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RESEARCH ARTICLE

IMPACT OF LEGUMES AND CEREALS ON OLIVE PRODUCTIVITY IN THE SOUTH MEDITERRANEAN

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ABSTRACT

Intercropping of trees with crops on the same piece of land at a given time has been hypothesized to: enhance crop yield, increase land-use and improve land equivalent ratio (LER). To address this hypothesis, we evaluated two legumes faba bean, lentil and three cereals durum wheat, soft wheat and barley grown in olive (*Olea europea*) agroforestry during two growing seasons (Y) with contrasting weather (Y1: 2015-2016 and Y2: 2016-2017) under a Mediterranean climate of north western Morocco. We assessed the effect of annual crops on olive growth and yield; the effect of trees on annual crop growth, yield components, and final yields; finally, we calculated the land equivalent ratio (LER) of olive agroforestry to assess the productivity of the associations. Legumes had no effect on olive growth and yield, while cereals negatively affected shoot elongation and olive yield compared to olive in sole crop. Olive limited crop growth and yield of all associated crops and yield reduction was around 33 % for legumes and 47 % for cereals in agroforestry than sole crop. The magnitude of reduction was higher in Y1 than Y2. Similar responses were found when comparing crops at different distances from trees. Annual crops generally had lower biomass and yield, near the trees compared to the middle of tree inter-rows, causing significant spatial heterogeneity in crops. The LER reached 1.36 with lentil and 1.33 with faba bean, the lowest LER was recorded with durum wheat in both years with 1.01 in Y1 and 1.02 in Y2, and the highest LER with cereals was registered with soft wheat and reached 1.19 in Y1.

KEYWORDS

Faba Bean, Lentil, Wheat, Barley, LER

1. INTRODUCTION

In the Mediterranean region, climate change is expected to result in increased risk of heat stress and drought (Woetzel et al., 2020). Agroforestry systems can be an effective means of stabilizing or even enhancing crop yields under climate change. Olive trees grown in rows or as scattered trees, have been intercropped with cereals and legumes such as wheat, barley, faba bean… for centuries in the Mediterranean area (Panozzo et al., 2019). A renewed interest in olive alley-cropping is currently emerging with the aim to improve the sustainability of both olive orchards and annual crop cultivation (Panozzo et al., 2019). Crop growth and development strongly depends on local climatic conditions. Each crop has different climatic and environmental requirements for normal growth (e.g. temperature, light, slope orientation, soil fertility, water availability, nutrients). These variables may be affected by climate change, especially temperature, due to its impact on the plant development (Tanasijevic et al., 2014). The mitigation effect that trees might have on these risks is uncertain, although trees can reduce air and crop temperature, the effect on crop phenology might lead to slower development and so a delay in the most sensitive stage, i.e. anthesis for cereals, which could happen when water stress occur and light interception is low (Panozzo et al., 2019; Temani et al., 2021; Zhang et al., 2018).

Some Mediterranean alley cropping systems have been successful for thousands of years. e.g.. olive trees intercropped with cereals and legumes (Wolpert et al., 2020; Pantera et al., 2018; Torquebiau et al., 2002). Intercrops of olive trees with cereals and legumes may increase the profitability and sustainability of the farm by the production of biomass and grains from the understory crops and positively affect olive tree productivity (Chehab et al., 2019; Panozzo et al., 2022). Besides, there is an increasing need to improve the resilience of annual crop especially wheat and legumes to climate change, while providing ecosystem services (Bedoussac et al., 2015; Jensen et al., 2012).

In Greece evaluate the productivity of barley and a mixture of barley and common vetch in an olive orchard, they found that the intercropping is a very promising practice for Mediterranean areas with traditional olive agroforestry systems, and total grain yield of barley in agroforestry was close to 80% of the average barley in monocultures (Mantzanas et al., 2021). In another study in Portugal compared four management practices (ordinary tillage, cover crop with self-reseeding annual legume species, natural vegetation fertilized, and natural vegetation unfertilized) in a rainfed olive orchard (Correia et al., 2015). They observed that the case with legumes cover crops reached higher cumulative yield than in the other cases.

In Morocco under Mediterranean condition, a study based on farmers

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estimation in mountainous areas of Morocco. Highlights that legume crops do not affect negatively olive production, whilst cereals do (Daoui et al., 2014). In a field survey conducted in northern Morocco which involved intercrops of olive trees with legumes (faba bean and chickpea (*Cicer arietinum*)) and cereals (wheat and barley) found that legumes do not affect negatively olive production and the Land Equivalent Ratio with legumes is higher than with cereals (Amassaghrou et al., 2021). A group researcher in a field survey conducted along a rainfall gradient in northern Morocco which involved intercrops of olive trees and barley, found that barley biomass production and grain yield at harvest was higher under the intermediate rainfall level compared to the wetter site (Temani et al., 2021). Regarding the rainfed olive orchards, the main factors affecting the understory crops productivity are water availability, depending on local meteorological conditions, and light intensity depending on tree age and canopy cover.

