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Assessing the performance of an agroforestry system based on quinoa and olive trees under saline irrigation.

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Abstract. In the context of climate change, agricultural productivity, especially in semi-arid areas, is facing serious challenges ranging from water scarcity to soil degradation and perpetual salinization. Therefore, looking for sustainable and resilient cropping systems has been a priority of the National strategy « Green Generation 2020-2030 ». Agroforestry could be a sustainable way to diversify and improve land productivity through the complementary and facilitating potential of its components. This study aims to introduce quinoa as a halophyte crop to scale up the performance of current olive-based intercropping systems. The field experiment was conducted in an organic farm under saline irrigation (6 dS/m) and was laid out in a randomized complete block design with two cropping systems: monocropping (SC) and agroforestry systems (AFS), four quinoa cultivars (Puno, Titicaca, ICBA-Q5 and ICBA-Q4) and one olive plot as a control (OR) in each block. The average grain and straw yields for quinoa were significantly reduced in AFS, respectively by 33 % and 45% while average olive yield was not affected by the cropping system. In addition, the Land Equivalent Ratio (LER) was always higher than one, confirming the performance of the agroforestry system based on quinoa and olive tree under saline irrigation.

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1-Introduction

Nowadays, agricultural productivity, particularly in semi-arid rural areas, is experiencing serious challenges. Climate change is at the top of the list since it exacerbates water scarcity, soil degradation and their salinization. This situation increases food insecurity and the vulnerability of an increasing population [1], which is expected to reach 9.7 billion people worldwide by 2050 [2]. Thereby, new national and international strategies have highlighted the need to adopt more sustainable agricultural practices that reconcile food production and environmental health [3]. Agroforestry has the potential to be a viable strategy for both mitigating and adapting to climate change [4,5]. Agroforestry does, in fact, play a crucial role by increasing nutrient availability and water usage efficiency [6,7] and biological activity and by generating sufficient food and additional income for vulnerable populations [8]. In Morocco, agroforestry is traditionally practiced, and the most common agroforestry systems are based on intercropping cereals or legumes with olive trees [9, 10, 11]. Nevertheless, it still needs to assess appropriate combinations between trees and crops and to look for adequate management.
In this context, we introduced quinoa (*Chenopodium quinoa*, Willd) in olive-based agroforestry systems, for the first time in water and salt-stressed areas in Morocco. In fact, quinoa is a halophyte with a large adaptation to severe soil and climatic conditions [12, 13]. It is also considered one of the world's healthiest foods [14], as its grains are substantially rich in vitamins, dietary fiber, fats, and high-quality, gluten-free proteins, with a balanced profile of all essential amino acids. In the present study, we aim to: (i) evaluate the performance of this new olive-based agroforestry system according to land equivalent ratio assessment as an indicator of land use efficiency and (ii) identify the suitable combinations between olive and quinoa by testing four quinoa varieties-olive associations.

2-Materials and Methods

2-1 Experimental Site

The field experiment was conducted in an olive grove of an organic farm located in the rural commune of Boughriba (Berkane province) (X=773058.03 m, Y=493943.30 m, Z=52.69 m), 13.4 km from the Mediterranean Sea, towards the northeast of Morocco. The soil analysis showed a silt loam to loamy texture with 3.13% organic matter, a pH of 7.36 and a CE of 0.8 dSm-1. The electrical conductivity of water irrigation was 6 dS.m-1 at 25 °C. The climate is semi-arid, with an irregular rainfall averaging 290 mm per year (average calculated from weather station data of Boughriba over a series of 30 years). In 2021, the total rainfall was 273 mm, and the annual mean air temperature was 17.2 °C, while during the quinoa growing season, the rainfall was 202 mm and the average temperature, the maximum and the minimum temperatures ranged from 11.9 to 20.5 °C, from 18.5 to 31.4°C and from 5.2 to 19 °C, respectively (Fig. A1).

The olive grove (*Olea europea*, subsp *europea*, cv. Picholine marocaine) was 65 years old in 2021, with a regular density of 6 m x 6 m and with uncultivated inter-rows. Before the experiment, the olive trees rarely received gravity-fed irrigation to complement the rainfall supply.

2-2 Experimental layout

To evaluate the performance of the olive agroforestry systems (AFS), in which four quinoa cultivars were intercropped with olive trees, we compared the agroforestry systems to corresponding sole crops (SCS) and olive orchard (OR) used as controls.

