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Agroforestry conservation agriculture based cropping systems an alternative to improve performance, resilience and adaptation to climate change in mediterranean drylands

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ABSTRACT

In the arid areas of Morocco, where sheep based faming systems dominate, traditional agriculture is vulnerable to climate change effects and harmful to the natural resources (soil, water and biodiversity). Sheep herders in these areas are facing increased forage and grazing feed shortages as they rely on extensive barley monocropping systems and overgrazed weedy fallow. The aim of this work is to evaluate the agroforestry cropping system based on annual fodder crop/pasture associations with fodder shrubs (Atriplex nummularia Lindl.), and to compare the agronomic performance of agroforestry-based conservation agriculture with that of local farmers' practices. A set of experiment trials were installed on 4.5 ha at four farmers' sites and monitored over three cropping seasons (2019–2022) in the arid sheep-farming zones of Central Western Morocco. The treatments consisted of three intercrop association options (annual crops + fodder shrubs), improved barley monocropping and farmers' extensive barley monocropping. The experimental protocol adopted is a Randomized Complete Block design with 5 treatments and 4 replications. data collection covered: stand density, canopy height, biological yield, grain yield, and calculated Land Equivalent Ratio. Results showed that the average herbaceous stand density, the botanical composition of the total biomass and the height of the herbaceous and shrubby strata were remarkably influenced by the climatic conditions of the different cropping years. The canopy height of annual herbaceous crops and shrubs was significantly improved under the agroforestry cropping system because of the favorable conditions created by the shrubs, such as improved rainwater infiltration, wind protection and reduced evaporation. The agroforestry cropping systems produced significantly higher total forage biomass yields than the improved barley monoculture and the barley grown by local farmers. The local control monoculture remains the least productive, with only an average of 1016 kg DM/ha. The agricultural land equivalence ratio (LER) was significantly improved by the agroforestry system. It reached an average of 2.4 for barley biomass production, 2.7 for fodder mix Pea/Barley biomass production and 1.8 for pasture fallow improved by NPK fertilization. In conclusion, the adoption of agroforestry as a sustainable approach of conservation agriculture improves the cropping systems performance, farming resilience and farms' adaptation to climate change in marginal arid Mediterranean climate areas.

Keywords: climate change, agroforestry, conservation agriculture, fodder production, resilience mediterranean drylands.

INTRODUCTION

Traditional agriculture in North Africa's semi-arid and arid zones is often vulnerable to the effects of climate change on farms living in these areas. Crops and agricultural production systems were designed to respond to stable and predictable climatic conditions [El Mzouri, 2023]. However, with ongoing changes, these traditional farming systems are no longer sufficiently resilient to face current and future challenges [FAO, 2016]. Indeed, in the arid marginal areas of Morocco, where sheep based faming systems dominate, sheep herders are facing increased forage and grazing feed shortages as they rely on barley monocropping systems and overgraze weedy fallow. Agronomic alternatives identified by agricultural research offer innovative solutions for adapting to climate change and for building more resilient farming systems. These approaches include crop diversification within the framework of conservation agriculture, such as agroforestry. Crop diversification consists in cultivating different species and cultivars with more rainwater use efficiency adapted to new climatic conditions [Passioura, 2006], thereby reducing the risks associated with dependence on a single crop/variety in mono-cropping and improving overall productivity. Agroforestry-based cropping systems that combine tree/shrub cultivation in association with annual herbaceous crops or pastures are a case of conservation agriculture where trees/shrubs provide shade, improve soil fertility, promote biodiversity and help regulate the local climate by mitigating the effects of strong winds and extreme temperatures [Verchot et al., 2007] and make a remarkable contribution to extending the duration of use of marginal agricultural lands [Tchoundjeu et al., 2005]. Conservation agriculture aims to preserve and improve soil health by eliminating ploughing, using ground cover practices and promoting biodiversity [Woodfine, 2009]. This approach reduces soil erosion, improves its capacity to retain rainwater and promotes carbon sequestration, thereby helping to mitigate the effects of climate change and improve the resilience of cropping systems in arid rainfed areas [Hatfield et al., 2001].

