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Comparing the vegetative and the productive behavior in intensive and super high density olive groves

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ABSTRACT

This study was carried out at the Agricultural Research Station, Ismailia, Egypt, during two studied seasons 2022 and 2023. Three olive cultivars (Coratina, Koroneiki and Maraki) were used to compare their growth behavior and productivity under different planting densities (intensive system and super high density system). The results showed that the vegetative growth behavior of the used olive cultivars was not affected by the difference in plant density, with the exception of the total leaf area/m, which increased under intensive system. Also, an increase in sex ratio was observed in intensive system, while no significant differences appeared between the tested planting densities in the number of flowers/inflorescences. The super high-density system showed superiority in terms of flower density compared to intensive system only in the first year. The use of super high density achieved the higher significant values for olive fruit yield, oil productivity and flesh/fruit ratio, while, the intensive system resulted in obtaining the highest significant values for fruit weight; the use of either system did not result in any significant differences in moisture content and fruit shape. As for the best yield performance of the cultivated olive cv. under different planting system, Koroneiki olive cv., recorded the highest values for fruit yield (7.27-8.93 ton/fed) and the highest oil productivity (1.14-1.42 ton/fed) under super high density, which will lead to an increase in the total income/fed.

Keywords: Olive-Planting- Density- Productive.

INTRODUCTION

Olive (*Olea europaea* L.) is one of the most important and widely planted fruit trees (Ali et al., 2022). It was originated in the eastern Mediterranean region and quickly expanded to other countries. (Langgut et al., 2019). Despite the fact that many cultivars have been chosen from the beginning of olive domestication, the major modifications in olive cultivation over the past few years have exposed the significant disadvantages of the majority of traditional cultivars in newly established olive orchards (Hammami and Ben Mimoun, 2015 and Lo Bianco et al., 2021).

Traditionally, olive trees were planted with wide spacing between trees. In this case, olive orchards were characterized by being rain-fed farms, big tree canopy, low tree density (<100 trees ha^{-1}), manual harvest (Guerrero-Casado et al., 2021 and Sobreiro et al., 2023). With the increase in demand for olive products and the development of irrigation systems, traditional system was replaced by younger, smaller trees and higher densities at the intensive-system (IS) (>300 trees ha^{-1}), high phytosanitary input and mechanical harvesting (Martínez-Sastre et al., 2017). In addition, the super high-density (SHD) olive groves, which known as super intensive or hedgerow olive groves, that have densities higher than 1500 trees ha^{-1} (Díez et al., 2016). The SHD shows high levels of profitability due to decreasing production costs, full mechanization (including harvesting, pruning, and phytosanitary treatments) and a significant increase in the productivity/area (Barranco et al., 2017 and AEMO, 2020).

There are a few varieties suitable for SHD orchards such as: Arbequina, Arbosana, and Koroneiki which are the cultivars most frequently used in SHD orchards (Tous et al., 2014). Other cultivars, such as Chikitita, Oliana and Lecciana are also being used (Rallo et al., 2008 and Camposeo et al., 2021).

Olive is typically planted in Egypt with a spacing of 6 m between rows and 5 m between trees within the row. The total planted area is around 268124 Fed; of these, about 219014 Fed., is productive and yielding roughly 1011444 tons (Agricultural Ministry of Egypt, 2022).

Ismailia governorate is one of the areas where olive cultivation is widespread in Egypt. In order to compare some of the varieties cultivated in Egypt and to know their suitability for intensive cultivation and super high-density olive groves were established to determine the optimal cultivation system for each variety, which ultimately results in the amount of the crop, oil content, fruit quality, resistance to pests and diseases, and the ability to adapt to local environmental conditions.

Materials and Methods

Trail location and plant material

The trial was conducted in Agricultural Research Station, Ismailia, Egypt (30°6180538' E longitude, 32°2370527' N latitude), in the fifth (2022) and sixth (2023) year after planting Coratina, Koroneiki and Maraki cultivars. The trees were planted in two different ways; Intensive-system (IS) >300 trees ha^{-1} (Martínez-Sastre et al., 2017) spaced 5 * 6 m (about 140 trees/fed) and Super High-Density (SHD) >1500 trees ha^{-1} (Díez et al., 2016) spaced 1.5 * 4 m (about 700 trees/ fed). Olive trees received the recommended horticulture practices and were free from pathogens. The trees were cultivated in a sandy texture soil and irrigated with a drip system. The chemical and mechanical properties of the soil and the water used for irrigation were estimated as maintained by (Chapman and Pratt, 1975 and Page et al., 1982) **Tables (1 and 2).**

Table (1). Chemical and mechanical characteristics of tested soil.

Soil mechanical analysis (%)			
Particle size distribution %	Sand	83.61	**Textural classes**: Sandy
	Silt	9.05	
	Clay	7.34	

Soil chemical properties									
PH (1:2.5)	**E.C. dSM^{-1} (1:5)**	**Soluble cations (meq/ L)**				**Soluble anions (meq/ L)**			
		Ca^{++}	**Mg^{++}**	**Na^{+}**	**K^{+}**	**$CO_3^{=}$**	**HCO_3^{-}**	**Cl^{-}**	**$SO_4^{=}$**
7.82	0.82	2.70	1.75	3.25	0.51	--	1.82	3.30	3.09

Available nutrients mg kg^{-1}						
N	**P**	**K**	**S**	**Fe**	**Mn**	**Zn**
15.4	5.38	79.05	0.99	4.65	1.05	0.47

Table (2). Chemical characteristics of tested irrigation water collected from tested area

EC dsM^{-1} (1:5)	**pH (1:2.5)**	**Cations (meq/l)**				**Anions (meq/l)**				**SAR**
		Ca^{2+}	**Mg^{2+}**	**Na^{2+}**	**K^{2+}**	**CO_3^{-}**	**HCO_3^{-}**	**Cl^{-}**	**SO_4^{2-}**	
0.35	7.8	1.38	1.90	1.65	0.18	--	0.63	1.94	2.54	0.91

Experimental design:

The trail focused on comparing the performance of the three olive cultivars (Coratina, Koroneiki and Maraki) under two planting system (IS and SHD). The experiment was designed as a split plot design. The two-planting density represented the main plots, while the three olive cultivars were randomly distributed in sub plots (4 trees per each cultivar = 12 trees per each planting density = 24 trees in the trail).

