PC) of 25% to achieve a yield advantage. In our study, the LEC values for all treatments were higher than 0.25 (Table 3). The LEC ranged from 0.47 to 0.86 in the first season and from 0.50 to 0.87 in the second season, depending on the lupine cultivar and plant density.

Economic return

Total return/fad: The total return of interplanting can be maximized by strategically selecting complementary crops that benefit each other's growth. The economic benefits of interplanting lupine with

Table 3: Competitive relationships and economic return of interplanting three lupine cultivars with orange trees under three lupine planting densities in both seasons

		First season (2021/2022)				Second season (2022/2023)			
Lupine plant density	Lupine cultivar	LER	LEC	Total return/fad (Egyptian pounds)	MAI	LER	LEC	Total return/fad (Egyptian pounds)	MAI
50.0%	Giza 1	1.52	0.49	32974	11280.58	1.57	0.51	36902	13246.87
	Giza 2	1.52	0.47	33116	11329.16	1.57	0.50	37295	13540.22
	Giza 3	1.65	0.57	37836	14905.09	1.67	0.57	41129	16500.86
Mean		1.56	0.51	34642	12435.59	1.60	0.53	38442	14415.75
62.5%	Giza 1	1.71	0.65	38263	15886.98	1.70	0.65	41311	17010.41
	Giza 2	1.74	0.66	39561	16824.79	1.77	0.69	43666	18995.94
	Giza 3	1.89	0.80	45324	21343.05	1.89	0.80	49120	23130.58
Mean		1.78	0.71	41049	17987.76	1.79	0.71	44698	19727.05
75.0%	Giza 1	1.75	0.69	39460	16911.43	1.78	0.72	43216	18937.35
	Giza 2	1.82	0.73	41658	18768.99	1.80	0.72	44712	19872.00
	Giza 3	1.94	0.86	47105	22824.07	1.95	0.87	51382	25032.26
Mean		1.83	0.76	42740	19384.81	1.85	0.77	46436	21335.46
Recommended sole orange		1.00	1.00	15520	---	1.00	1.00	17200	---

Recommended sole orange yield: 1.94 ton/fad in 1st season and 2.15 ton/fad in 2nd season, market price (2023) was 8000 Egyptian pounds/ton, Recommended sole Giza 1 yield: 793 kg/fad in 1st season and 835 kg/fad in 2nd season, market price (2023) was 45000 Egyptian pounds/ton, Recommended sole Giza 2 yield: 837 kg/fad in 1st season and 889 kg/fad in 2nd season, market price (2023) was 45000 Egyptian pounds/ton, Recommended sole Giza 3 yield: 896 kg/fad in 1st season and 957 kg/fad in 2nd season, market price (2023) was 45000 Egyptian pounds/ton, LER: Land equivalent ratio, LEC: Land equivalent coefficient and MAI: Monetary advantage index orange trees, compared to the recommended sole orange trees, are presented in Table 3. The total return/fad varied from 32974 Egyptian pounds when interplanting lupine cultivar Giza 1, with a plant density of 50.0% of recommended sole lupine, to 47105 Egyptian pounds when interplanting lupine cultivar Giza 3, with a plant density of 75.0% of recommended sole lupine in the first season. In the second season, the total return/fad varied from 36902 Egyptian pounds when interplanting lupine cultivar Giza 1, with a plant density of 50.0% of recommended sole lupine, to 51382 Egyptian pounds when interplanting lupine cultivar Giza 3, with a plant density of 75.0% of recommended sole lupine.

MAI: The economic performance of the interplanting was evaluated to determine if lupine and orange combined yields were high enough for the farmers to adopt this system (Table 3). The MAI varied from 11280.58 when interplanting lupine cultivar Giza 1 at 50.0% of recommended sole lupine, to 22824.07 when interplanting lupine cultivar Giza 3, which had a plant density of 75.0% of recommended sole lupine in the first season. Meanwhile, MAI varied from 13246.87 when interplanting lupine cultivar Giza 1, which had a plant density of 50.0% of recommended sole lupine, to 25032.26 when interplanting lupine cultivar Giza 3, which had a plant density of 75.0% of recommended sole lupine in the second season. Differences between the highest and the lowest values were 11543.49 in the first season and 11785.39 in the second season.