Agroforestry systems are sustainable conservation agriculture cropping systems that generate diverse economic, environmental and social benefits [FAO, 2005; Verchot et al., 2007]. Agroforestry trees and shrubs perform faster and more consistently than forest stands, producing more biomass per hectare than crop stands in which trees and agricultural crops are separated (+20 to 40%) [Tchoundjeu et al., 2005]. It enables the improvement of farming methods involving trees, zero-tillage for soil and water conservation, mulching and other proven techniques for sustainable land management [FAO, 2005]. It can also improve both herbaceous and woody crops yields [Sood and Mitchell, 2009]. The main advantages and agronomic impacts of the alley cropping system reported in the literature include [Kaeser et al., 2010; Cogliastro et al., 2012]: improvement in productivity and biological yields per unit area (between 30 and 65%) and per unit of water consumed (between 14 and 37%), stabilization of yields in difficult periods and significant gains in favorable years, extension of the period of use of marginal farmland from less than 3, 5 months to more than 11 months per cropping year, increased choice of suitable forage alternatives in addition to diversification of species used in the same system (minimum 2 and maximum 6 not counting fallow) and more flexible crop management practices.

The LER is a very useful concept in cases where the available agricultural land is a major constraint, as is the case for small and medium-sized farms in the marginal areas of Morocco and North Africa. LER indicates the degree of improvement in the efficiency of agricultural land use [Dariush et al., 2006; Kaeser et al., 2010]. In Morocco, this ratio was improved under alley cropping for all barley crop components (straw, grain and total biomass) and for fallow [El Mzouri, 2009]. This ratio, calculated over a 14-year period, varied on average between 1.54 and 1.68 for the barley crop and between 1.43 and 1.90 for the pasture fallow. The relationship between LER and annual rainfall shows that under dry years, this ratio increases for both fallow and grain barley. Other environmental benefits of Shrubs-annuals intercropping are also reported such as:

- improving natural soil fertilization [Kaeser et al., 2010].
- improving rainwater infiltration, storage and use efficiency [Saber and Roose, 2012].
- landscape improvement and diversification [Cogliastro et al., 2012; Mahyou et al., 2004].
- restoring soil fertility [AFA, 2015],
- increased Carbon storage and sequestration [Saber and Roose, 2012]. Agroforestry can store up to twice as much carbon in soils and standing biomass each year [Jorge-Mustonen et *al.*, 2014].

The aims of this study are to:

1. introduce and evaluate the agroforestry cropping system based on annual fodder crop/pasture associations with fodder shrubs (*Atriplex nummularia* Lindl.) in the arid sheep-farming zones of Central Western Morocco, and
2. to compare the agronomic performance of agroforestry-based conservation agriculture with that of local farmers' practices.

The overall aim is to improve the resilience and adaptation of farms in arid Mediterranean climates to climate change.

MATERIALS AND METHODS

Location of experimental platforms

The agronomic trials on conservation agriculture based on intercropping fodder crops were set up in the arid sheep farming area of the Chaouia plain, Central Western Morocco. This area belongs to the arid bioclimatic zone, with average annual rainfall of around 220 mm/year, mild winters (minima between 3 and 5 °C) and relatively hot summers (maxima between 38 and 45 °C). The soils are Calcimagnesic with a dominance of Rendzine group (52.5%). Small grain cereals (mainly barley and wheat) are the main crops grown in the area. They are grown either in monocropping systems or in rotation with weedy fallow, with a minimum of agricultural inputs (fertilizers, improved varieties, weeding, etc.). Sardi sheep farming is the main activity of the local population. This type of farming is highly integrated into local cropping systems, which has made it highly vulnerable to climate change over the last four decades. The experimental platforms were set up on farmers' representative soils with alkaline pH values ranging from 8.0 to 8.7; and an organic matter content of 1.8 to 2.4%. These soils are rich in phosphorus with more than 23 ppm P_2O_5, but fairly poor in potash with 150 to 250 ppm K_2O.

The cultivars and species choice in the association

Given that in the arid zone targeted by our study, the length of the annual crop growth period does not exceed 100 days/year [El Mzouri, 2021a and b], the choice of the woody and herbaceous species was judiciously made to adapt crop growth cycles to environmental conditions of the area, to improve and stabilize productivity and to extend the duration of farmland use. For this reason, we chose to associate the forage shrub Atriplex nummularia Lindl, known for its summer growth and tolerance to extreme water stress, with short-cycle annual forage crops (for grain, mowing or grazing) and winter/spring growth. These associations will enable the production of fodder/pastoral biomass during different periods of the year (for extending the period of agricultural land use), improve and stabilize agricultural productivity (for improving rainwater use efficiency), and maintain vegetation cover over a long period of the year (for soil conservation and protection through improved soil organic matter levels). The varieties and management of annual crops used were those recommended by the dryland agronomic research for arid zones (e.g. drought-tolerant short-cycle varieties, direct seeding, early weed and pest control, etc.).