Experimental parameters:

Vegetative activity: In 2022 and 2023, eight healthy one-year-old shoots/tree (2 shoots in each tree direction)/cultivar were randomly selected and labeled at the end of July. The average shoot length (cm) and number of leaves /m were measured. The leaf area (cm^2) was measured by using a plain meter (model cl-203, USA) and total leaves area/m (as assimilation area) was calculated by multiply leaf area by number of leaves.

Flowering characteristics: The flowering data of olive/tree at full bloom stage 2022 and 2023 was determined. Flowering density was assessed as (No. of inflorescence/ m). The number of flower/inflorescences was recorded and sex ratio (%) is the ratio between the number of perfect flower and the total number of flower/inflorescences was calculated.

Light intensity: The intensity of light in the canopy were recorded at the end of growing season (beginning of Aug.), at 9 am and 12 pm by measuring light intensity in the canopy by using a luxmeter (LX-101) at 150 cm from the ground (El-Bably and Amin, 2014).

Yield and oil productivity: The total yield of olives/fed was determined (by multiplying yield/tree by the number of trees/fed) at harvest time at the end of Oct. of 2022 and 2023 seasons. Oil content (%) on fresh weight bases was measure in these samples using Soxhlet fat extraction apparatus. Olive oil yield calculated by multiplying yield/fed by oil % in fresh weight as described in the (AOAC, 2010).

Fruit characteristics: The fruit characteristics were evaluated by sampling each cultivar and density. The average fruit weight was measured by using the average of 10 fresh fruits/replicate, flesh-fruit ratio was calculated as a ratio between flesh fruit weight and fruit weight. The fresh fruit samples were dried in a force-air oven at 70°C till stable weight to estimate the moisture content (%) (IOC, 1997), shape index was estimated by divided fruit length by its diameter.

Leaves chlorophyll content: Samples of one-year-old leaves for each cultivar were taken at the beginning of Aug. 2022 and 2023 seasons. Chlorophyll a, b and carotenoids contents were calorimetrically determined according to (AOAC, 2010).

Leaf anatomical characteristics: Samples necessary for anatomical characteristics study were obtained (at the beginning of Aug. 2023) from each cultivar at both planting density and were taken from the middle portion of the leaf (about 1 cm^2). Samples were immediately fixed in FAA solution (10 ml formalin, 5 ml glacial acetic acid and 85 ml ethyl alcohol 70%). Afterwards, samples were dehydrated with normal butyl alcohol then the samples were infiltrated with paraffin wax (m. p. 58-60°C) (Johanson, 1940). Transverse sections of 10–12-micron thickness was cut with a rotary microtone, stained with safranin T and fast green technique, then washed in absolute ethanol and cleared in xylene and mounted in Canada balsam. Slides were oven dried at 40°C for 1 week. The thickness of leaf blade, epidermis layers, mesophyll parenchyma (palisade and spongy), xylem and phloem in vascular bundle were determined microscopically.

The rate of thickness change of the olive leaf blade tissues as a planting densities effect was tabulated according the following equation: [(Tissue thickness in SHD - Tissue thickness in IS)/ Tissue thickness in IS] *100 (Ebtesam, 2018).

Statistical analysis: Significance of the differences among the averages were statistically tested for variance analysis (ANOVA) using Statistics Software according to Snedecor and Cochran (1967). The differences between means were compared multiple tests at 5% of probability by using Duncan (1955).

Results

Vegetative activity: -

Results of vegetative growth in **Table (3)** exhibit a marked variation among cultivars type and slightly difference as the planting density. The tested planting density failed to show any significant differences regarding the shoot length (cm), number of leaves and leaf area (cm^2) of the investigated olive cultivars (Coratina, Koroneiki and Maraki) during both seasons of the study. While, the total leaves area/m was significantly higher for olive trees planted in intensive system.

According to cultivars' type effect on shoot length (cm), Maraki cv. was superior to others; it gave higher shoot length (33.12 and 32.75 cm) in the 1st and 2nd seasons, respectively. Similarly, Coratina olive cv. gave the highest significant values of number of leaves and leaf area (cm^2) and total leaves area/m, followed by Maraki olive cv. while Koroneiki cv.

exhibited the least significant average of the vegetative growth parameters in the 1st and 2nd seasons, respectively.

Concerning the combined effect of planting density and olive cultivar, data showed different trends. The highest value of olive shoot length was achieved by Maraki olive trees cultivated in IS system. Also, Coratina olive cv. in IS system gave significantly higher values of number of leaves and total leaves area/m. Whereas, the highest values of leaf area (cm^2) were recorded by Coratina olive cv. cultivated in SHD system in both seasons of study.

Table (3). Vegetative activity in Coratina, Koroneiki and Maraki olive cultivars under different planting density.

Planting Density	IS	SHD	Mean	IS	SHD	Mean
		Frist season			Second season	
Cultivar			Shoot length (cm)			
Coratina	31.18 c	27.86 d	**29.52 B**	30.67 bc	28.00 d	**29.34 B**
Koroneiki	25.67 e	33.52 b	**29.60 B**	25.50 e	32.00 b	**28.75 C**
Maraki	35.77 a	30.47 c	**33.12 A**	34.83 a	30.67 c	**32.75 A**
Mean	**30.87 A**	**30.62 A**		**30.33 A**	**30.22 A**	
			Number of leaves/m			
Coratina	137.25 a	109.73 b	**123.49 A**	158.30 a	129.31cd	**143.81 A**
Koroneiki	72.21 d	113.40 b	**92.83 C**	106.16 e	143.91 b	**125.03 B**
Maraki	115.51 b	91.32 c	**103.42 B**	140.34 bc	120.55 d	**130.45 B**
Mean	**108.33 A**	**104.82 A**		**134.93 A**	**131.26 A**	
			Leaf area (cm2)			
Coratina	4.55 b	5.11 a	**4.83 A**	4.68 c	5.13 a	**4.91 A**
Koroneiki	2.35 e	2.70 d	**2.53 C**	2.55 f	3.23 e	**2.89 C**
Maraki	4.69 b	3.57 c	**4.13 B**	4.84 b	3.67 c	**4.26 B**
Mean	**3.86 A**	**3.79 A**		**4.02 A**	**4.01 A**	
			Total leaves area/m			
Coratina	624.49 a	560.72 ab	**592.60A**	740.84a	663.36 b	**702.10 A**
Koroneiki	169.69 d	306.18 c	**237.94 C**	270.71 d	464.83 c	**367.77 C**
Maraki	541.74 b	326.01 c	**433.88 B**	679.25 b	442.42 c	**560.83 B**
Mean	**445.18 A**	**397.64 B**		**563.61 A**	**523.54 B**	

IS= Intensive-system, SHD= Super High-Density

Values of interaction (planting density × cultivar) followed by different lowercase letters are significantly different ($p < 0.05$). Mean values of planting density or cultivar followed by different uppercase letters are significantly different.