To prevent any interactions between trees and sole quinoa systems, the agroforestry system and the control orchard were planted in the same olive grove. The sole quinoa cultivars were planted 150 meters away on an adjacent plot. The experiments were laid out on randomized complete blocks design for both agroforestry and solo cropping systems with three replicates. In the unit plot, quinoa cultivars were grown on either side of the middle row of olive trees for the agroforestry system (Figure 1). The olive grove's overall size was 2940 m2, which was split up into 15 plots measuring 196 m2 each (14 m × 14 m). Of these, 12 were used for the agroforestry systems (AFS), while 3 were used for the control orchard (OR). The rows of olive trees and quinoa were lined up parallel. Similarly,12 plots of 36 m^2 (6 m x 6 m) were attributed to soles crops covering a total area of 432 m^2.

In AFS, we manually sown seven lines of each quinoa variety respecting 2 m far from the olive tree rows. The distance between two quinoa lines and two plants in the same line was 50 cm and 25 cm, respectively. Similarly, we sown quinoa cultivars in the SCS. The sowing and harvesting dates were February 20th and 10th July in 2021. As our experiment was conducted on an organic farm, local organic manure (10 t/ha) and manual weeding were exclusively applied. We used the drip irrigation method to supplement the rainwater supply. The water irrigation salinity level was 6 dS.m-1 (Figure.1)

The selected quinoa cultivars (Puno, Titicaca, ICBA-Q5 and ICBA-Q4) are characterized by short growing cycle (90 to 120 days), good performance and large-scale adaptation under semi-arid conditions in Morocco [16, 17]

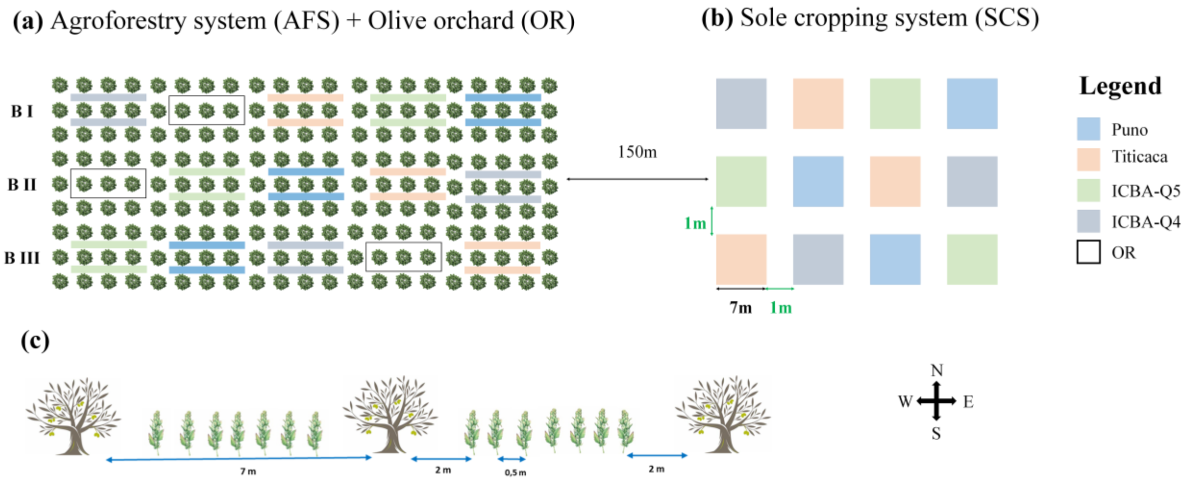


Fig. 1. Experimental layout showing (a) agroforestry system (AFS) and olive orchard (OR); (b) sole cropping system (SCS); (c) distances between the test plants. The layout was generated using MS PowerPoint (version 2013).

2-3 Field measurements and sampling

At maturity, plants of three adjacent lines on either side of the olive trees were randomly selected avoiding borders in each sub-plot and 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 and the total grain biomass.

The thousand-grain weight (MGW) was weighed, and harvest index (HI) was calculated as the ratio between grain biomass and total aboveground biomass.
To evaluate the olive yield per tree, trees were randomly selected at the middle of each sub-plot to avoid the border effects. Then olives were manually harvested and the yield of fruit per tree was weighed.