Treatments and experimental layout

Three intercrop association options (annual crops + fodder shrubs) were installed alongside improved barley monocropping (improved management-Scientific control) and farmers' local practice (extensive barley monocropping-Local control) (Table 1). These trials were installed on 4.5 ha (0.25 ha/treatment) at four farmers' sites and monitored over three cropping seasons (2019–2020; 2020–2021and 2021–2022). The experimental protocol adopted is a Randomized Complete Block design with 5 treatments and 4 replications.

In addition to these treatments, monocrop plots of improved barley, pea/barley mix, improved fallow and forage shrub (Atriplex nummularia Lindl) were installed and harvested each season to calculate the agricultural LER (see definition below).

Sampling and data collection

At the level of each experimental unit, 3 plots of 1 m² each were randomly sampled for the agronomic data collection: stand density, canopy height, biological yield, grain yield, etc.

Table 1. List of forage and pasture associations (treatments) evaluated during three cropping seasons under arid agroclimatic conditions in West-Central Morocco

Treatments	Specifications
Association 1: Atriplex + Barley	Recommended package for Barley intercropped with Atriplex shrubs
Association 2: Atriplex + Peas/Barley	Recommended package for Barley: Pea mixture intercropped with shrubs
Association 3: Atriplex + Fallow	Fallow fertilized with N-P_2O_5 -K_2O:20-40- 40 kg /ha
Improved barley monoculture	Recommended package for barley (variety, fertilization, weeding, etc.)
Local control (local barley)	Local management without fertilizer or crop maintenance

The collected data were analyzed using the appropriate analysis of variance method [ANOVA, SAS Institute. 2011] with multiple factors (treatments, blocks, years) and subsampling to detect whether there was a difference between treatments. If there was a significant difference between treatments, means were compared using the least significant difference (LSD (5%) – [SAS Institute. 2011].

Land equivalent ratio (LER)

The LER is used to compare the performance of the alley cropping crop association with that of the same species grown separately in monocultures. The LER is defined as the relative area required in pure crops to have the same production as the association. When the LER is greater than 1, this means that the association performs better than the pure crop [Balde, 2011]. Area of land required, by separating tree and crop, to obtain the same production as one hectare of associated crop [Shili-Touzi, 2009]. The LER is defined as the sum of the fractions:

$$LER = Y_1/Y_{11} + \ldots + Y_i/Y_{ii} + \ldots + Y_m/Y_{mm} \quad (1)$$

where: *Yi* – yield (kg/ha) i^{th} of species grown in the intercropping system, *Yii* – the yield (kg/ha) the same species grown in monocropping, m-number of crops grown in the intercropping.

RESULTS AND DISCUSSIONS

It is important to recall and the climatic conditions that prevailed during the three experimental cropping seasons: 2019–2020, 2020–2021 and 2021–2022. The first cropping season was characterized by a pronounced water deficit with only 129 mm/year, accompanied by high minimum and maximum temperatures, particularly during the months of January and February. The following cropping season was rainy (207 mm/year), with a good distribution despite the slightly late arrival of the first rains and their early cessation in April. Whereas the third cropping season was characterized by a severe water deficit throughout the season, (less than 100 mm/year) accompanied by fairly high temperatures in all months, particularly in February, which aggravated water stress in crops. The late arrival of rains in March contributed to shrub biomass production.

Stand density, plant height and botanical composition

The density of Atriplex nummularia Lindl shrubs in intercropping was quite low, between 522 and 584 shrubs/ha, compared with monoculture of this species where it generally exceeds 1100 to 1200 plants/ha. These densities at the time of their installation in 2012–2013 were 600 plants/ha, they have remained almost stable since their installation in 2014. Mortality rates varied from 7.3 to 10% for shrubs in the 'Alley-cropping' system due to drought and overgrazing (Table 2).