DISCUSSION

According to the results, interplanted lupine may not be as efficient in using agricultural resources as sole lupine. There may be fewer overall benefits for agricultural production from interplanted lupine compared to sole lupine due to its potential lack of resource efficiency. In terms of improved soil fertility and insect management, however, the interplanting strategy proved beneficial. In general, farmers who want to diversify their crops may still find that planting lupine and orange trees together is a good alternative.

While lupine plants with high plant density had fewer branches overall, those with low plant density had more branches per plant. One explanation could be that, in comparison to higher densities, edaphic variables positively affect the nutritional status of lupine plants at lower densities. Given that the plants have more resources available for growth; this may result in more branching. Additionally, branching may be restricted in lupine plants due to competition for resources at higher densities. These outcomes agreed with what Ahmed[12] found. Furthermore, compared to other planting densities, Hunegnaw *et al.*[18] observed that lupine interplanted with tef had more branches at low planting densities.

With low plant density and no intra-specific rivalry among lupine crops, the best use of growth resources was encouraged, resulting in the highest pod/plant density. Borowska *et al.*[19] supported these results in this regard by demonstrating that a higher plant density reduced the number of pods per plant. The results show that when lupine planting density increases, the number of pods per plant decreases[18]. Competition for light and minerals may be the cause of increased lupine density per unit area. This competition lowers photosynthesis and the number of seeds produced by each plant. The results of Tobiasz-Salach *et al.*[20], who found that fewer plants per unit area increased the weight of seeds per plant, which was connected to better growing circumstances for plants, were in line with these findings.

In sandy soil, lupine plant density was increased to overcome high intra-specific competition, resulting in higher seed yield/fad. This strategy reduces competition and optimizes resource utilization, ultimately enhancing lupine productivity in sandy soil conditions.

The genetic composition of the examined cultivars may impact the branch growth rate. Variations in branch development may have resulted from genetic differences between Giza 3 and the other cultivars. To completely comprehend the underlying mechanisms causing these disparities, more research might be required. El-Harty *et al.*[21] found similar results, demonstrating that the genotypes Qous 5, Sakolta, Qous 4, Isna 1, Qous 1, P 20950 and Edfo had greater values of branches and plants in comparison to the other genotypes. When it comes to pod production, Giza 2 or Giza 1 has a higher yield potential than Giza 3. The variations in pod output between the cultivars may be explained by a more thorough examination of the growing season's environmental factors and management strategies. These findings are the same as those of E1-Harty *et al.*[21]. The Giza 3 would be a preferable choice for growers looking to maximize seed output in terms of yield/fad. Further research could be conducted to determine the exact causes of Giza 3's higher yield when compared to the other cultivars. These outcomes agree with those of El-Harty *et al.*[21] who found that the Egyptian landraces Sohag 2, Fayed 1 and Giza 1 produced higher seed yields/ha.

With respect to the interactions, interplanting orange trees with lupine seems to have formed an unfavorable environment, which was made worse by growing the density of lupine plants from 50.0 to 75.0% of the recommended sole lupine during their early growth and development, which in turn raised plant hormone levels. The orange trees thus had varying negative effects on the density of lupine plants as compared to sole plantings of the tested densities. It is noteworthy that augmenting the density of lupine plants from 50.0 to 75.0% of the recommended sole lupine intensified the shading surrounding lupine plants, thus diminishing the accumulation of dry matter in lupine plants. The results show that plant height and seed yield/fad increased with higher plant density in both interplanting and sole planting systems. However, the number of branches per plant decreased with higher plant density. This suggests that while increased plant density boosts seed yield/fad, dry matter buildup may suffer as a result. To maximize lupine productivity, the ideal equilibrium between dry matter buildup and seed yield must be found.

With regard to the interaction between cropping systems and lupine cultivars, when comparing the yield of different cultivars under sole cropping versus interplanting, it is clear that shade had a negative impact on the seed output of the evaluated cultivars. Among the cultivars, Giza 3 was slightly less affected by interplanting compared to the other two cultivars. This resulted in more favorable seed production for Giza 3 when shaded by orange trees. Overall, the data suggests that Giza 3 may be a better cultivar for interplanting with orange trees than the other two cultivars. Further research is needed to fully understand the dynamics of intercropping with different cultivars in shaded environments.