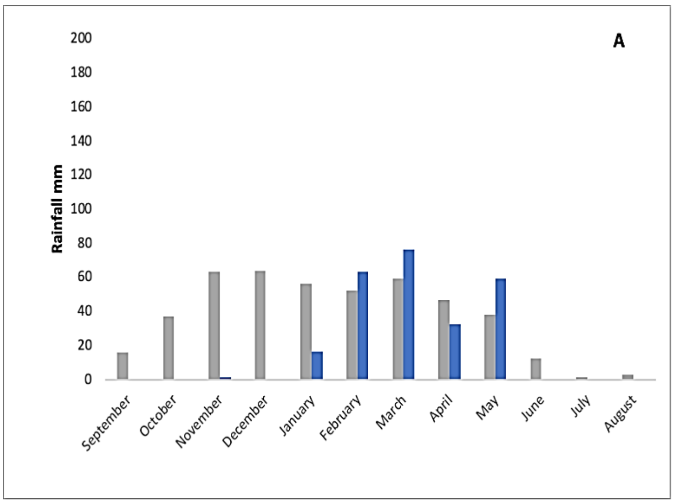
Another study conducted in Morocco compared the cultivation of wheat, faba bean and coriander (*Coriandrum sativum*) in two distances from the tree (close to trunk and from the limit of olive tree canopy) (Razouk et al., 2016). In rainfed olive orchards. The results showed that vegetative growth and yield of olive tree were reduced by sowing wheat even from the canopy limit. In contrast, faba beans induced an improvement of olive production at the two tested sowing distances. The reduction in annual crops biomass was recorded over an aureole around the tree canopy and shading induced a reduction of 70% in wheat yield and of 10% in grain weight. Other studies have demonstrated that the impact of trees on the understory vegetation could be negative (Noumi et al., 2011). For example, the roots compete for water and nutrients with understory vegetation. The role played by competition from tree roots is likely to be influential in the reduction of available soil moisture and hence in the reduction of plant growth (Artru et al., 2017). Trees can also reduce light availability, which can also limit plant production (Dufour et al., 2013; Xu et al., 2016; Noumi et al., 2011).

The aim of this study was to evaluate the growth and productivity of understory intercrops with olive trees: cereals and legumes, used grain production and their possible interactions, focusing on the spatial variability of crop growth during two climatic years. Specifically, we asked whether: (1) olive trees would have different growth and yield potential in association with legumes than with cereals; (2) legumes and cereals species would have different yield potential under agroforestry regarding their physiological requirements (especially light) and crop growth cycle duration; (3) olive agroforestry systems are more land-productive than soles crops and trees and improve soil fertility under trees.

2. Materials and Methods

2.1 Study Site

The experiments were carried out at the experimental station of the National Institute for Agricultural Research (INRA Morocco) in Ain Taoujdate (33°93’07.1” N. 5°27’35.7” W. 550 m a.s.l) for two growing seasons (Y): Y1: 2015-2016 and Y2: 2016 - 2017. Based on historical data (30 years), the site has a sub-humid Mediterranean climate, with a yearly average temperature of ∼15 ◦C and a maximum daily temperature that increased from 34 ◦C at the end of the last century up to 38 ◦C in 2017. The historical average annual precipitation is about 450 mm with high heterogeneity in the rainfall pattern across years (figure 1); 248 mm during Y1 and 202 mm during Y2 (figure 1).



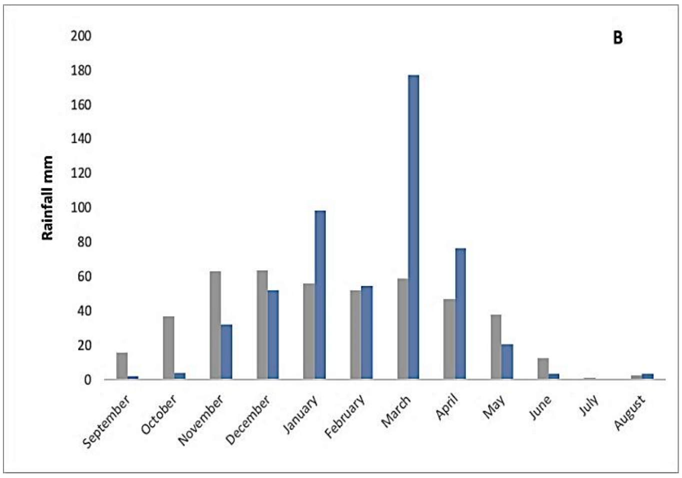


Figure 1: Distribution of monthly precipitation (mm) for the two years of study (a: Y1 and b: Y2) (blue bars), as compared to the mean historical precipitation for the last 30 years (1988–2017) at the study site (gray bars).

2.2 Plant Material and Experimental Design

We compared two agroforestry systems, the first one with two widespread Mediterranean food legume crop species, faba bean (*Vicia faba,* Cv. ‘Aguadulce’), and lentil (*Lens culinaris*, Cv.’ Bakria’) and the second system with three cereals, durum wheat (*Triticum durum.* cv. 'Karim') soft wheat (*Tritium eastevum.* cv 'Arrehane') and barley (*Hordeum vulgare.* cv 'population'), grown in an olive-based agroforestry (AFS). The experimental design is shown in figure 2. The olive grove (*Olea europaea. Subsp. Europaea.* Cv. ’Picholine marocaine’) was 50-years old with an average height of 5.2 m (ranging from 4.5 to 6.0 m), average trunk diameter of 0.4 m, average canopy diameter of 5.0 m. The density of olive trees was 200 trees ha^{-1} with a regular 6×8 m plantation design following an East-West orientation.

The trial was arranged as a randomized block design with four replicates, crop sampling was distributed over three main ‘Areas’ to represent the spatial heterogeneity caused by trees in the AFS plot. Each sampling Area consisted of 4 adjacent crop lines and had contrasting exposure to tree shade and belowground interactions (figure 2). The choice of the three Areas was made on the way in which shade is projected in the inter-row. At the beginning of the growing season, Area 1 (A1) and Area 2 (A2) are much more in the shade than Area 3 (A3). At the end of the season, A1 and A3 are under tree shade. We can therefore say that A2 is an intermediate between A1 and A3 (figure 2) from the point of view of aerial influence. A1 receives no shade at the beginning of the cycle but a little at the end, unlike A3 which is exposed to tree shade throughout the crop cycle.