2-4 Statistical analysis
To characterize land use efficiency and consequently the agroforestry system's performance, we calculated the Land Equivalent Ratio (LER) as the relative land area required for sole crops and trees to achieve the same total yield as agroforestry (Mead and Willey, 1980). LER is calculated as the sum of relative yields in agroforestry compared to the sole crop and the orchard tree yields:

$$LERAFS = LERAFS\text{-}Olive + LERAFS\text{-}crop \quad (1)$$
$$LERAFS\text{-}Olive = (Olive\ yieldAFS / Olive\ yieldOR) \quad (2)$$
$$LERAFS\text{-}crop = (Crop\ yieldAFS / Crop\ yieldSCS) \quad (3)$$

The LER reflects a higher (or lower) productivity of the agroforestry system (AFS) than the corresponding orchard (OR) and sole crop (SCS) when its value is above (or below) one. When this value is equal to one, the agroforestry system has no significant impact on land productivity.
To test the differences between grain yields of quinoa varieties, olive yields and harvest index, we used ANOVAs with two factors: (1) the cropping system (AFS, SCS, OR) and (2) the quinoa varieties (Puno, Titicaca, ICBA-Q5 and ICBA-Q4). This statistical analysis was performed using SAS 9.0 software. For a better interpretation, a two-way analysis of variance (ANOVA) was used to assess the effects of cropping system type, quinoa variety and their interaction on monitored parameters. Student's test (LSD) was used for means comparison ($p \leq 0.05$).

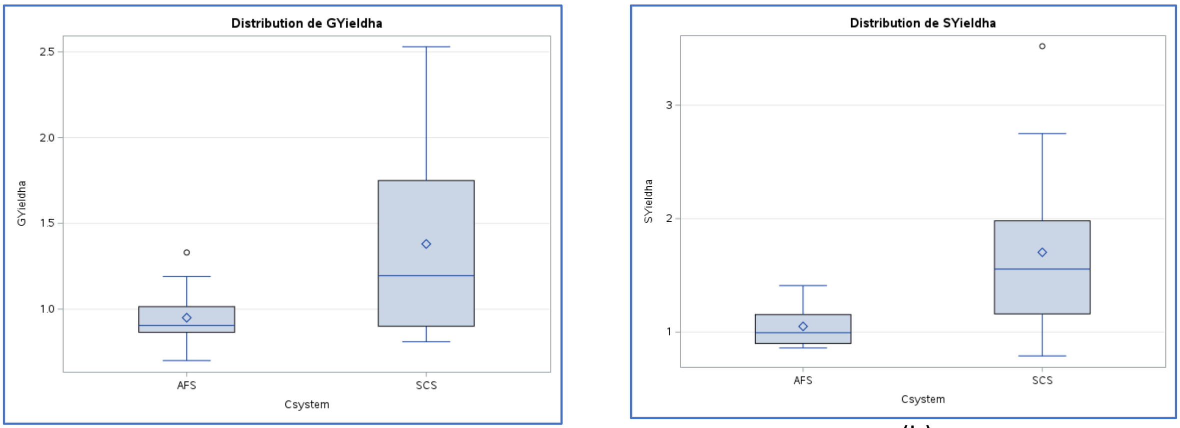
3- Results

3-1 Quinoa yields and harvest index comparison between AFS and SCS.

The results of the analysis of variance for grain and straw yields and for harvest index for the four quinoa varieties grown in the sole cropping and in agroforestry systems are reported in Table 1.
The comparison of obtained results revealed highly significant effects of the cropping system, the quinoa variety and their interaction on the grain and straw yields (** $p < 0.01$ and *** $p < 0.01$). However, harvest indexes (HI) were statistically equal between the two systems and for all quinoa varieties. Moreover, overall quinoa varieties recorded lower grain and straw yields in AFS than in SCS, except Puno variety which achieved an increase of 20 % for grain yield in AFS relative to SCS. Furthermore, higher grain and straw yields were obtained by ICBA-Q5 (2.12 t/ha vs 2.84 t/ha) in SCS. We also noted a significant reduction in averages of grain and straw yields, respectively of 33% and 45% in AFS relative to SCS (Fig. 2).

Table 1: Grain and straw quinoa yields (t/ha) and Harvest Indexes of four quinoa varieties in agroforestry (AFS) and sole crop (SCS). Lowercase letters *** $p < 0.001$, ** $p < 0.01$ and n.s indicate significant differences levels between cropping systems (AFS, SCS) for each of the quinoa varieties.