With respect to the interaction between lupine plant densities and lupine cultivars, the integration of Giza 3 with the highest plant density can result in improved soil stability and enhanced nutrient uptake. Additionally, this integration can also contribute to better water retention and reduced erosion in the area. With regard to the interaction between cropping systems, plant densities of lupine and lupine cultivars, the sole lupine of Giza 3 had the most branches per plant, with a plant density of 50.0% of the recommended sole lupine compared to the other treatments.

Concerning the orange crop, when lupine plants were planted 0.75 meters away from orange trees, the rhizosphere was probably better able to mediate important plant-soil interactions, such as rhizosphere bacteria colonizing roots and nutrient uptake, than it was at other planting densities. Because orange trees were able to absorb nutrients more effectively thanks to this spacing, orange fruit and soil health were probably enhanced. Furthermore, the increased closeness probably made it easier for nutrients to be exchanged and increased microbial activity in the rhizosphere, which improved plant-soil interactions even more. More accessible soil nutrients for orange trees were probably created in response to the BNF process by a network of almost horizontal lupine roots and their laterals at a density of 75.0 % of the recommended sole lupine. According to Nassib *et al.*[22], legumes are acknowledged as having played a significant role in the farming system. Postgate[23] demonstrated that fixed N is available to other plants and aids in soil fertilization in this regard. These outcomes concurred with those of Selim *et al.*[5].

With respect to lupine cultivars, the genetic makeup of Giza 3 is responsible for the outcomes; it has a tapering root structure that allows it to reach lower soil strata in search of nutrients and water. When compared to other cultivars in the study, Giza 3's ability to blend in with orange trees is enhanced, resulting in vigorous development and a high potential yield for orange trees. In European circumstances, the Dijon 2 type is suited to cooler regions. Therefore, by lessening competition for essential resources both above and below ground, Giza 3 may be able to increase fruit yield. This is probably the situation. Given that Giza 3 is thought to have had nodule ability in its roots for a longer time than the other cultivars, it is possible that this indicates more advantageous residual effects for orange trees. This shows that Giza 3 might offer long-term N fixation in the soil, which would eventually promote orange tree development. These outcomes concurred with those of Selim *et al.*[5].

Furthermore, the data indicate that lupine plant densities and lupine cultivars have independent effects on the yield of orange trees in both seasons. Concerning the competitive relationships, interplanting lupine cultivar Giza 3 with orange trees had the greatest LER and LEC due to its longer vegetative growth period, which enhanced the accumulation of dry matter under the orange trees. Increasing the plant density to 75.0% of recommended sole lupine had a favorable effect on the relative yield in line with Selim *et al.*[5].

With regard to the economic return, interplanting Giza 3 with 75.0% plant density of recommended sole lupine with orange trees is more profitable than sole planting of orange trees for Egyptian farmers. Growing Giza 3 with 75.0% plant density of recommended sole lupine with orange trees was mainly influenced by the complementary effects between both species which resulted in high MAI and could be recommended. The profitability of lupine production in Egypt can be increased by practicing this technique to utilize effective farming techniques. These results were in agreement with Selim *et al.*[5].

CONCLUSION

The Giza 3 can continuously fix N in the soil, resulting in enhanced growth of orange trees. This increased N availability can lead to larger fruit yields and improved overall development for the orange trees. Additionally, the improved soil quality from Giza 3's N-fixing abilities can benefit other plants in the surrounding area as well. Farmers might want to consider growing Giza 3 alongside orange trees to maximize these advantages. Therefore, the profitability of lupine production in Egypt can be increased by growing Giza 3 at a 75.0% plant density of recommended sole lupine, utilizing effective farming techniques. Further research is needed to fully understand the reasons behind these differences in yield potential among the three cultivars in different cropping systems.

SIGNIFICANCE STATEMENT

Integrating Giza 3 into farming practices can improve orange yield and soil health. By incorporating this N-fixing plant, farmers can enhance productivity and sustainability on their farms. The use of Giza 3 can improve fertility and soil structure, leading to healthier orange trees and increased fruit production. Additionally, Giza 3 can reduce the need for synthetic fertilizers, resulting in cost savings and a reduced environmental impact.

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