The stand density of annual forage crops grown between rows of the shrubs varied with the type of cultivated crop. The average plant density of barley under the intercropping system was higher (232 plants/m²) than that of the improved barley monoculture (215 plants/m²) and the local barley of the control (212 plants/m²). The pea/barley forage mixtures had fairly balanced grass and legume densities (Table 2). Where barley was sown as a pure crop, grass density averaged 215–232 plants/m², while legume density was low.

The average herbaceous stand density, the botanical composition of the total biomass and the height of the herbaceous and shrubby strata were remarkably influenced by the climatic conditions of the different cropping years. Indeed, the rainy crop year 2020–2021 positively affected these parameters, and the values obtained during this year were significantly higher than those of the other two cropping seasons, which experienced severe to very severe water deficit. The lowest values for these parameters were recorded during the very dry 2021–2022 cropping season (Table 2).

The canopy height of annual herbaceous crops and shrubs was significantly improved under the agroforestry cropping system. This was because these alley crops took advantage of the favorable conditions created by the shrubs, such as improved rainwater infiltration, wind protection and reduced evaporation.

Over the three cropping seasons, botanical composition as described by grass and broadleaf density was strongly influenced by the type of forage crops grown, either in alley cropping or monoculture. Grasses significantly dominated in treatments with barley monocultures, followed by barley-based forage mixtures. In contrast to grasses, broadleaf weeds, particularly legumes, dominated in treatments where the pea/barley mixture was present, followed by barley-based treatments

Table 2. Stand density and average canopy height of alley-cropped crops under arid agroclimatic conditions in West-Central Morocco

Cropping season	Fodder alternatives	Fodder shrub		Annual herbaceous crop		
		Density (Plants/ha)	Height (cm)	Gramineae (Plante/m²)	Broadleaves (Plante/m²)	Height (cm)
2019–2020	Association 1: Atriplex + Barley	561^{b}	147.6^{a}	2313^{a}	66.8^{b}	48.6^{a}
	Association 2: Atriplex + Peas/Barley	584^{b}	139.6^{ab}	95.3^{c}	137.1^{a}	48.3^{a}
	Association 3: Atriplex + Fallow	522^{b}	130.6^{b}	35.7^{d}	44.4^{c}	47.9^{a}
	Improved barley monoculture	-	-	180.8^{b}	36.3^{cd}	40.8^{a}
	Fodder shrub Monoculture	1124 ^{a}	112^{c}	18.5^{e}	32.4^{d}	21.2^{c}
	Local control (local barley)	-	-	210.8^{a}	58.6^{b}	33.3^{b}
2020–2021	Association 1: Atriplex + Barley	561^{b}	172.3^{a}	300.2^{a}	75.4^{b}	77.9^{a}
	Association 2: Atriplex + Peas/Barley	584^{b}	164.3^{ab}	123.2^{b}	156.1^{a}	77.9^{a}
	Association 3: Atriplex + Fallow	522^{b}	155.3^{b}	59.3^{c}	62.4^{b}	80.2^{a}
	Improved barley monoculture	-	-	309.9^{a}	73.7^{b}	59.9^{b}
	Fodder shrub Monoculture	1124^{a}	145.6^{c}	27.3^{d}	29.4^{d}	33.4^{c}
	Local control (local barley)	-	-	300.3^{a}	44.9^{c}	75.2^{a}
2021–2021	Association 1: Atriplex + Barley	561^{b}	156.1^{a}	165.1^{a}	16.8^{bc}	42.2^{a}
	Association 2: Atriplex + Peas/Barley	584^{b}	150.3^{ab}	62.8^{c}	81.5^{a}	46.2^{a}
	Association 3: Atriplex + Fallow	522^{b}	143.2^{b}	18.3^{d}	17.3^{bc}	47.8^{a}
	Improved barley monoculture	-	-	154.3^{a}	7.5^{c}	24.2^{b}
	Fodder shrub Monoculture	1112^{a}	114.8^{c}	17.2^{d}	18.7^{b}	15.4^{c}
	Local control (local barley)	-	-	127.1^{b}	16.1^{bc}	28.5^{b}
Overall average	Association 1: Atriplex + Barley	561^{b}	158.7^{a}	232.2^{a}	53.0^{b}	56.2^{a}
	Association 2: Atriplex + Peas/Barley	584^{b}	151.4^{ab}	93.8^{b}	124.9^{a}	57.5^{a}
	Association 3: Atriplex + Fallow	522^{b}	143.0^{b}	37.8^{c}	41.4^{bc}	58.6^{a}
	Improved barley monoculture	-	-	215.0^{a}	39.2^{c}	41.6^{b}
	Fodder shrub Monoculture	1120^{a}	124.1^{c}	21.0^{d}	26.8^{d}	23.3^{c}
	Local control (local barley)	-	-	212.7^{a}	39.9^{c}	45.7^{ab}

Note: numbers followed by different letters are statistically significantly different ($p \leq 0.05$).