Flowering characteristics: -

Regarding the effect of planting density on flowering characteristics **(Table 4)** it could be noticed that, the flower density was significantly affected by planting intensity in the first season, but, no significant difference was attained in the second one. Regarding the number of flower/ inflorescences, data evident that, no significant difference was observed between the two planting systems in both seasons. Meanwhile, olive trees planted in IS gave the highest significant average value of sex ratio in the two investigated seasons.

As for the effect of cultivar type, data in **Table (4)** revealed that, the maximum flower density and sex ratio were recorded by Koroneiki olive cultivar. Meanwhile, Maraki olive cv. gave the uppermost number of flower/ inflorescences in the 1st and 2nd seasons, respectively.

The interactions between planting density and olive cultivar demonstrated that, all characteristics of olive flowering were significantly affected. Koroneiki olive cv. cultivated in SHD gained the most constant significant effect in terms flower density in both seasons. Meanwhile, Koroneiki olive cv. cultivated in IS system achieved the highest significant values in terms of sex ratio in both seasons and without significant differences with those obtained by Koroneiki olive cv. cultivated in SHD system in the 2nd season only, whereas, Maraki olive cv. in SHD system gave the highest number of flower/ inflorescences in both seasons, respectively.

Table (4). Flowering characteristics in Coratina, Koroneiki and Maraki olive cultivars under different planting density.

Planting Density	IS	SHD	Mean	IS	SHD	Mean
	Frist season			Second season		
Cultivar	**Flower density**					
Coratina	17.07 d	28.10 b	**22.59 B**	25.00 e	45.25 c	**35.13 C**
Koroneiki	22.42 c	35.00 a	**28.71 A**	50.00 b	54.90 a	**52.45 A**
Maraki	22.04 c	12.77 e	**17.41 C**	32.53 d	52.17 ab	**42.35 B**
Mean	**20.51 B**	**25.29 A**		42.23 **A**	**44.39 A**	
	Number of flower/inflorescences					
Coratina	23.00 bc	26.33 ab	**24.67 A**	20.00 c	17.67 d	**18.83 B**
Koroneiki	19.67 c	20.67 c	**20.17 B**	17.33 de	15.67 e	**16.50 C**
Maraki	21.00 bc	29.00 a	**25.00 A**	23.33 b	25.33 a	**24.33 A**
Mean	**21.22 A**	**25.33 A**		**20.22 A**	**19.56 A**	
	Sex ratio					
Coratina	73.49 b	67.91 c	**70.70 B**	66.99 bc	60.44 cd	**63.72 B**
Koroneiki	79.62 a	75.39 b	**77.51 A**	74.77 a	69.54 ab	**72.16 A**
Maraki	64.03 d	56.89 e	**60.46 C**	53.89 d	43.63 e	**48.76 C**
Mean	**72.38 A**	**66.73 B**		**65.22 A**	**57.87 B**	

IS= Intensive-system, SHD= Super High-Density

Values of interaction (planting density × cultivar) followed by different lowercase letters are significantly different ($p < 0.05$). Mean values of planting density or cultivar followed by different uppercase letters are significantly different.

Light intensity: -

It is clear from the results presented in **Table (5)** that; the values of light intensity were affected by planting densities in both seasons. The highest light intensity at 9 am were recorded by IS density (318.63 and 323.50 lux) and at 12 pm (420.67 and 452.45 lux) in both studied seasons.

Table (5). Light intensity in Coratina, Koroneiki and Maraki olive cultivars under different planting density.

Planting Density	IS	SHD	Mean	IS	SHD	Mean
	Frist season			Second season		
Cultivar	**Light intensity (Lux) at 9 am**					
Coratina	325.38 b	133.25 e	**229.31 B**	321.25 b	214.13 d	**267.69 B**
Koroneiki	371.25 a	289.25 c	**330.25 A**	385.00 a	257.88 c	**321.44 A**
Maraki	259.25 c	155.13 d	**207.19 C**	264.25 c	126.25 e	**195.25 C**
Mean	**318.63 A**	**192.54 B**		**323.50 A**	**199.42 B**	
	Light intensity (Lux) at 12 pm					
Coratina	404.75 ab	303.13 bc	**353.94 A**		275.38 c	**322.38 B**
Koroneiki	367.13 b	298.75 bc	**332.94 A**	495.50 a	247.88 c	**371.69 A**
Maraki	490.13 a	208.88 c	**349.50 A**	492.46 a	168.63 d	**330.54 B**
Mean	**420.67 A**	**270.25 B**		**452.45 A**	**230.63 B**	

IS= Intensive-system, SHD= Super High-Density

Values of interaction (planting density × cultivar) followed by different lowercase letters are significantly different ($p < 0.05$). Mean values of planting density or cultivar followed by different uppercase letters are significantly different.

Concerning the effect olive cultivar, data showed that, Koroneiki implemented the highest light intensity at 9 am in both seasons, while it failed to show the same trend for light intensity at 12 pm in the 1st season and recorded the highest value in this concern in the 2nd one (371.69 lux).

Regarding the interactions between both studied variables data in **Table (5)** cleared that, Koroneiki olive cv. planted in IS system recorded the highest values of light intensity at (9 am and 12 pm) in most cases during both studied seasons.