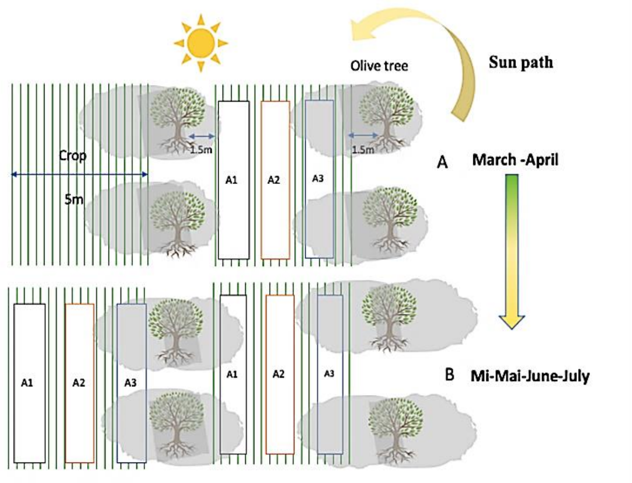


Figure 2: Experimental layout showing the plot of agroforestry (AFS) faba bean, lentil, durum wheat, soft wheat and barley were sown in an east-west orientation leaving 1.5 m distance between the outer rows of the crop strip and the tree line. (A) represent shade tree distribution until April and (B) represent shade tree distribution until July; A1, A2 and A3 represent the three area where measurements were done during growing season

A survey of six farmers in the study area under the same conditions (type of soil, fertilization) and same crops (variety) was set up to compare yields in SCS with AFS. Legumes and cereals were sown on the same date for the two years of the experiment, in January 2015 and December 2016. The sowing rates in AFS 180 kg. ha^{-1} for cereals, 100 kg.ha^{-1} for faba bean and 50 kg.ha^{-1} for lentil. Crops were seeded in strips spaced at a distance of 0.3 m, for cereals and lentil and 0.5 m for faba bean, crop strips started 1.5 m far from olive tree rows, every treatment covered an area of 120 m^2 and the total area was 600m^2.

Fertilizer application rate for legumes was 48 kg P2O5 ha^{-1}, and P was applied as triple superphosphate at the sowing date, while the fertilizer application rate for cereals was 150 kg ha^{-1} of Diamomiun phosphate (18-46-00) and 360 kg ha^{-1} of ammonitrate (33%) in march. Technical management (weed, disease, and pest control) has been performed to ensure the safe growth of crops. In Y1, crops were harvested at maturity on the 28th of June for faba bean and lentil and the 2 of July for cereals. In Y2, crops were harvested at maturity on the 8th of May for lentil and 18th of May for faba bean and the 1st of June for cereals. Olive trees were manually harvested in November Y1 and Y2, and all the fresh olive fruit were weighed to measure the yield.

The experimental plot is derived from alluvial soil. Soil samples were collected from a depth of 0–30 cm near to tree and in the middle of inter-row, and were mixed, to evaluate fertility and organic matter at the beginning of the experiment (December Y1) Organic Matter in this soil layer was 0.8 %, Olsen-P 21.9 mg kg^{-1}, and K2O 331.2 mg kg^{-1}. After harvesting annual crops in June Y1 and June Y2, soil samples were taken from 0-30 cm layer at three different distances from tree rows inside each treatment with four repetitions. These soil samples were subjected to chemical analysis to determine their levels of fertility. Analyses were performed by the following methods: organic matter by the Walkley and Black method, available phosphorus by Olsen method and exchangeable potassium by ammonium acetate.

2.3 Field Measurements and Sampling

On olive tree, the measurements included diameter at breast height, tree canopy, tree height and the annual shoot elongation of all trees of the experimental plot in AFS and in SCS. In each tree we selected two shoot (similar length) and measured their size every 15 days from February to June in total 10 measurements were carried out. The olive yield per tree was estimated at harvest in each sub-plot based on a total of 8 olive trees in each association and in SCS. Annual crop growth monitoring was performed by three repeated measures at flowering, fructification, and maturity stages in Y1 and Y2. At each stage, 60 plants/treatment (stratified sampling of 5 selected plants/row along 1 m line) were randomly selected to measure plant height.

Once they reached maturity, crop plants were entirely harvested at ground level using hand-clippers. Plants were sorted by organs, oven-dried (70 ◦C. 48 h) and weighed to determine the total aboveground biomass. Yield components were also assessed (number of pods/spikes per unit area, number of grains per unit area, and hundred grain weight (HGW) for legumes and thousand grain weight (TGW) for cereals). The harvest index was calculated as the ratio between grain biomass and total aboveground biomass. At harvest time, a survey of six farmers in the study area under the same conditions (type of soil, fertilization, and variety) was conducted to identify the final grain yield of the different species studied in sole crop, and to be able to compare with the yields in agroforestry in our experiment.