Quinoa varieties	Grain yield (t/ha)		Straw yield (t/ha)		HI	
	AFS	SCS	AFS	SCS	AFS	SCS
V1 : Puno	1.14 ± 0.13 bc	0.95 ± 0.12 c	1.22 ± 0.09 bc	1.23 ± 0.19 bc	0.48 ± 0.01a	0.44 ± 0.02a
V2 : Titicaca	0.9 ± 0.08 c	1.01 ± 0.11 bc	0.95 ± 0.05 c	1.15 ± 0.22 bc	0.49 ± 0.03 a	0.47 ± 0.04a
V3 :ICBA-Q5	0.92 ± 0.03 c	2.12 ± 0.23 a	1.08 ± 0.17	2.84 ± 0.37a	0.46 ± 0.03 a	0.43 ± 0.01a
V4: ICBA-Q4	0.84 ± 0.25 b	0.95 ± 0.05 c	1.44 ± 0.25 b	1.59 ± 0.07 b	0.47 ± 0.01a	0.47 ± 0.04 a
System	** p < 0.01		*** p < 0.001		n.s	
Variety	** p < 0.01		** p < 0.01		n.s	
Sys * Var	** p < 0.01		** p < 0.01		n.s	



(a) (b)

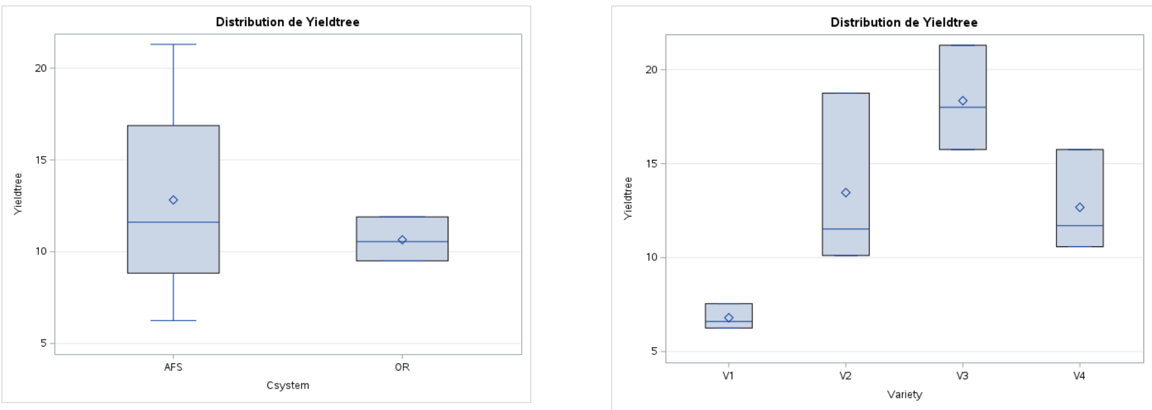
Fig. 2: Quinoa grain (a) and straw (b) yields in AFS and SCS

3-2 Olive yields in agroforestry system and in pure orchard

Statistical analysis results presented in table 2 revealed no significant differences between the average yields of the olive tree in AFS and in OR (12.82 vs 10.64 kg/tree, p=0.24, n.s) (Fig.3a). However, quinoa variety associated with the olive tree affected significantly olive yields (p*= 0.019 < 0.05) with a maximum (18.35 kg/ha) and a minimum (6.8 kg/ha) recorded for the Olive-ICBAQ5 and Olive-Puno associations, respectively (Fig. 2b). Furthermore, we noted a highly significant effect of cropping systems (AFS, OR) and quinoa varieties interaction on olive yield (**p=0.0048). Actually, all associations were better than Olive Orchard except AFSO-Puno.

Table 2: Olive yields (kg/tree) in agroforestry systems (AFSOlive-Quinoa) and Pure orchard (OR). Lowercase letters ** p < 0.001, * p < 0.01 and n.s indicate significant differences levels between cropping systems (AFS, OR).

Cropping systems	Olive yield (kg/tree)
AFSO-Puno	6.80 ± 0.39 c
AFSO-Titicaca	13.46 ± 2.68 ab
AFSO-ICBAQ5	18.35 ± 1.61 a
AFSO-ICBAQ4	12.67 ± 1.57 b
Pure orchard	10.64 ± 0.69 bc
Crop. System	p=0.24, n.s
Quinoa variety	*p=0.019
Crop.sytem*Quinoa variety	**p=0.0048



(p=0.24, n.s) (Fig.2a) (*p=0.019) (Fig.2b)

Fig.3: Olive yields according to AFS and OR (Fig. 3a) and to Olive-quinoa variety associations (Fig.3b).

3.3 Land equivalent ratio

The land equivalent ratio of the whole agroforestry system (LERAFS) was always higher than 1 and ranged from 1.83 to 2.16 without significant differences between the different associations (p=0.64, n.s) (Table 3). However, we noted significant variations in partial LER (LERAFS-Quinoa, *p=0.033) and (LERAFS-Olive, **p=0.0043).