Yield and oil productivity: -

Table (6) shows the yield and oil productivity for three olive cultivars (Coratina, Koroneiki and Maraki) under two planting system (IS and SHD). The studied parameters (yield/fed and oil productivity) were significantly increased with the increase in planting density (SHD). On the other hand, the oil content (%) in fresh weight was increased in the intensive-system in both seasons.

As for the effect of cultivar type, Koroneiki olive cv. gave the maximum values for productivity (fruit yield and oil/fed) in both seasons followed by Coratina cv. Otherwise, Maraki cv. exhibited the least significant average of fruit yield and oil productivity/fed in both seasons of the trail. On the other hand, Maraki cv. recorded the highest values of oil (%) in fresh weight in both seasons, respectively, and without significant differences with those recorded by Coratina cv. in the first one.

Concerning the interactions between planting densities and olive cultivars, data showed that, the highest value of olive fruit yield and oil production/fed were recorded by Koroneiki olive trees cultivated in SHD system. Meanwhile, Maraki olive cv. in both systems gave significantly higher values of oil (%) in fresh weight.

Table (6). Yield and oil productivity in Coratina, Koroneiki and Maraki olive cultivars under different planting density.

Planting Density	IS	SHD	Mean	IS	SHD	Mean
		Frist season			**Second season**	
Cultivar			**Yield (ton/Fed)**			
Coratina	1.89 e	5.51 b	**3.70 B**	2.61 d	6.83 b	**4.72 B**
Koroneiki	2.47 d	7.27 a	**4.87 A**	2.80 d	8.93 a	**5.87 A**
Maraki	1.26 f	3.50 c	**2.38 C**	1.70 e	5.08 c	**3.39 C**
Mean	**1.87 B**	**5.43 A**		**2.37 B**	**6.95 A**	
			Oil % (in fresh weight)			
Coratina	19.34 a	16.84 b	**16.84 B**	17.79 b	15.21 c	**16.50 B**
Koroneiki	17.56 b	15.69 c	**15.69 C**	16.84 b	15.94 c	**16.39 B**
Maraki	19.54 a	19.74 a	**19.64 A**	19.01 a	18.77 a	**18.89 A**
Mean	**18.81 A**	**17.42 B**		**17.88 A**	**16.64 B**	
			Oil productivity (ton/Fed)			
Coratina	0.37 e	0.93 b	**0.65 B**	0.46 d	1.04 b	**0.75 B**
Koroneiki	0.43 d	1.14 a	**0.79 A**	0.47 d	1.42 a	**0.95 A**
Maraki	0.25 f	0.69 c	**0.47 C**	0.32 e	0.95 c	**0.64 C**
Mean	**0.35 B**	**0.92 A**		**0.42 B**	**1.14 A**	

IS= Intensive-system, SHD= Super High-Density

Values of interaction (planting density × cultivar) followed by different lowercase letters are significantly different ($p < 0.05$). Mean values of planting density or cultivar followed by different uppercase letters are significantly different.

Fruit characteristics: -

Data in **Table (7)** showed the different effects of planting density on fruit weight, flesh-fruit ratio, moisture % and shape index. According to the tabulated data in **Table (7),** fruit weight was affected by planting density in both seasons, however the IS system recorded statistically the highest average of fruit weight (3.74 – 3.69 g) in the two investigated seasons. In addition, the highest flesh-fruit ratio (79-81) was achieved by olive trees in SHD in both seasons. Meanwhile, the tested planting density showed no statically differences in terms of moisture content and fruit shape index.

Continuations the physical properties in **Table (7)** data illustrate that, olive fruit characteristics were affected by the type of cultivar grown. The highest significant average of fruit weight 6.31 and 5.98 g were recorded by Maraki olive cv. in 1st

and 2nd seasons, respectively. Additionally, Maraki olive cv. gave the highest significant flesh-fruit ratio (82) in the first season, (79) in the second one. the uppermost significant values of moisture content and fruit shape index came from Koroneiki followed by Coratina olive cv. in both studied seasons.

As for the interactions between planting density and cultivar type, data in **Table (7)** revealed that, the highest values of fruit weight obtained by Maraki cultivar planted in IS (6.39 g) and (6.25 g) in the both seasons, respectively. Also, Maraki olive cv. in SHD achieved the highest significant values of flesh-fruit ratio (82-81) in both seasons, shared with Koroneiki (81) and Coratina trees (80) under SHD system in second one. As for moisture (%), Koroneiki olive cv. under IS system provided the highest and most statistically values (60.99- 60.05%) in both seasons, respectively. Furthermore, the highest fruit shape index (1.56- 1.52) was recorded by Koroneiki trees in SHD in the 2022 and 2023 seasons, respectively.

Table (7). Fruit characteristics in Coratina, Koroneiki and Maraki olive cultivars under different planting density.

Planting Density	IS	SHD	Mean	IS	SHD	Mean
	Frist season			Second season		
Cultivar	Fruit weight (gm)					
Coratina	3.72 c	3.45 d	**3.58 B**	3.66 c	3.39 c	**3.53 B**
Koroneiki	1.11 e	1.01 f	**1.07 C**	1.16 d	1.25 d	**1.21 C**
Maraki	6.39 a	6.22 b	**6.31 A**	6.25 a	5.71 b	**5.98 A**
Mean	**3.74 A**	**3.56 B**		**3.69 A**	**3.45 B**	
	Flesh fruit / Fruit weight Ratio					
Coratina	77 b	77 b	**77 B**	77 b	80 ab	**78 AB**
Koroneiki	74 c	78 b	**76 B**	73 c	81 a	**77 B**
Maraki	81 a	82 a	**82 A**	77 b	81 a	**79 A**
Mean	**77 B**	**79 A**		**76 B**	**81 A**	
	Moisture %					
Coratina	56.91 c	59.13 bc	**58.02 B**	57.70 ab	59.77 a	**58.74 AB**
Koroneiki	60.62 ab	61.35 a	**60.99 A**	59.15 ab	60.95 a	**60.05 A**
Maraki	58.28 c	54.02 d	**56.15 C**	59.04 ab	54.98 b	**57.01 B**
Mean	**58.60 A**	**58.17 A**		**58.63 A**	**58.57 A**	
	Shape index					
Coratina	1.45 ab	1.44 bc	**1.45 A**	1.46 ab	1.34 cd	**1.40 A**
Koroneiki	1.45 ab	1.56 a	**1.51 A**	1.40 bc	1.52 a	**1.47 A**
Maraki	1.28 cd	1.24 d	**1.26 B**	1.25 de	1.19 e	**1.22 B**
Mean	**1.39 A**	**1.41 A**		**1.36 A**	**1.37 A**	

IS= Intensive-system, SHD= Super High-Density

Values of interaction (planting density × cultivar) followed by different lowercase letters are significantly different ($p < 0.05$). Mean values of planting density or cultivar followed by different uppercase letters are significantly different.

