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Forage Potential of Cereal–Legume Mixtures as an Adaptive Climate Change Strategy under Low Input Systems

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Abstract: Mixed cropping systems can constitute important agroecological adaptation strategies for enhancing crop growth and productivity in view of climate change, while reducing the need for synthetic fertilizers and providing important ecosystem services. The aim of this study was to investigate growth, competitiveness, and productivity of two forage mixtures combining triticale (*X triticosecale Wittmack*) to common vetch (*Vicia sativa* L.), and to fenugreek (*Trigonella fœnum-græcum* L.) in different mixture combinations (40% T–60% V vs. 60% T–40% V and 40% T–60% F vs. 60% T–40% F). Field results showed that both forage legumes were higher inside the different crop mixtures (+225% for vetch, +94% for fenugreek) than in monocropping. In regard to the competition ration (CR), triticale was the more dominant and competitive species in three out of four studied mixtures. Forage yield was higher in crop mixtures than for corresponding sole crops. Yield gain was greater for common vetch-based mixtures than fenugreek ones (+60% vs. +30%). The results show that using cereal–legume mixtures can provide important productivity increase for fodder yield compared to conventional pure crops. The method is an important adaptive agricultural strategy in view of climate change.

Keywords: mixed cropping systems; triticale; fenugreek; common vetch; adaptation; climate change; agriculture

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1. Introduction

During the 20th century, a sizable percentage of farmers around the world depended on chemical inputs, especially synthetic N fertilizers, for enhancing agricultural productivity. However, it is now recognized that the excessive fertilizer use is likely to lead to numerous environmental hazards including soil pollution and groundwater contamination. This raises the need for adopting innovative farming practices that increase environmental services, while increasing productivity. At the same time efficient adaptation strategies are needed to combat negative effects of climate change. Mixed cropping systems may be such an adaptation. Mixed cropping systems, especially those combining legumes with cereals, can be proposed as one of the main important agroecological strategies for improving yields, with reducing synthetic fertilizers, as well as to provide several environmental benefits. Mixed cropping is defined as growing two or more crop species simultaneously in the same field during a cropping season. It is an ancient practice that is receiving increased attention due to its advantages over pure stands, in terms of crop yield, quality, and climate change effects [1].

Recently, researchers have reported effects of agricultural intercropping systems and investigated possible benefits. Major advantages of these mixtures in agriculture seem to include bio-fixation of nitrogen from the atmosphere and reduction of harmful leaching of nutrients, thereby reducing necessary energy and chemical nutrient inputs [2,3]. Other important advantages of intercropping systems may be the ability to reduce pest and disease impacts and improve crop growth and productivity, efficient use of the water resources, and nitrogen assimilation and radiation, besides nutritional quality [4–7]. It has been shown that incorporating legumes in intercropping with grasses can improve quality of the whole forage biomass, mainly the protein content, and increase the biodiversity if compared to cereal monoculture [8,9]. The advantage of intercropping compared to pure stands in term of crop production is due to the synergy between components of the intercrops and non-competition for the same resource niches [10]. To quantify intercrop efficiency and species interactions, researchers have used indices such as the Land Equivalent Ratio (LER) [11]. This index represents the relative land area for growing sole crops required to produce the same yield obtained in the intercrops. Other used indices are competition ratio (CR), aggressivity (A), relative crowding coefficient (K), and monetary advantage index (MAI). These have all been developed to describe competition and economic advantages of intercropping systems [12].

Intercropping is a traditionally common practice for forage production used in many countries to support sustainable forage supply in low input agricultural systems. Due to the increasing industrialization of agriculture, however, these traditional systems have largely been abandoned in favor of high-intensive mono-culture systems. In Tunisia, traditional intercropping practices such as production of hay for ruminants have been abandoned in favor of oat monocrop, due to limited diversity of forage species and cultivars. Fodder oat now represents about 70% of the total forage area while producing low quality hay [13]. Thus, the challenge is to reintegrate intercropping in the production systems to improve forage yield and quality. This is also an important climate change adaptation strategy since water resources are becoming increasingly scarce and irrigated mono-agriculture may need to be abandoned over large areas. Instead, intercropping may be seen as a way to improve eco-system services from low input forage systems. There exist numerous forage species and registered cultivars from legumes and grass that can be used to improve biodiversity of these systems. Therefore, the objectives of the current study were to (i) evaluate the productive potential of two forage mixtures associating triticale (*X triticosecale Wittmack*) to common vetch (*Vicia sativa* L.), and triticale to fenugreek (*Trigonella fœnum-græcum*, L.) in two different mixture combinations (40T–60V; 60T–40V; 40T–60F; 60T–40F) and (ii) quantify the competition between species within each mixture.