2.4 Data Analysis

We calculated the land equivalent ratio (LER), defined as the relative land area required for sole crops to achieve the same yield than intercropping, using annual crops grain yields and olive yield over two years for each agroforestry system (Mead and Willey, 1980). The LER indicates a higher (or lower) productivity of agroforestry ('AFS') than the corresponding orchard ('OR') and sole crops ('SCS') when the value is above or below 1, the value is equal to 1 when agroforestry does not impact land productivity.

$$Eq\ 1: \quad LER_{AFS} = LER_{AFS}\ Olive + LER_{AFS}\ Crop$$

$$Eq\ 2: \quad LER_{AFS}\ Olive = Olive \frac{Yield_{\ AFS}}{Yield_{\ SCS}}$$

$$Eq\ 3: \quad LER_{AFS}\ Crop = Crop \frac{Yield_{\ AFS}}{Yield_{\ SCS}}$$

The relative yield index (RY) were calculated as the ratio between olive yield in Agroforestry and sole crop for each association (de Wit and Van den Bergh, 1965):

$$Eq\ 4: \quad RY = Y_{AFS}/Y_{SCS}$$

where Y_{AFS} and Y_{SCS} are respectively the yields of olive tree in agroforestry system and sole crop system. A ratio higher than 0.5 indicates that olive tree had higher yield in AFS than in SCS. while a ratio lower than 0.5 indicates that olive tree was less productive in AFS. We tested the differences in crop growth, yield components, final grain yield, and soil fertility using ANOVA with two factors: (1) type of system ('AFS', or, 'SCS'), and (2) year (2016, 2017). Each crop species (faba bean, lentil, durum wheat, soft wheat and barley) was tested separately. After significant ANOVA ($p < 0.05$), the means were compared with Tukey multiple comparison test. All statistical analyses were performed using IBM SPSS statistics (version 26.0).

3. Results and Discussion

3.1 Tree Growth and Yield are Enhanced by Legumes in Agroforestry

Average shoot elongation of olive tree was the lowest in association with cereal ($P<0.001$) which reduced shoot length of olive tree by 69 %, 75 % and 71% in association with durum wheat, soft wheat and barley respectively comparatively to olive tree growing in monoculture (figure 3). The depressive goods induced by wheat on vegetative growth of olive tree are substantially due to the competition for soil humidity and nutrients during the critical period of olive shoots growth. In the study area this period occurs during June, that overlaps with wheat grain filling. In fact, several studies indicated that water stress during the rapid shoots growth of olive tree induce a significant reduction on shoots growth, thereby affecting their final length (Razouk et al., 2016).

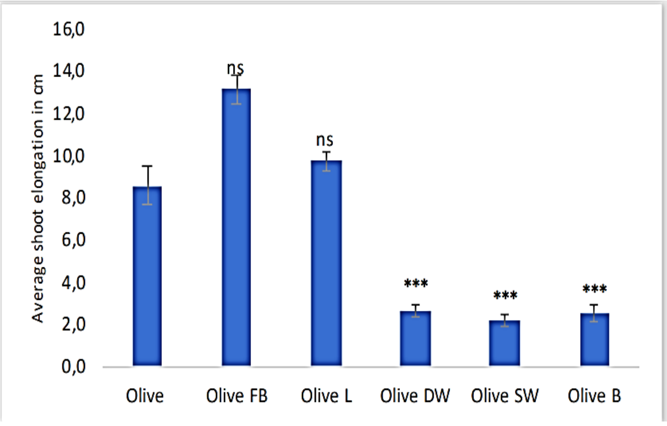


Figure 3: Average shoot elongation in Y1 of olive tree in sole crop (olive) and olive tree grown in AFS with faba bean (Olive FB). lentil (Olive L), Durum wheat (Olive DW), Soft wheat (Olive SW) and Barley (Olive B). Significance level (differences between olive in sole crop and olive in agroforestry): * p < 0.05; ** p < 0.01; *** p < 0.001.

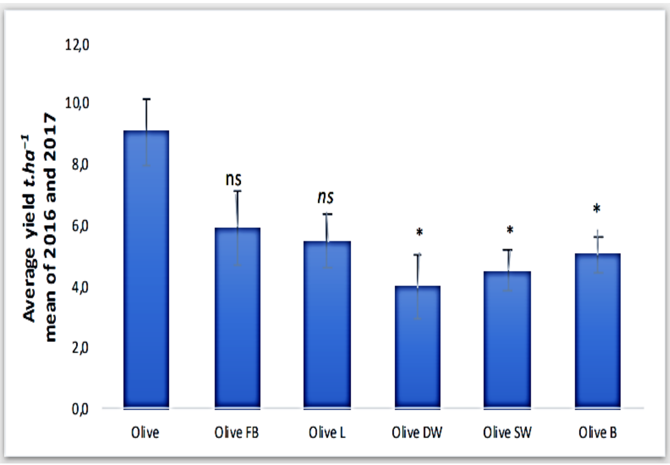


Figure 4: Olive yield (t.ha−1) in sole crop (olive) and olive tree grown in AFS with faba bean (Olive FB), lentil (OliveL), durum wheat (OliveDW), soft wheat (OliveSW) and barley (OliveB). Significance level (differences between olive in sole crop and olive in agroforestry): * p < 0.05

In association with legumes olive tree shoot elongation was higher and increased with 53% and 14% in association with faba bean (p=0.61) and lentil (p=0.99) respectively comparatively to olive tree growing in sole crop (figure 3), in contrast to the association with cereals, the association with faba bean and lentil improved vegetative growth of olive same results were found in another study at the same conditions (Razouk et al., 2016). The favorable effect of legumes could be explained by the enrichment of soil by nitrogen biologically fixed by this legume (Chehab et al., 2018). According to previous studies carried out in the study region, this crop may fix an important amount of nitrogen up to 300 kg/ha, that is largely sufficient to satisfy olive nitrogen requirements, particularly during the vegetative departure (Razouk et al., 2016).