(Table 2). These results show that agroforestry enables diversification of crop species and biodiversity and is a risk management tool for farmers and stockbreeders in the arid mediterranean areas as advanced bay Cogliastro et al. [2012].

Forage biomass yield

The production of total consumable fodder biomass from intercropped fodder shrubs was significantly lower than that the one of the monoculture, with respective averages of 1907 and 2755 kg DM/ha. This is in fact due to the higher shrub density of the monoculture compared with the intercropping (almost double; see Table 2). However, the productivity of total consumable biomass per shrub plant was higher for Atriplex in agroforestry, as shown by the difference in heights in Table 2. The highest herbaceous yields were obtained by the agro-forestry cropping systems, which produced more than 1800 Kg DM/ha of biomass. The improved barley monoculture and the control system produced significantly lower yields, at 1357 and 1016 kg DM/ha respectively (Table 3).

When we consider the total fodder biomass produced per hectare (digestible standing shrub biomass + herbaceous annual plant biomass), we notice that intercropped herbaceous crops produced significantly higher yields than the improved barley monoculture and the barley grown by local farmers - the local control. In fact, agroforestry systems based on forages mixtures, improved barley or fertilized fallow, they all achieved highest average total biomass yields over the three cropping seasons of 3834, 3637 and 3733 kg DM/ha, followed by the improved barley monoculture with 1357 kg DM/ha. The local control monoculture remains the least productive, with only an average of 1016 kg DM/ha. The gains achieved by the intercropping systems compared with the

Table 3. Biomass production of alley cropping compared to the monocropping systems under arid agroclimatic conditions in western-central Morocco

Cropping season	Fodder alternatives	Fodder shrub (Kg DM/ha)	Herbaceous (Kg DM/ha)	Total biomass (Kg DM/ha)	Gain/ local control %
2019–2020	Association 1: Atriplex + Barley	1602^{c}	2173^{a}	3775^{a}	217
	Association 2: Atriplex + Peas/Barley	1721^{b}	2170^{a}	3891^{a}	227
	Association 3: Atriplex + Fallow	1760^{b}	2207^{a}	3967^{a}	233
	Improved barley monoculture	-	1604^{b}	1604^{c}	35
	Fodder shrub Monoculture	2351^{a}	856^{d}	3207^{b}	169
	Local control (local barley)	-	1190^{c}	1190^{d}	-
	Mean	903^{b}	1667^{b}	2570^{b}	-
2020–2021	Association 1: Atriplex + Barley	2199^{b}	2347^{a}	4546^{a}	240
	Association 2: Atriplex + Peas/Barley	2528^{b}	2344^{a}	4872^{a}	264
	Association 3: Atriplex + Fallow	2356^{b}	2381^{a}	4737^{a}	254
	Improved barley monoculture	-	1831^{b}	1831^{b}	37
	Fodder shrub Monoculture	3562^{a}	1123^{c}	4685^{a}	250
	Local control (local barley)	-	1338^{c}	1338^{c}	-
	Mean	1230^{a}	1901^{a}	3131^{a}	-
2021–2021	Association 1: Atriplex + Barley	1653^{b}	938^{a}	2591^{ab}	398
	Association 2: Atriplex + Peas/Barley	1781^{b}	959^{a}	2740^{a}	427
	Association 3: Atriplex + Fallow	1606^{b}	890^{a}	2496^{b}	380
	Improved barley monoculture	-	638^{b}	638^{c}	23
	Fodder shrub Monoculture	2352^{a}	352^{c}	2704^{a}	420
	Local control (local barley)	-	520^{b}	520^{c}	-
	Mean	868^{b}	704^{c}	1573^{c}	-
Overall average	Association 1: Atriplex + Barley	1818^{b}	1819^{a}	3637^{ab}	258
	Association 2: Atriplex + Peas/Barley	2010^{b}	1824^{a}	3834^{a}	277
	Association 3: Atriplex + Fallow	1907^{b}	1826^{a}	3733^{a}	267
	Improved barley monoculture	-	1358^{b}	1358^{c}	34
	Fodder shrub Monoculture	2755^{a}	777^{d}	3532^{b}	248
	Local control (local barley)	-	1016^{c}	1016^{d}	-