Table 3: Land equivalent ratio of agroforestry system (LERAFS) and partial equivalent ratio of quinoa ($LER_{AFS-Quinoa}$) and olive trees ($LER_{AFS-Olive}$).

Quinoa varieties	$LER_{AFS-Quinoa}$	$LER_{AFS-Olive}$	LER_{AFS}
Puno	1.25 ± 0.25 a	0.64 ± 0.074 c	1.90 ± 0.30 a
Titicaca	0.90 ± 0.05 ab	1.27 ± 0.25 ab	2.18 ± 0.31 a
ICBA-Q5	0.44 ± 0.06 b	1.72 ± 0.04 a	2.16 ± 0.09 a
ICBA-Q4	0.64 ± 0.17 b	1.18 ± 0.07 b	1.83 ± 0.17 a
Statistical significance	*P =0.0332	**P =0.0043	P=0.647 n.s

4- Discussions

The average quinoa grain and straw yields were significantly reduced in AFS, respectively by 33 % and 45% relative to SCS. These results were similar to the findings obtained by Fidae and *al*. [15] in Morocco on wheat and faba bean intercropped with olive trees. If we assume that this reduction could be assigned to the level of tolerance of each variety to the drought that occurred during the quinoa growth (202 mm) and to the salinity of the irrigation water (6 dSm^{-1}), Puno would not have achieved an increase in grain yield of 20% in AFS, since according to previous work, all of these varieties tolerate a salinity level up to 10 dSm^{-1} [16]. In addition, other works conducted in the eastern region of Morocco have confirmed the tolerance of ICBA-Q_5 to up 10.5 dSm^{-1} [17]. Hence, based on the finding that trees and crops primarily compete more for light than for water [18]. We suggest that the shade provided by olive trees significantly reduced the grain yield of all varieties except Puno which seems more shade-tolerating. Moreover, in our experiment, the high density of olive trees (6 m x 6 m), caused shading even if the samples were taken in the middle avoiding the edges. In addition, the distance from the tree was lower than recommended (1.5 m) [19].

Regarding the whole agroforestry system, we can conclude that it is a high-performance one since LER is greater than 1 and overall, a relationship of profitability and complementarity has been established between quinoa and olive trees. Similar findings were obtained by Duchene and *al*. [20]. Considering these results, we put forward the hypothesis that the integration of halophyte crops such as quinoa in agroforestry systems conducted under saline irrigation could improve the performance of these systems [21, 22, 23, 24].

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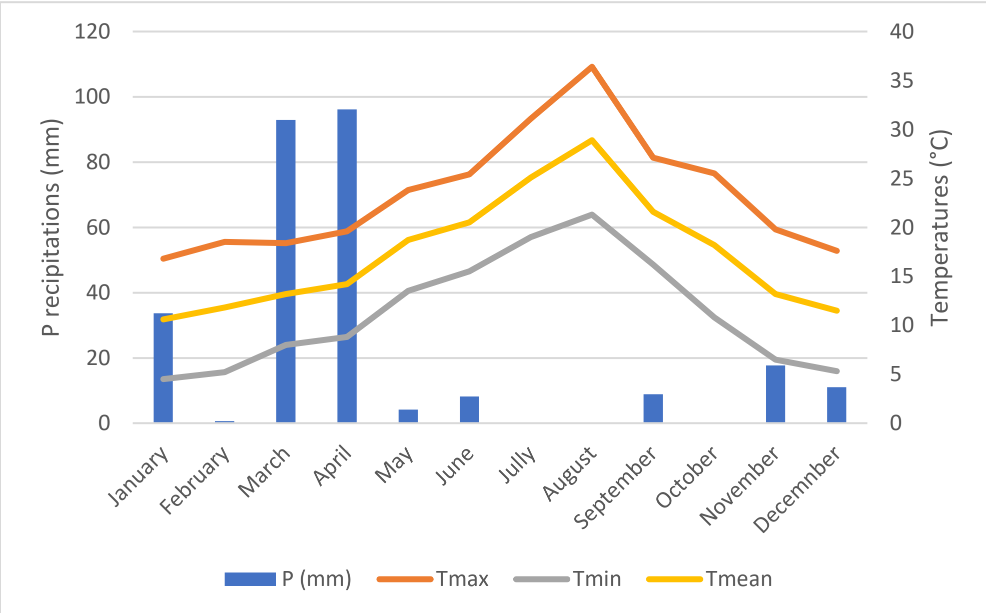

Fig. A1: Climatic parameters (Rainfall, Temperatures (mean, max and min) during 2021.