Chemical analysis: -

Data in **Table (8)** showed that, leaf photosynthetic pigments took the same trend under IS and SHD planting density and seems no significant differences between them during two studied seasons.

Meanwhile, the values of chlorophyll A, B and carotenoids significantly varied from cultivar to another. the highest chlorophyll A, B and carotenoids were recorded by Coratina olive cultivar (0.640, 0.433 and 0.448 mg/g) in 1st season, but in the 2nd one Coratina achieved the highest values of chlorophyll A (0.879 mg/g), Koroneiki olive cultivar recorded the highest values of chlorophyll B (0.595 mg/g). The highest significant value of carotenoids content was obtained by Coratina olive cv. (0.448 mg/g) and without significant difference with those recorded by Maraki c.v. (0.420 mg/g) in 1st season, while, olive cultivars failed to show any significant differences regarding the carotenoids content in the 2nd one.

As for the means of interactions between planting densities and olive cultivars, data in **Table (8)** illustrated that, Coratina cv. planted in IS implemented the highest chlorophyll A (0.837 mg/g), chlorophyll B (520 mg/g) and carotenoids (0.547 mg/g) in the 1st season, while in the second one, there were an intermediate significantly value was observed.

Table (8). Chemical analysis in Coratina, Koroneiki and Maraki olive cultivars under different planting density.

Planting Density	IS	SHD	Mean	IS	SHD	Mean
	Frist season			Second season		
Cultivar	**Chlorophyll A (mg/g)**					
Coratina	0.837 a	0.443 d	**0.640A**	0.869 a	0.889 a	**0.879 A**
Koroneiki	0.353 e	0.547 c	**0.450B**	0.753 bc	0.695 c	**0.724 B**
Maraki	0.497 cd	0.737 b	**0.617 A**	0.883 a	0.832 ab	**0.8578 A**
Mean	**0.562 A**	**0.576 A**		**0.835 A**	**0.805 A**	
	Chlorophyll B (mg/g)					
Coratina	0.520 a	0.347 c	**0.433 A**	0.437 c	0.643 a	**0.540 B**
Koroneiki	0.320 c	0.427 b	**0.373 C**	0.640 ab	0.550 b	**0.595 A**
Maraki	0.347 c	0.443 b	**0.395 B**	0.617 ab	0.440 c	**0.528 B**
Mean	**0.396 A**	**0.406 A**		**0.564 A**	**0.544 A**	
	Carotenoids (mg/g)					
Coratina	0.547 a	0.350 cd	**0.448 A**	0.570 b	0.787 a	**0.678 A**
Koroneiki	0.307 d	0.423 bc	**0.365 B**	0.773 a	0.637 b	**0.705 A**
Maraki	0.350 cd	0.490 ab	**0.420 AB**	0.787 a	0.583 b	**0.685 A**
Mean	**0.401 A**	**0.421 A**		**0.710 A**	**0.669 A**	

IS= Intensive-system, SHD= Super High-Density
Values of interaction (planting density × cultivar) followed by different lowercase letters are significantly different ($p < 0.05$). Mean values of planting density or cultivar followed by different uppercase letters are significantly different.

Leaf anatomical characteristics:

From the microscopic scrutinization of cross sections, a typical mature olive leaf of the studied cultivars has the following tissues: the upper palisade parenchyma consisting of three layers of elongated cells, positioned side-by-side and boarding the intercellular spaces, and the spongy parenchyma cells have loosely arranged, irregularly shaped and containing intercellular spaces and vascular tissue.

The study of the anatomical characteristics of leaves of three olive cultivars under IS and SHD systems in **(Tables 9 and Figures 1- 3),** noted that, there were differences among (Coratina, Koroneiki and Maraki) cultivars in the thickness of the leaf tissue, except for two epidermis layers (upper and lower), no differences appeared between them. In fact, the SHD system increased the leaf blade thickness of both Koroneiki (16.67%) and Coratina (7.47%), while the leaf blade thickness of Maraki decreased by (18.42%).

Mesophyll tissue was affected by each of cultivars and planting density. Indeed, the use of SHD cultivation system led to an increase in the thickness of palisade parenchyma in Koroneiki leaves (27.27%), followed by Coratina leaves (9.17%), while, the palisade parenchyma thickness in Maraki leaves decreased by (38.89%) under SHD system compared to other cultivars.

Similarly, there was an increase in the thickness of the spongy parenchyma of Koroneiki leaves (9.09%) under SHD system, followed by Coratina leaves (6.67%). Meanwhile, no differences were observed in Maraki spongy parenchyma thickness with the two planting systems.

As shown the central vascular bundles in Coratina, Koroneiki and Maraki leaves, (Fig.1-3), it noticed the increased in xylem thick cell walls in SHD system compared to the IS system; The xylem area thickness increased by 55.56% in Coratina leaves, followed by 44.44% in Koroneiki leaves, and the lowest rate of increase was in Maraki leaves 7.69%. Meanwhile, the thickness of the phloem area increased only in Koroneiki leaves (20.00%) with the SHD system, while the thickness of the phloem tissue was thinner in Maraki leaves (16.67%) in the same planting system on the same orchard.

Table (8). Anatomical structure of leaf blade in Coratina, Koroneiki and Maraki olive cultivars under different planting density.

Characters		Leaf blade thickness (mm)	Epidermis thickness (mm)		Palisade thickness (mm)	Spongy thickness (mm)	Xylem thickness (mm)	Phloem thickness (mm)
Cultivars	Planting density		Upper	Lower				
Coratina	IS	495	15	15	240	225	135	75
	SHD	532	15	15	262	240	210	75
Koroneiki	IS	360	15	15	165	165	135	75
	SHD	420	15	15	210	180	195	90
Maraki	IS	570	15	15	270	270	195	90
	SHD	465	15	15	165	270	210	75

IS = Intensive-system, SHD= Super High-Density.