Note: numbers followed by different letters are statistically significantly different ($p \leq 0.05$).

local control varied on the average between 258 and 277% for the three years (Table 3).

Biomass production of annual herbaceous plants and forage shrubs varied significantly with the climatic conditions of the cropping seasons. The highest productions were obtained during the rainy cropping season, 2020–2021, with respective yields of 1901 kg DM/ha, 1230 kg DM/ha, respectively, resulting therefor in the total highest yield of 3131 kg DM/ha. The lowest average yields of the different alternatives were obtained during the very dry year, 2021–2022; with only 704 kg DM/ha and 868 kg DM/ha, respectively (Table 3).

The greatest gains in biomass, compared with farmers' local practices (local control), were systematically achieved by intercropping crop associations over the three cropping seasons. Agroforestry cropping systems' gains varied between 217 and 233% in the first year, between 240 and 264% in the second year and between 380 and 427% in the third growing season. The drier the year, the greater the gains achieved by the agroforestry systems, in contrast to the improved barley monoculture, which achieved the lowest gains in dry years, indicating the need to diversify biomass crops on the same plot to improve and stabilize biomass production (Table 3).

Compared to the local control, biomass gains achieved by the improved barley monoculture ranged from just 23% to 37% over the three years, in contrast to the Atriplex nummularia Lindl monoculture, which achieved greater gains of up to 420% in the dry year (Table 3), indicating the need to radically change the current cropping systems if we are to improve both the resilience of these farmers and their ability to adapt to climate change.

Improving productivity through agroforestry, in which fodder shrubs are combined with the annual agricultural crops, has a number of advantages. Firstly, the presence of shrubs alternating with crops creates a favorable microclimate [Tchoundjeu et al., 2005], leading to increased productivity [Balde, 2011; Shili-Touzi, 2009]. These conservation agriculture agroforestry cropping systems have been specially designed to meet the needs of livestock farmers in marginal arid zones, where natural resources are rapidly degrading. By combining summer-growing crops with herbaceous spring crops, it is possible to intensify production twice a year, thus extending the period of agricultural land use in these arid zones. Productivity per mm of water and per unit area will be improved and stabilized, especially during difficult periods, the period of use of marginal agricultural land will be extended, and soil conservation/rehabilitation will be ensured [AFA, 2015; Jorge-Mustonen et al., 2014; Dariush, et al., 2006; Kaeser et al., 2010].

Grain yield of barley

Intercropping barley with fodder shrub rows achieved grain yields significantly higher than those of monocrops improved barley and farmers' barley for the three years of experimentation. In fact, it produced yields of 882, 1764 and 609 kg/ha over the three consecutive cropping seasons, with respective average gains of 116, 450 and 221% compared with local practices (Table 4). In this arid zone, priority should be given to the production of biomass for the livestock and not to grain production, as the farmers of this zone claim. This is confirmed by the results obtained for monocrops improved barley, which fails to improve grain yields to the same level as those of the agroforestry system. Indeed, the average gain of the monocrop improved barley over local controls did not exceed 55% for the three crop years (Table 4).

The grain yields obtained for barley in this arid area remains very low even when improved cultivars are used or conservation agriculture are practiced (no-till, alley cropping, weed control, and so on…). According to Passioura [2006], in the semi-arid areas, the upper limit of water productivity, in the field, of well-managed, disease-free, water-limited cereal crops is generally 20 kg/ha/mm (grain yield per water used). In farmers' fields in arid zones, productivity is well below this, suggesting that major stresses in addition to water are at work, such as monoculture, crop undernutrition, irrational soil and seedbed preparation, inappropriate sowing date and rate, disease and insect attacks. This imbalance is created

Table 4. Grain yields of barley in alley cropping and monoculture systems under arid agroclimatic conditions in West-Central Morocco