The olive yields average did not vary between years (p= 0.95) and between olive in SCS and in AFS with faba bean (p =0.24) and lentil (p=0.29) (figure 4), same results were found under Mediterranean condition confirming our hypothesis that olive yield may benefit from legumes cultivated in interrow (Amassaghrou et al., 2021; Temani et al., 2021; Razouk et al., 2016). A significative difference was recorded between olive in SCS and olive in AFS (figure 4) with durum wheat (p=0.02), soft wheat (p=0.01) and barley (p=0.01) confirming that olive trees were under stress, and cereals induced a depressive effect on olive yield (Amassaghrou et al., 2021; Panozzo et al., 2020; Razouk et al., 2016; Daoui et al., 2014).

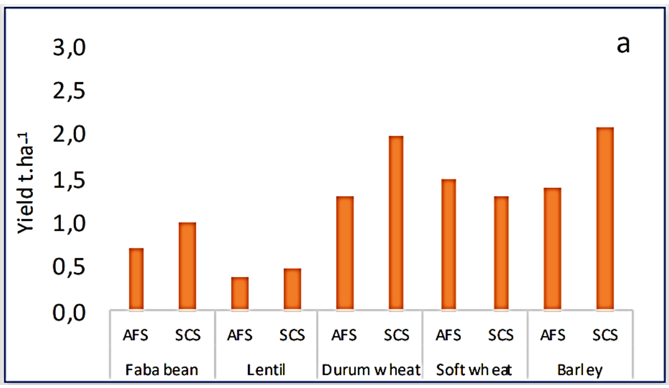
Table 1: Relative yield index for olive yield (RY) in association with faba bean ($Olive_{FB}$), lentil ($Olive_{L}$), durum wheat ($Olive_{DW}$), soft wheat ($Olive_{SW}$) and barley ($Olive_{B}$). in Y1 and Y2. The highest values in each Row are shown in bold and the lowest values in italics.

	RY				
Year	$Olive_{FB}$	$Olive_{L}$	$Olive_{DW}$	$Olive_{SW}$	$Olive_{B}$
Y1	**0.75**	0.70	*0.46*	*0.46*	0.60
Y2	**0.56**	0.52	*0.42*	0.53	0.52

Relative yield (RY) ranged from 0.60 to 0.94 in Y1 and ranged from 0.53 to 0.70 in Y2 across different association with legumes and cereals (Table 1). In general, RY were lower in year 2 than in year 1. and $Olive_{FB}$ had the highest RY in both years. Compared to cereals, legumes performed better, opening possibilities for improving the productivity of the actual olive AFS with more legumes. In a similar experiment, a group researchers found that the relative yield was superior for faba bean (0.54) than for wheat (0.19). Other studies also confirmed that the relative yield in AFS was higher for legumes than cereals (Temani et al., 2021; Amassaghrou et al., 2021; Daoui and Fatemi, 2014).

3.2 Olive Trees Reduce Cereals Yield Compared to Legumes

In opposition to our main hypothesis, olive trees negatively affected yield of all intercrops, during both years (figure 5), legumes and cereals grain yield was lower in AFS than in SCS, the reduction was around 35% for faba bean and 33% for lentil in Y2, the reduction was less pronounced in Y1 with 30% for faba bean and 20% for lentil. Same results were recorded with cereals, when yields were lowest in AFS in Y2 than Y1 and the magnitude of reduction was around 43%, 44% and 56% for Durum wheat, soft wheat and barley respectively. Climatic conditions were mostly responsible for low yields, During Y1 and Y2, very severe climatic conditions took place, due to an accentuated rainfall deficit (248 mm between December and June in Y1 and 202 mm between December and June in Y2) with an irregular temporal distribution. The air temperature was in continuous evolution especially during the period which extends from March until the harvest (early July). In another studies on the effect of trees on crop yield found similar results where olive tree reduced grain yields by around 20 %, 52% and 44 % for faba bean, wheat and barley respectively (Panozzo et al., 2022; Amassaghrou et al., 2021; Temani et al., 2021).



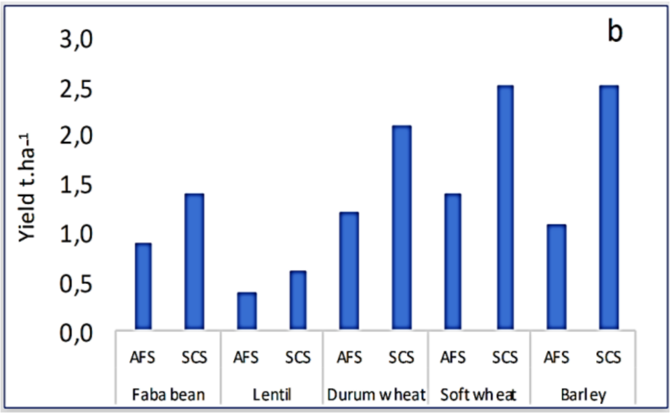


Figure 5: Grain yield (t.ha-1) of faba bean, lentil, durum wheat, soft wheat and barley during Y1 (a) and Y 2(b) in AFS and SCS

3.3 Olive Trees Reduce the Number of Grains Per Unit Area

Faba bean and lentil grain yield recorded significant difference between area (P<0.05, figure 6), and was higher in A2 in both years. Legumes yield was negatively affected by olive tree and the lowest grain yield was under A1 and A3, the areas near to trees. Durum wheat (P<0.05) and soft wheat (p< 0.001) recorded a significative difference between areas in Y1 and no difference in Y2 (figure 6), while no significant differences recorded for barley (P=0.77) in both years. For all cereals, the highest yield was recorded in A2, and the lowest yield in A3 (figure 6). Legumes and cereals plant height recorded a significant difference between areas (P<0.01), in Y1 and Y2 the highest plant height was in A1. Faba bean pods number and grains number (P < 0.001) varied significantly between areas; and no significant difference was recorded for aboveground biomass (P =1.24) and HGW (P=0.15) (table 2). For lentil, grains number (P<0.05), and HGW (P<0.01) varied significantly between Areas (table 2), in both years the highest values were recorded in A2.