Discussion

Olive growing behaviors and productivity were affected by planting density and cultivar type. The aim of this research was to determine the optimal planting density of the three olive cultivars used for oil production in Ismailia governorate, Egypt.

Numerous researchers cleared that increasing tree density had a negative effect on olive trees vigor (Larbi et al., 2012 and Díez et al., 2016). This effect depends on several factors, including the amount of light intercepted, strength of tree growth, water and nutrient absorbed and soil type (Stutte and Martin, 1986 and Eduardo et al., 2015).

The availability of light affects the photosynthetic activity of olive trees and carbohydrates translocation (Reale et al., 2019). Also, Trentacoste et al. (2016) demonstrated that, fruit growth and oil% increased linearly with increasing irradiance, this is because fruits have priority in the partitioning of photosynthetic products over vegetative growth (Cherbiy-Hoffmann et al., 2013). A study of light intensity for different cultivar and planting systems might state this issue.

Rosati et al. (2024) stated that, the sustainability of intensive and highly intensive olive orchard depends on the vigor growth of the cultivar grown. Trees with small canopies have the highest average vegetative surface area exposed to light (Jackson and Palmer, 1981). In addition, Pastor and Humanes (1990) cleared that, the radiant energy that trees benefit from and use it in growth and fruiting is greater in agricultural systems consisting of small trees.

Koroneiki olive cv. under the experiment carried out was characterized by limited vegetative growth compared to Coratina and Maraki olive cultivars **(Table, 3).** Also, it was distinguished by being the cultivar most exposed to light **(Table, 5).** Good flowering and high fertility are another characteristic that must be present in trees suitable for intensive cultivation (Lo Bianco et al., 2021). Flowering characterization of cultivars under study **(Table, 4)** are in accordance with Fayek et al. (2014) who showed that, Maraki olive cv. recorded the highest number of flower/inflorescence and Koroneiki recorded the lowest number, while Coratina olive cv. gave intermediate values in this concern. The variation in floral characteristics was depends on the cultivars (Lavee et al., 1996).

One of the most important characteristics that must be present in densely planted varieties is high production **(Table 6)** with stability under the conditions of climate change that the region is witnessing. Trabelsi et al. (2023) showed that, Koroneiki olive oil cultivar had a high productivity and is adapted to different climate conditions.

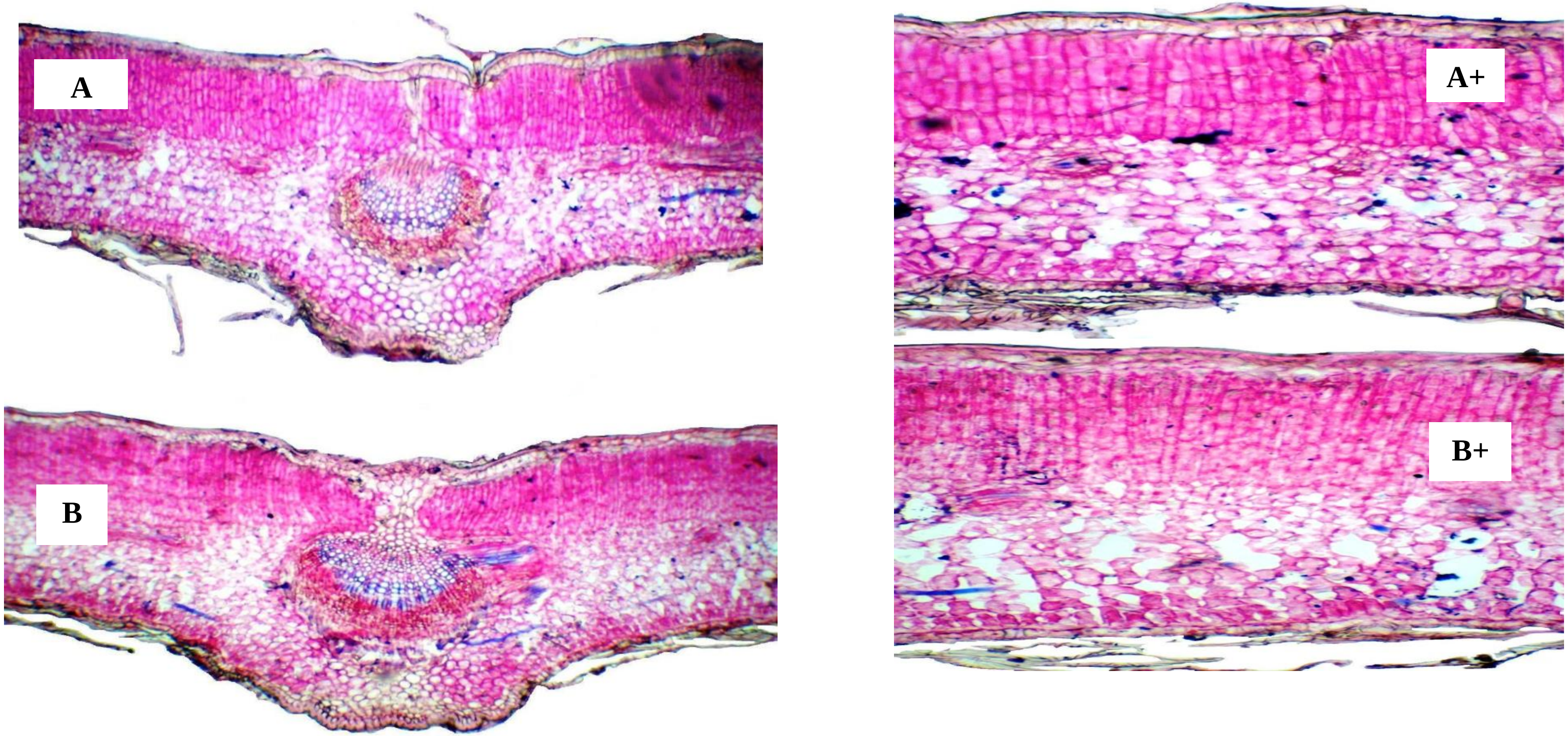

Fig (1). Anatomical structure in Koroneiki olive leaf blade in cross section as affected by planting density: (A and A+) cross sections of the IS system, (B and B+) cross sections of the SHD system, (A and B) general view of the main vein of leaf (10Xs), (A+ and B+) mesophyll leaf (40Xs).