2. Materials and Methods

The field trial was conducted at the experimental station of the Regional Field Crop Research Center Beja, north-west of Tunisia on a vertisol (clay loam: 66% clay; 23% loam; 10% sand). The experimental site is characterized by a typical Mediterranean sub-humid climate. Climatic data registered during the growing season (2018–2019) are given in Table 1. Total rainfall was 449 mm (November–April) and average temperature was 11.2 °C.

Table 1. Monthly data of rainfall and temperature during the experimental period (November 2018–April 2019).

Month	Rainfall (mm)	Min Temperature (°C)	Max Temperature (°C)
November	75.4	9.5	17.1
December	39.8	5.9	15.6
January	138.4	4.1	13.7
February	49.8	6.7	12.9
March	108.8	10.8	16.6
April	37.0	8.4	13.2

Source: Meteorological station of the Field Crop Research Center, Beja.

Three annual forage species Triticale (*X triticosecale*, Witt), common vetch (*Vicia sativa* L.), and fenugreek (*Trigonella fœnum-græcum* L.), commonly used in the region as pure stands, were utilized to constitute four binary mixtures in two seeding ratios, namely, triticale (60%)–vetch (40%), triticale (40%)–vetch (60%), triticale (60%)–fenugreek

(40%), and triticale (40%)–fenugreek (60%). Each mixture was grown on 0.25 ha plots, in which two subplots of corresponding monocrops were maintained to serve for competition indices calculation. Seeding was undertaken on November 23rd, 2018. Before sowing, the paddocks were harrowed and divided into four blocks (each 24 m × 100 m). The previous crop was winter wheat, which was harvested in mid-June 2018.

Fertilization consisted of 100 kg ha^{-1} of diammonium phosphate (DAP) and 20 kg ha^{-1} of N (as ammonium nitrate, 33%) applied to the mixtures at tillering stage of triticale. Pure triticale stands received 70 kg ha^{-1} of N and no nitrogen was given to legume stands. Crop mixtures were harvested at mid-May, when legume partners reached pod-filling stage and triticale at soft dough stage. Four linear meters (equivalent to one square meter) were selected randomly from each treatment and hand harvested for biomass determination. Also, ten representative plants of each species (in sole and intercrop) were followed to assess rates of height change over the growing period.

The advantage of intercropping and the effect of competition between intercrop species were quantified by three competition indices: land equivalent ratio (LER) was used to verify the effectiveness of intercropping for using the land resources for different crops in mixture as compared to sole cropping [14]. When LER is greater than 1, the intercropping favors growth and yield of different species. In contrast, when LER is lower than 1, the intercropping negatively affects the growth and yield of plants grown in mixtures [14]. The LER was calculated as:

$$\mathrm{LER} = \mathrm{LER_l} + \mathrm{LER_c} \quad (1)$$

$$\mathrm{LER} = (\mathrm{Y_{li}}/\mathrm{Y_{ls}}) + (\mathrm{Y_{ci}}/\mathrm{Y_{cs}}) \quad (2)$$

where LER is the land equivalent ratio; Y_{ls} and Y_{cs} are the yields of legume and cereal, respectively, as sole crops and Y_{li} and Y_{ci} are the yields of legume and cereal, respectively, as intercrops. The LER is the sum of the partial LER (LER_l and LER_c) for the individual crops in the intercropping system. The second index used to determine the competitive relationship between two crops in mixtures is aggressivity (A), formulated as:

$$\mathrm{A_l} = (\mathrm{Y_{li}}/\mathrm{Y_{ls}} \times \mathrm{Z_{li}}) - (\mathrm{Y_{ci}}/\mathrm{Y_{cs}} \times \mathrm{Z_{ci}}) \quad (3)$$

$$\mathrm{A_c} = (\mathrm{Y_{ci}}/\mathrm{Y_{cs}} \times \mathrm{Z_{ci}}) - (\mathrm{Y_{li}}/\mathrm{Y_{ls}} \times \mathrm{Z_{li}}) \quad (4)$$