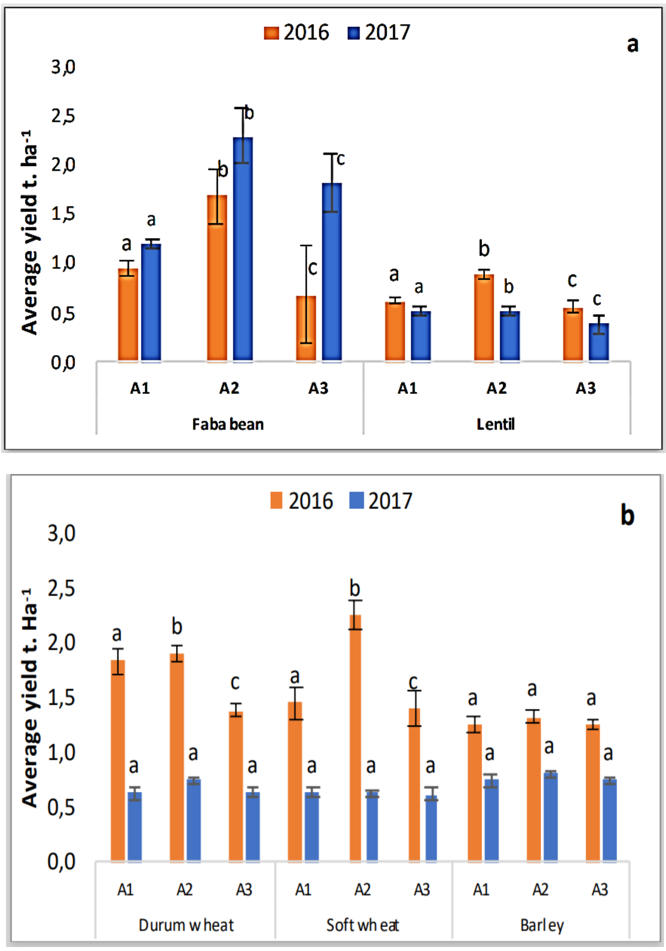


Figure 6: Grain yield (t.ha-1± sd) at harvest in agroforestry (AFS) at the three area (A1, A2, and A3) for legumes (a) and cereals (b) during Y1 and Y2. Letter indicates significance difference between areas at the same year

Table 2: Plant height(cm), number of pods/spikes and grains (m-2), weight of 100 grains for legumes (HGW) and 1000 grains for cereals (TGW) (g) Biomass (g) and the harvest index (HI) of faba bean, lentil, durum wheat, soft wheat and barley in 2016 and 2017 in agroforestry (AFS). according to the three Areas (A1. A2 and A3). Lowercase letters indicate significant differences between among Areas (HSD Tukey test. P ≤ 0.05).

Year	Species	Plant Height (cm)			CV %	Pods/Spikes Number.m-2			CV %	Grains Number.m-2			CV %	HGW/TGW (g.m-2)			CV %	Biomass (g.m-2)			CV %
		A1	A2	A3		A1	A2	A3		A1	A2	A3		A1	A2	A3		A1	A2	A3	
Y1	Faba bean	88.9a	75.2b	79.8c	8.6	102.0a	163.0b	75.5c	39.5	102.8a	129.0b	104.8c	13.0	662.4a	667.6a	654.1a	1.0	234.3a	351.8a	241.0a	23.9
	Lentil	59.2a	45.9b	50.9c	12.9	2700.0a	2465.0b	2836.5a	7.0	1256.5a	1646.8b	1238.0c	16.7	5.0a	5.4b	4.6c	8.7	322.3a	387.3b	332.1c	10.1
	DW	75.8a	58.1b	65.9c	13.3	510.3a	546.7a	363.9a	20.4	4268.1a	4496.1b	3480.0c	13.1	163.4a	187.7a	159.7a	6.9	358.3a	556.5b	538.5c	27.7
	SW	84.4a	67.3b	74.7c	11.3	563.4a	745.3b	470.3c	23.6	3749.4a	5703.1b	3462.5c	28.3	161.2a	176.2a	139.4a	11.7	299.0a	548.8b	335.5c	34.2
	Barley	79.5a	66.6b	75.0c	8.9	432.8a	563.1b	284.4c	32.7	3206.9a	3311.1a	2716.7a	10.3	137.2a	196.9b	135.1c	22.4	303.0a	451.8b	369.8c	19.9
Y2	Faba bean	99.2a	90.0b	90.6c	5.6	61.0a	101.0b	81.5c	24.6	167.5a	189.3b	161.5c	8.5	413.8a	537.8a	515.5a	13.5	358.8a	393.3a	387.0a	4.8
	Lentil	62.5a	53.5b	56.1c	8.1	1362.5a	1419.5a	956.5a	20.3	968.6 a	1055.9b	818.2c	12.7	5.0a	5.4b	4.6c	8.7	105.1a	112.1a	85.7a	13.5
	DW	75.7a	69.6b	70.7c	4.5	295.7a	419.2a	264.5a	25.0	28299a	2999.2a	2568.4a	7.7	116.3a	117.5a	116.6a	0.5	177.6a	230.2b	180.4c	15.1
	SW	80.4a	70.6b	74.5c	6.6	272.8a	305.6b	246.1c	10.8	2567.2a	3435.8a	1890.0a	29.5	105.4a	127.1a	108.8a	10.2	188.2a	256.0b	212.6c	15.7
	Barley	78.1a	70.8b	75.6c	5.0	132.6a	175.8b	194.4c	18.9	1627.1a	2016.4a	1730.6a	11.3	144.5a	145.4b	165.9c	8.0	245.4a	210.3b	262.4c	11.1