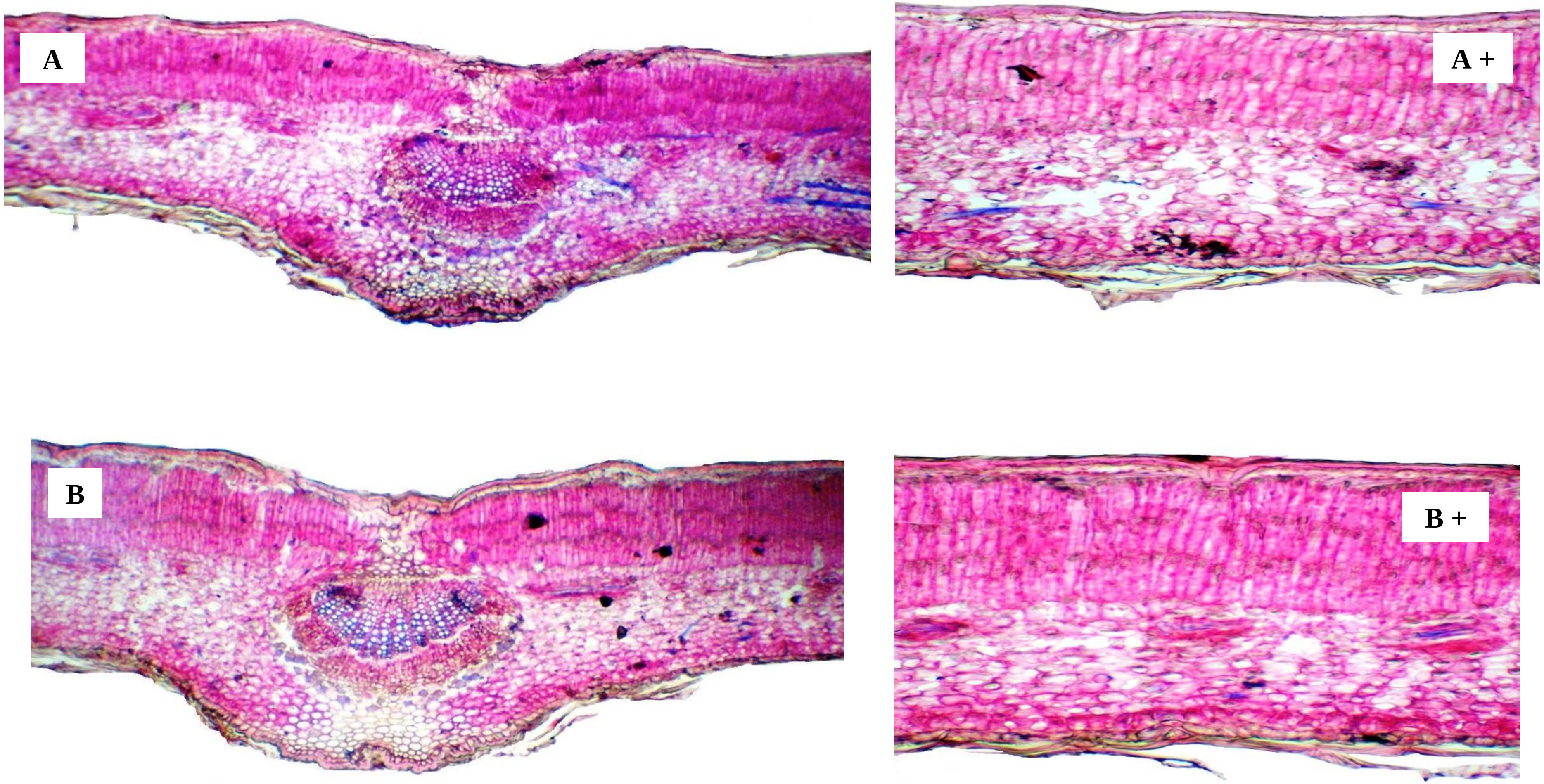

Fig (2). Anatomical structure in Coratina olive leaf blade in cross section as affected by planting density: (A and A+) cross sections of the IS system, (B and B+) cross sections of the SHD system, (A and B) general view of the main vein of leaf (10Xs), (A+ and B+) mesophyll leaf (40Xs).