where A is the aggressivity of each species in the mixture; Z_{li} is the sown proportion of legume in mixture with cereal, and Z_{ci} the sown proportion of cereal in mixture. The final index is the competitive ratio (CR) that assesses the competition between different species growing in mixture. CR indicates competitive ability of the crop and it is often more useful than the above-cited indices. CR represents the ratio of individual LER of the two component crops and considers the proportion of the crops where they were initially sown. The CR index was calculated according to [14]:

$$\mathrm{CR_l} = (\mathrm{LER_l}/\mathrm{LER_c}) \times (\mathrm{Z_{ci}}/\mathrm{Z_{li}}) \quad (5)$$

$$\mathrm{CR_l} = (\mathrm{LER_l}/\mathrm{LER_c}) \times (\mathrm{Z_{ci}}/\mathrm{Z_{li}}) \quad (6)$$

Collected data were analyzed and statistically examined using analysis of variance (ANOVA) of the Statistical Analysis System (SPSS 20.0 for Windows). Means of four samples were compared by the Duncan Test at the 5% level of significance.

3. Results and Discussion

3.1. Plant Height

The data relevant to the response of triticale, fenugreek, and vetch plant height growing in mixtures are presented in Figure 1.

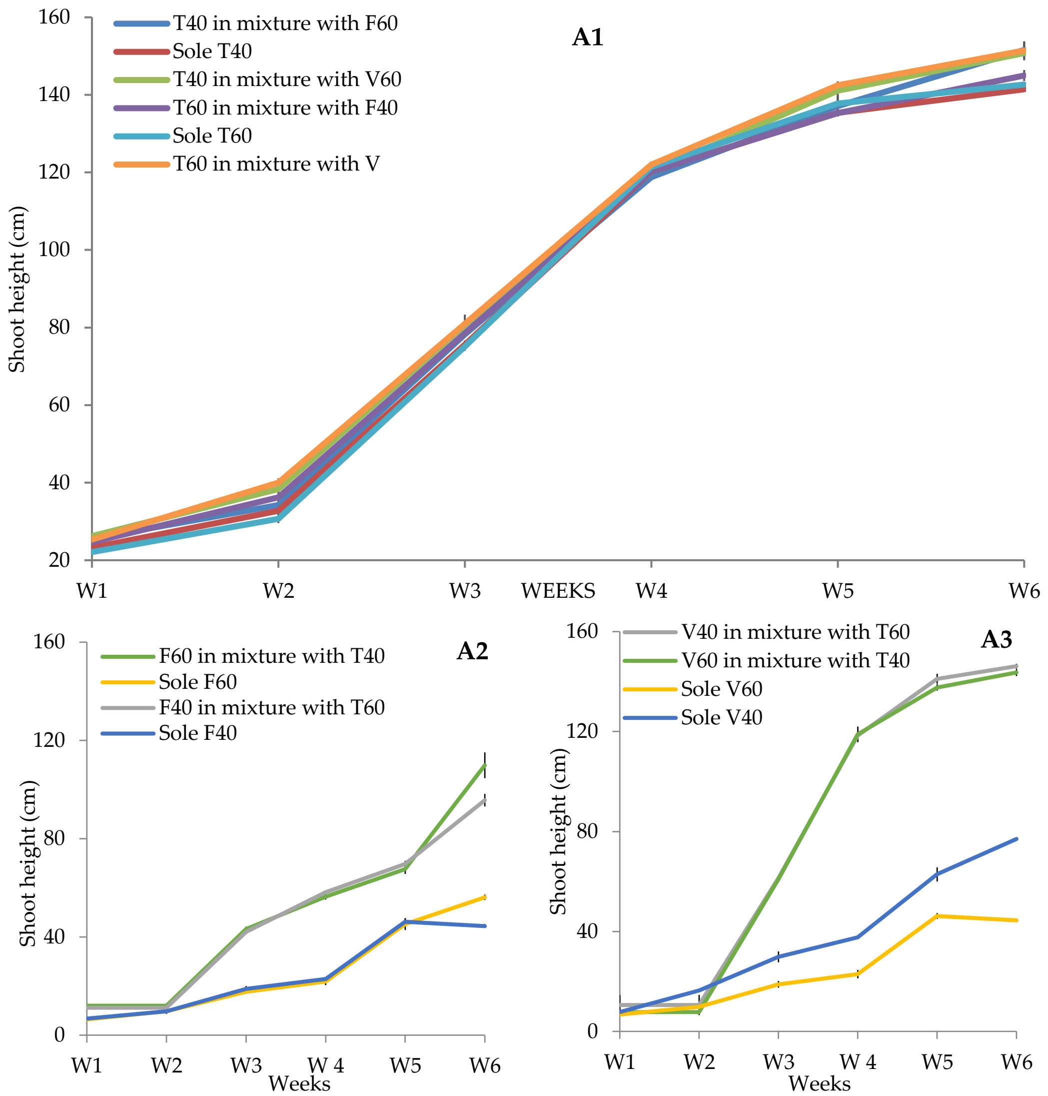

Figure 1. Average height (cm) throughout the development cycle of triticale (**A1**), fenugreek (**A2**), and vetch (**A3**) in pure and in mixture stands at two sowing rates (40 and 60%).

Plant heights recorded at different crop stages showed differences among species. For triticale, plant heights appeared to be comparable or slightly affected by intercropping, with only 4 to 7% of growth increase recorded at the end of development cycle, as compared to triticale pure stands. The highest triticale height (average of 151.0 cm) was obtained from mixtures T60–V40 and T40–V60, while the lowest plant height (139.7 cm) came from 40% pure stands of triticale (Figure 1(A1)). Comparable height growth increases were recorded for intercrops of oat, barley, and wheat with vetch [15]. Ansar et al. [15] suggested that this effect is due to the efficiency of utilization of natural resources and minimum competition among species used in the mixtures. This advantage is probably attributed to the ability of vetch legume to share fixed nitrogen from atmosphere with its cereal counterpart. This effect was also shown by Pirhofer-Walzl et al. [16], who demonstrated that the direct benefits of nitrogen fixation in root nodules of leguminous plant contributed to soil fertility, which was utilized by neighbor grasses as well as subsequent crops. These findings differ however from those of Gill and Akim [17], who reported that plant height of cereals tended to be reduced in intercrops compared to respective monocrops, without any influence of the cereal type or pea variety.