Durum wheat spikes number (P=0.766), grains number (0.181), and TGW (P=0.386) were higher in A2 in Y1 and Y2 and no significant difference was recorded between areas; only biomass (P<0.01) varied significantly between areas in both years (table 2). Soft wheat spikes number (P<0.05), grains number (P<0.01) and biomass (P < 0.001) varied significantly between areas. Like durum wheat highest values were registered in A2 in Y1 and Y2. Barley spikes number (P<0.01), TGW (P<0.05), biomass (P<0.01) varied significantly between areas and were higher in A2 in Y1 and A3 in Y2. No significant difference was recorded for grains number (P=0.42) (table 2).

The reduction in final crop grain yield in agroforestry was a direct result of the reduction in the number of grains per unit area. The number of grains is a major yield component for legumes (Lake et al., 2019). Since the number of grains per unit area is closely related to the number of pods, the impact of trees on crops was important for crop yield in agroforestry. Besides, drought and heat are considered major constraints in faba bean growth and production, and lentil is sensitive to shade, the two years were characterized by very severe climatic conditions (figure 1) with an irregular temporal distribution; this condition makes crops more under stress and competition in agroforestry, and contrary to our hypothesis, tree shade had a negative effect on yield (Karkanis et al., 2018; Darabi et al., 2014). For cereals the variations in grain number per unit area determine the final yield more than other yield components (Temani et al., 2021; Li et al., 2020; Zhang et al., 2000). In both years, final grain yield was highest under non shaded conditions and declined with increased shade near to trees. Other studies found that the yields in wheat were relatively low under trees, primarily due to shade and competition for nutrients and water (Razouk et al., 2016; Noumi et al., 2011).

In some cases, trait plasticity allows plants to adapt efficiently to shade, resulting in light uptake and biomass production at levels similar to single crops, especially during critical periods (Guadalupe Arenas-Corraliza et al., 2018). However, even if we noticed significant morphological changes in the plants (stem elongation, increased leaf area, etc.), it was not enough to fully compensate for the reduced light under the olive trees. In agroforestry in China in a humid, semi-tropical climate and in Europe under Mediterranean climate, many other studies have been conducted on how trees affect cereal productivity and reveal that the main cause of cereal yield decreases is competition for light (Qiao et al., 2020; 2019; Pantera et al., 2018; Li et al., 2010). Shade usually limits biomass production and therefore decreases crop yields (Li et al., 2010). Legumes differ in many physiological aspects compared to cereals and potentially have many advantages in agroforestry, the indeterminate growth habit of legumes may improve the performance of agroforestry systems by valuing the shade under trees better than cereals (Kato et al., 2019) . The capacity of legumes to fix the atmospheric nitrogen can enhance soil nitrogen available for the olive trees, improve soil fertility, and hence have positive effects on olive production (Dwivedi et al., 2015; Jensen et al., 2010).

3.4 Soil Fertility is Increased Under Tree in Agroforestry

The distance from the olive row had different effects on soil parameters measured in each plot of the intercropping to the olive tree. Soil organic matter content is the only parameter that was affected by this distance (highly significant effect) and was higher in agroforestry with legumes than with cereals in Y1 and Y2. Indeed. the highest value was recorded near the olive tree in A1 (table 3) for durum wheat and in A3 for legumes, soft wheat and barley (table 3), this is usually in the area close to the tree rows that the physical-chemical and biological parameters characterizing soil fertility are particularly improved and trees add organic matter to the soil system in various manners, whether in the form of roots or litterfall or as root exudates in the rhizosphere (Corbeels et al., 2018). A group researchers under the same conditions of our study found also that soil fertility varied between the olive row in agroforestry with faba bean and the parameters measured (P-olsen, K and NO-3) were higher in the middle of plot, 3m away from olive row, this suggest that crop fertilization in agroforestry should take in to the count, the associated species and the distance from olive tree for an efficient use of mineral resources (Bouhafa et al., 2015).

Table 3: OM%. K (mg.kg-1) and P (mg.kg-1) of the soil samples collected at (0-30 cm) depth in the three Area (A1, A2 and A3) after harvest during June in Y1 and Y2. The highest values in each Row are shown in bold. Lowercase letters indicate significant differences between among Areas (HSD) Tukey test P ≤ 0.05