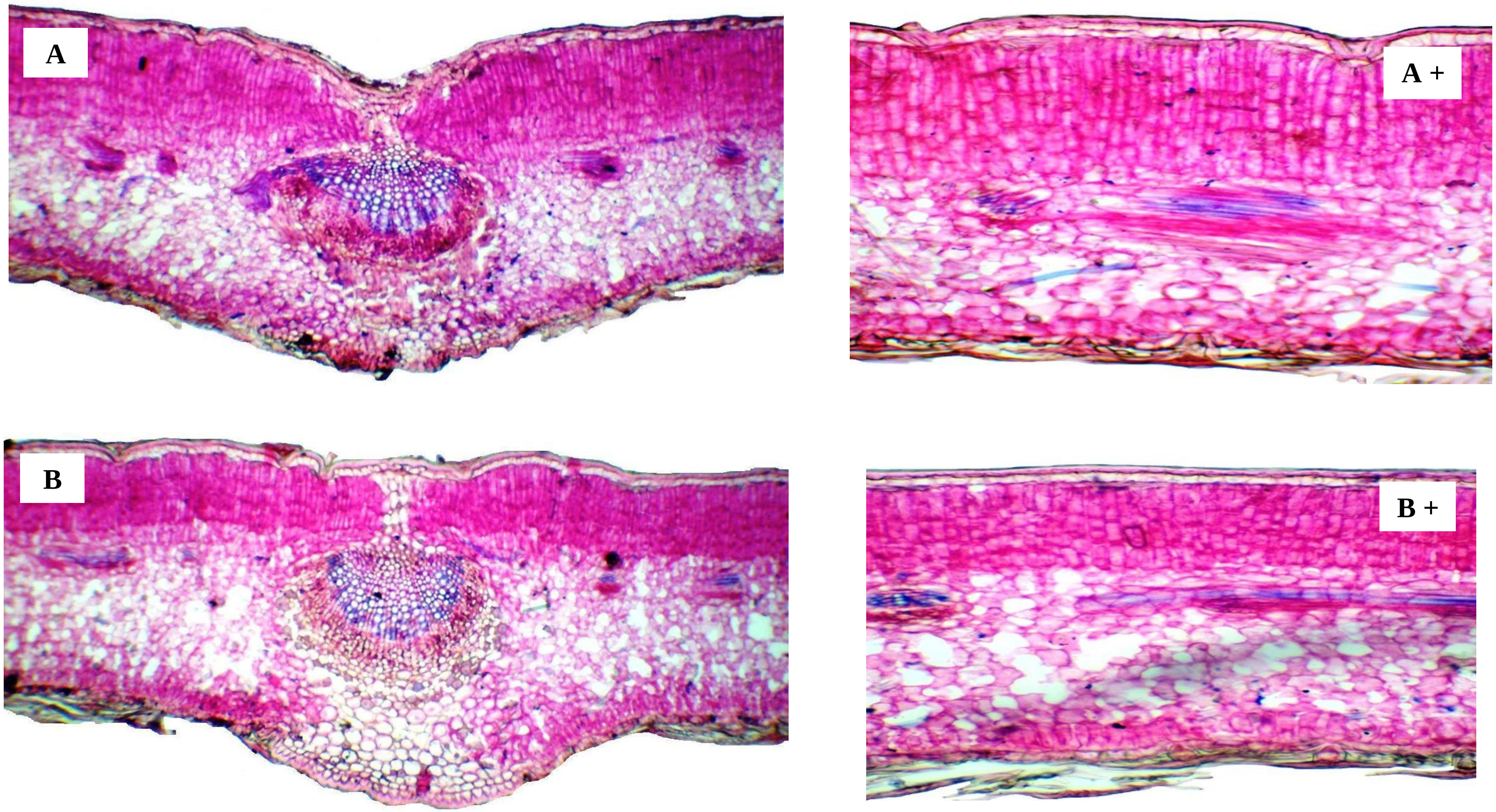

Fig (3).Anatomical structure in Maraki olive leaf blade in cross section as affected by planting density: (A and A+) cross sections of the IS system, (B and B+) cross sections of the SHD system, (A and B) general view of the main vein of leaf (10Xs), (A+ and B+) mesophyll leaf (40Xs).

As for the results obtained from leaf anatomical characteristics, olive leaves had more intercellular spaces and more mesophyll conductivity when the mesophyll thickness increased, these results are in agreement with Bongi and Loreto (1989). Consequently, increased mesophyll conductance enhances CO_2 diffusion within leaf cells, which helps to raise the rate of photosynthesis (Paramita et al., 2007). In addition, Ennajeh et al. (2010) stated that, a thicker palisade parenchyma may have more CO_2 fixation sites, while a thicker spongy parenchyma could result in easier diffusion of CO_2 of these sites to facilitate gas exchange. In particular, the upper palisade parenchyma and the spongy parenchyma could be considered as a key structural feature of leaves that govern the ability of a tree to grow. Furthermore, the ability for water and soluble movement is determined by the area of the xylem, and, there is a considerable correlation between olive tree growth and phloem thickness as the sugars produced in the leaves are transported to tree parts and roots by phloem (Hegazi et al., 2013).

This could explain, the larger amount of intercellular space suggests a greater photosynthesis rate facility in the mesophyll tissue in Koroneiki cultivar by SHD system. On the other hand, the same is true for Coratina and Maraki cultivars under IS planting system.

It could therefore use the leaf tissue parameters as criteria to select olive cultivars that are more suitable to planting density.

Conclusion

Based on data presented in this study, it could be noted that Koroneiki olive cultivar was more successful under super high-density system, while Coratina and Maraki olive cvs. were more successful under intensive system cultivation.

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الملخص العربي

مقارنة السلوك الخضري والإنتاجي في بساتين الزيتون الكثيفة و العالية الكثافة

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أجريت هذه الدراسة في محطة البحوث الزراعية بالإسماعيلية بمصر خلال موسمين دراسيين 2022 و2023. وتم استخدام ثلاثة أصناف من الزيتون (كوراتينا وكروناكي ومراقي) لمقارنة سلوك نموها وإنتاجيتها تحت نظامي زراعة مختلفة (كثيفة وعالية الكثافة).

أظهرت النتائج أن سلوك النمو الخضري لأصناف الزيتون المستخدمة لم يتأثر باختلاف الكثافة النباتية باستثناء المساحة الكلية للأوراق/المتر والتي زادت تحت النظام الكثيف، كما لوحظ زيادة في صفات الإزهار (كثافة الأزهار ونسبة الجنس) في النظام الكثيف، بينما لم تظهر فروق معنوية بين الكثافات النباتية المختبرة في عدد الأزهار/النورات، وقد اظهر نظام الزراعة العالي الكثافة تفوقاً من حيث الكثافة الزهرية مقارنة بنظام الزراعة الكثيف وذلك في السنة الاولي فقط، أما فيما يتعلق بصفات الثمار والمحصول، فقد أدى استخدام نظام الزراعة عالي الكثافة إلى الحصول على أعلى القيم لمحصول الثمار/فدان ومحصول الزيت/فدان وكذلك نسبة لحم الثمار/وزن الثمرة، وأدى استخدام النظام الكثيف إلى الحصول على أعلى القيم المعنوية لوزن الثمار ، بينما لم يؤدي استخدام أي من النظامين إلى أي فروق معنوية في نسبة الرطوبة بالثمار أو شكل الثمار. بالنسبة لأفضل أداء محصولي لأصناف الزيتون المزروعة تحت أنظمة الزراعة المختلفة، سجل صنف الكروناكي أعلى قيم لإنتاج الثمار (7.27-8.93 طن/فدان) وأعلى إنتاجية للزيت (1.14-1.42 طن/فدان) تحت نظام الزراعة فائق الكثافة، وهو ما سوف يؤدي إلى زيادة إجمالي الدخل للفدان.