For legume crops, plant height clearly differed among sole crops and intercrops (Figure 1(A2,A3)). The general results showed an increment in legume height (vetch and fenugreek) at different mixtures compared with monocropping, indicating an advantage from intercropping over pure stands. The increase in legume height for different mixtures may be attributed to the role of triticale, facilitating the climbing of legumes, hence leading to improved use of natural resources (especially nitrogen and light), compared with monocropping. Similar conclusions were drawn by Yong and Shahrajabian [18] who reported that intercropping had positive effects on common vetch plant height.

The largest fenugreek height (109.8 cm) was obtained from the mixture combining 60% fenugreek with 40% triticale, while the smallest plant height (average of 44 cm) came from pure stands of fenugreek at a seeding percentage of 40%. Likewise, mixture stands of vetch were taller than pure stands. Our findings agree with previous studies showing that in vetch–cereal intercropping, cereals serve as a structural support for vetch growth, enhancing the light absorption and facilitating mechanical harvest [19].

In general, the increment in vetch plant height was more pronounced than in fenugreek over the growing period (Figure 1). It reached an average of 225% in T40–V60 mixture versus 94% obtained from the same seeding rate of fenugreek with triticale (T40–F60). This effect may be due to that competition between species is more pronounced in triticale-vetch than that of triticale-fenugreek. Our findings also suggest that when scaling the triticale, the vetches (with their terminal tendrils) were physically more supported by triticale plants, and this resulted in better establishment and development (see also, e.g., [19]).

3.2. Forage Dry Matter Production and Land Equivalent Ration

Data pertaining to dry matter production in the various mixtures are presented in Table 2.

Table 2. Means of total, triticale and legume (vetch or fenugreek) dry matter yields, and total and partial Land Equivalent ratios (LER) for triticale and legumes in the different mixtures.