Year	Species	Organic matter %			K (mg.kg-1)			P (mg.kg-1)		
		A1	A2	A3	A1	A2	A3	A1	A2	A3
Y1	Faba bean	1.8a	1.5b	**2.4c**	255.6a	263.4a	**268.5a**	20.4a	**22.0a**	19.9a
	Lentil	1.7a	1.3b	**2.1c**	277.2a	**302.4a**	289.3a	19.5a	**21.5a**	20.8a
	durum wheat	**1.6a**	1.1b	1.5c	298.8a	284.6a	**305.4a**	21.7a	23.0a	**24.0a**
	soft wheat	1.4a	1.2b	**1.6c**	2782a	283.5a	**289.0a**	**24.5a**	19.0a	22.0a
	Barley	1.6a	1.3b	**1.8c**	280.4a	279.1a	**283.2a**	21.0a	21.0a	**22.0a**
Y2	Faba bean	1.3a	1.1b	**1.9c**	266.4a	**278.5a**	263.4a	19.7a	**21.0a**	18.9a
	Lentil	1.6a	1.2b	**2.2c**	267.3a	278.9a	**281.3a**	18.5a	**19.6a**	18.0a
	durum wheat	**1.4a**	0.7b	1.3c	298.4a	287.9a	**312.1a**	17.0a	**22.0a**	22.5a
	soft wheat	1.1a	0.9b	**1.7c**	259.9a	267.3a	**287.4a**	**19.7a**	18.6a	15.9a
	Barley	1.2a	1.1b	**1.5c**	269.5a	279.2a	**281.6a**	22.0a	**22.3a**	18.4a

3.5 Overall Yield of Agroforestry System in Mediterranean Conditions

LER represents the relative area of land required for a single crop to produce the same yield per unit area as a cover crop (Mead and Willey, 1980). In Y1, the land equivalent ratio (LER) was always > 1 and ranged from 1.01 with durum wheat to 1.36 with lentil without a clear distinction between legumes and cereals (table 4). In Y2, LER was lower and ranged from 1.02 with Durum wheat to 1.20 with faba bean. Despite some negative effects on yields, the values of LER>1 confirm the hypothesis that agroforestry systems are more productive and efficient than pure cropping systems, and that olive agroforestry systems exhibit high LERs under drier conditions than previous evaluations in Europe (Panozzo et al., 2019). Same results were found when olive in associated with annual crop under Mediterranean condition (Amassaghrou et al., 2021; Temani et al., 2021; Panozzo et al., 2019).

Table 4: Land equivalent ratios of olive-faba bean, olive-lentil, olive-durum wheat, olive-soft wheat and olive-barley agroforestry systems in 2016 and 2017. Partial LERs are indicated in brackets for crops and olive, respectively.

	LER				
Year	Faba bean + olive	Lentil + olive	Durum wheat + olive	Soft wheat + olive	Barley + olive
Y1	1.33 (0.58+0.75)	1.36 (0.66+0.69)	1.01(0.55+0.46)	1.19 (0.73+0.46)	1.16 (0.57+0.59)
Y2	1.20 (0.64+0.56)	1.18 (0.66+0.52)	1.02(0.61+0.41)	1.08 (0.56+0.52)	1.07 (0.55+0.52)

Although tree effects on the crops varied between years, it was positive in the years with extreme weather events such as high spring temperatures, which are expected to be more frequent in the coming years as a consequence of climate change in Mediterranean areas (Guadalupe Arenas-Corraliza et al., 2018). Many other studies found an LER >1, found an average LER of 1.22 ± 0.02 in a database of 100 mixed culture studies, while independently selected 126 papers from the literature and found an average LER of 1.30 ± 0.01 (Yu et al., 2015; Martin-Guay et al., 2018). Compared to cereals, legumes are less competitive for soil resources (nitrogen) and reach maturity earlier, leaving more resources available to olive trees, especially at the beginning of summer, when trees start to grow actively, and water availability sinks (Razouk et al., 2016).

4. Conclusion

Rainfed cropping systems are critically affected by climate change in the South Mediterranean, especially by increasing rainfall scarcity and irregularity. Our study compared legumes with cereals in olive agroforestry systems, we showed that olive trees limited crop growth and affected grain yields of all crops by reducing pods/spikes number and grains numbers in the rows near to trees. However, our results reveal that legumes did not impact olive yields. Legumes in association with olive trees are less competitive than cereals for soil resources and mature earlier, especially in early summer when trees begin to grow vigorously and water availability decreases, in addition, the ability of legumes to fix atmospheric nitrogen can increase soil nitrogen availability to olive trees, improve soil fertility, and have a positive impact on olive production. The indeterminate growth habits of legumes also may improve the performance of agroforestry systems by valuing the shade under trees better than cereals.

The tree competition for light is considered in several articles about agroforestry, for wheat. In our study cereals negatively affected olive yield, and olive trees on crop yields. Cereal yield in the agroforestry system is related to shade tolerance and the influence of trees at different developmental stages (grain filling). Stress before crop flowering can affect carpel growth by decreasing the size of the ovaries, then reducing potential grain weight regardless of conditions during grain filling. Tree shape and pruning, tree row orientation and spacing and tree phenology can reduce the effect of the tree on the crop. However, looking for crop varieties with adequate physiological and morphological responses to shade will be promising to buffer the effects of trees on crop growth in Mediterranean agroforestry.

Regardless of the negative impact of agroforestry on final yield, LERs were higher than 1 and revealed that an agroforestry system integrating legumes and cereals between rows can improve the profitability of the orchard and soil fertility. Therefore, we strongly recommend legumes to increase and diversify the global productivity of olive groves and invite to consider a greater diversity of legume species, because its precocity and rapid ripening have advantages in water use by avoiding the common terminal water stresses, particularly in dry Mediterranean conditions.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

Asmae Amassaghrou: Conceptualization, Methodology, Writing – review & editing. original draft preparation, Formal analysis. Karim Barkaoui: Methodology, Writing - review & editing. Ahmed Bouaziz: Methodology, review & editing. Si Bennasseur Alaoui: Review & editing. Rachid Razouk: Conceptualization, Methodology. Khalid Daoui: Conceptualization, Methodology, Writing review & editing.

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