Intercropping	**Dry Matter Yield kg ha^{-1}**			**Land Equivalent Ratio LER**		
	Total	Triticale	Legume	Total	Triticale	Legume
T40–F60	9166.8 a	8176.8 a	990.0 b	1.33 b	0.88 b	0.44 c
T40–V60	8660.8 a	6253.1 b	2266.2 a	1.65 a	0.95 a	0.70 b
T60–F40	10,586.1 a	9682.5 a	903.6 b	1.37 b	0.96 a	0.41 c
T60–V40	9024.1 a	6713.3 b	2310.8 a	1.6 a	0.71 c	0.89 a

Note: In each column, mean (n = 4) values followed by the same letter in each column are not significantly different at the $p < 0.05$ level.

The table shows that dry matter yield of the crop mixtures was comparable regardless of the species and proportion studied. It generally oscillated between 8.6 and 10.5 t/ha. In each mixture (T–V or T–F), partial dry matter yield of each species was not affected significantly with seeding ratio (Table 2).

With its higher partial dry matter in all mixtures (between 73 and 90% of the total production), triticale showed the highest competitive ability as compared to mixed legumes (vetch and fenugreek). The largest was obtained in T–F intercrops (an average of about 9.9 t·ha^{-1}, the equivalent of 90% of the total production). Our findings are similar to Lithourgidis et al. [9] who found that, in many cases, cereals are superior in terms of producing forage dry matter to legumes. Indeed, our results showed that for the same legume proportion, fenugreek contribution to dry matter of the mixture was less important than that of vetch (Table 2). This effect could be attributed to the lower competitive ability of fenugreek against its cereal counterpart in mixtures [9].

The analysis of competition indices, especially LER, showed that the competitiveness of the intercropped plants is different (Table 2). Partial LER vetch values were higher (larger than 0.7) than those of fenugreek. On the other hand, in almost all cases, partial LER of triticale was higher than that of legumes (vetch and fenugreek), about 0.96 for the T60-F40 mixture, which indicates that there was an advantage for cereal in these intercropping systems and a disadvantage for legumes. This confirms that triticale is the most dominant and competitive species in the various mixtures. Our findings agree with those of Bedoussac and Justes [20] who reported that cereals usually grow faster at early stages and are dominant in the intercrop.

The total LER exceeded unity (1.0) in all the mixtures (Table 2). This implies that intercrop–ping yielded more growth for the same number of stands of each species compared to sole crops, which was interpreted as an advantage of intercropping over sole cropping. These findings corroborate those of Bybee-Finley and Ryan [21], that crop productivity can be increased by the use of intercropping. Hauggaard-Nielsen et al. [22] reported that the mixture interactions based on functional complementarity could be a more suitable way to obtain high yield stability along with simultaneous atmospheric nitrogen inputs as compared to the more classical introduction of legumes as sole crops.

Yield advantage, in terms of total LER, was greatest in the case of T40-V60 mixture, reaching an average of 1.65. This indicates that a 65% area under sole cropping of triticale and vetch separately is needed to obtain equal amounts of yield from one hectare of intercropped area. In general, the productivity gain was greater for the triticale–vetch mixtures (average of 60%) than for triticale–fenugreek mixtures (average of 30%) (Table 2). This shows the benefit of a further crop in the exploitation of environmental resources, especially the high land use efficiency of intercropped vetch as compared to that of fenugreek. Similar results were obtained by Yucel and Avci [23] who demonstrated that dry matter of a 50% vetch and 50% triticale mixture was about 63% more than dry matter of pure triticale. Similarly, Lithourgidis et al. [9] showed that common vetch–barley and vetch–winter wheat intercrops produced more dry matter than common vetch in the monoculture. In addition, the same study proved that the mixture of 65% of common vetch with 35% of barley was producing a higher quality forage as compared to other intercrops. Several studies have shown that vetch–barley intercropping is highly advantageous regarding yield, land use efficiency, and economic value compared to other mixtures or their respective monocultures [24].

3.3. Aggressivity and Competitive Ratio

As measured by the positive aggressivity (A) values, triticale was the dominant species in three out of four studied mixtures (Figure 2). Results of aggressivity (A) corresponded to those of LER. The aggressivity was more pronounced in triticale–fenugreek mixtures (Figure 2).

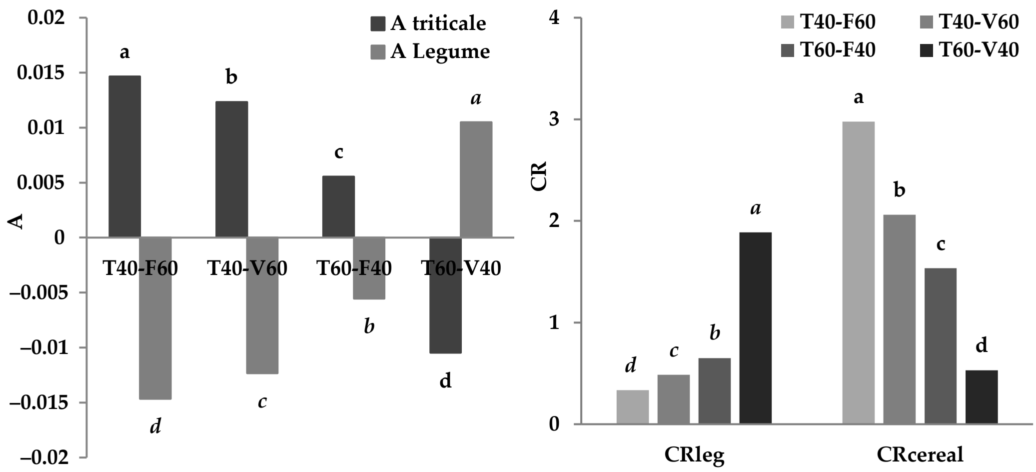

Figure 2. Aggressivity (A) and competitive ratio (CR) for mixtures of triticale (T), fenugreek (F), and vetch (V) in two seeding ratios (40 and 60%). (**a**,**b**,**c**,**d**) indicate significant difference in agressivity and competitive ratio of triticale within mixtures, (***a***,***b***,***c***,***d***) indicate significant difference in agressivity and competitive ratio of legumes within mixtures. Average values followed by the same letter are not significantly different at $p < 0.05$.

This could be explained by the probable behavior of fenugreek in the mixture known as a sensitive species to climate conditions, which affect its competitiveness on land use efficiency with its companion crop (triticale). Similarly, Lithourgidis et al. [12] showed that cereal species have a competitive ability to exploit resources in association with legumes. The authors of [25] reported that cereals (maize, sorghum, and pearl millet) were the dominant species in groundnut–cereal intercropping systems. Banik et al. [26] confirmed that, for mustard–legume intercropping, aggressivity was more important for mustard than for legume in all tested mixtures.

A similar trend to that of LER and aggressivity was also observed for the crowding ratio (CR). Intercropped triticale showed the highest values of CR in all triticale–legume mixtures, except for T60-V40 mixture. Corresponding findings were reported by Lithourgidis et al. [12] who showed that cereals (wheat, rye, and triticale) are more competitive than pea in all studied mixtures. For the same legume proportion, vetch had higher CR values than fenugreek (Figure 2), confirming greater competitive ability of vetch to exploit resources in mixture with triticale, compared to fenugreek.

4. Conclusions

The results of this study showed that all mixtures, at all seeding ratios, had a yield advantage for exploiting the available environmental resources, compared with all respective monocrops. However, the productivity gain was greater for the triticale–vetch mixture regardless of the seeding percentage (40 or 60%). Approximately 60% or more areas could be saved for a similar yield for forage crops, with a mixture of 60% vetch and 40% triticale, over their sole cropping. The competitive index values showed that triticale is the dominant species. Regarding mixed legumes, vetch species could be preferred for triticale–legume intercropping. Hence, its mixture with triticale could be used as a sustainable agroecological practice to increase forage production, under low input conditions. However, further studies evaluating the nutritional value of these mixtures are needed to confirm their forage performance and possibilities to substitute the oat monoculture, the usual forage crop used by the Tunisian farmer.

The results show that mixed cropping systems can constitute an important agroecological adaptation strategy in view of climate change. This is especially important for regions with low input of water and nutrients where climate change will force larger areas to become forage systems. These areas may be able to maintain or even increase their productivity by using mixed-crop systems. Basically, this is way to enhance important ecosystem services. It is urgent to experiment on different varieties and system combinations, introduce local resilient species, as well as adapt new systems to increasing temperature and less water to replace low-productive monoculture systems. Thus, the results of this study are important for other Tunisian regions, as well as other MENA countries, with similar climatic, soil, and socio-economic conditions.

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