Cropping season	Barley cropping systems	Grain yield (Kg/ha)	Gain/ Local control %
2019–2020	Association 1: Atriplex + Barley	882[a]	116
	Improved barley monoculture	551[b]	35
	Local control (local barley)	408[b]	-
	Mean	614[b]	-
2020–2021	Association 1: Atriplex + Barley	1764[a]	450
	Improved barley monoculture	608[b]	89
	Local control (local barley)	321[c]	-
	Mean	800[a]	-
2021–2021	Association 1: Atriplex + Barley	609[a]	221
	Improved barley monoculture	270[bc]	42
	Local control (local barley)	190[c]	-
	Mean	356[c]	-
Overall average	Association 1: Atriplex + Barley	1085[a]	254
	Improved barley monoculture	476[b]	55
	Local control (local barley)	306[c]	-

Note: numbers followed by different letters are statistically significantly different ($p \leq 0.05$).

either by the lack or irregularity of rainfall, or by a low water storage capacity in the soil [Quiza et al., 2010]. In addition to these climatic disturbances causing water scarcity, there is the degradation of natural resources (soil, water and biodiversity) and unsustainable agricultural management practices (clearing of pastoral land unsuitable for agriculture, elimination of fallows and crop rotations, low use of organic or mineral fertilizers and low use of inputs) [Alexandratos and Bruinsma, 2012; Mrabet et al., 2006]. In this case, the greatest advances will come from adapted crop management in addition to the choice of drought-adapted species and cultivars. Water productivity depends not only on how a crop is managed during its lifetime, but also on how it fits into the management of a farm as a whole, both spatially and temporally [Passioura, 2004]. Maintaining residue mulches on the surface under the no-till system, particularly in agroforestry, improves crop biomass and grain productivity and increases the soil's capacity to sequester CO_2 [Mrabet et al., 2011; El Khalil et al., 2013; Benmoula, 2013] and SOM [Khurshid et al., 2006].

Land equivalent ratio (LER)

The agricultural LER is significantly improved by the agroforestry system (Atriplex nummularia Lindl)/annual fodder crops). It reached an average of 2.4 for barley biomass production, 2.7 for fodder mix Pea/Barley biomass production and 1.8 for pasture fallow improved by NPK fertilization. This ratio clearly indicates the improvement in agricultural land-use efficiency in this area, where small farms dominate (Table 5). The LER is strongly influenced by the year's climatic conditions, as shown in Table 5. Indeed, the drier the year, the higher this ratio will increase to exceed 2.

These results indicate the unsuitability of the current extensive barley monoculture management in comparison with conservation and agroecological agriculture that requires the cultivated crops diversification in the same agricultural land, the direct seeding and the maintenance of the crop residues. Research carried out in Morocco during the last 25 years [El Mzouri, 2009; Mahyou et al., 2004, Maadid, 2017] on the evolution of the LER

Table 5. Agricultural land equivalence ratio (LER) for biomass production from fodder alley cropping and forage crops monocropping systems under arid agroclimatic conditions in West-Central Morocco

Cropping season	Fodder alternatives	LER
2019–2020	Association 1: Atriplex + Barley	2.4^{a}
	Association 2: Atriplex + Peas/Barley	2.6^{a}
	Association 3: Atriplex + Fallow	1.8^{b}
	Improved barley monoculture	-
	Local control (local barley)	-
	Mean	2.3^{a}
2020–2021	Association 1: Atriplex + Barley	1.9^{ab}
	Association 2: Atriplex + Peas/Barley	2.2^{a}
	Association 3: Atriplex + Fallow	1.4^{b}
	Improved barley monoculture	-
	Local control (local barley)	-
	Mean	1.8^{b}
2021–2021	Association 1: Atriplex + Barley	2.9^{b}
	Association 2: Atriplex + Peas/Barley	3.4^{a}
	Association 3: Atriplex + Fallow	2.1^{c}
	Improved barley monoculture	-
	Local control (local barley)	-
	Mean	2.8^{a}
Overall average	Association 1: Atriplex + Barley	2.4^{a}
	Association 2: Atriplex + Peas/Barley	2.7^{a}
	Association 3: Atriplex + Fallow	1.8^{b}
	Improved barley monoculture	-
	Local control (local barley)	-

Note: Numbers followed by different letters are statistically significantly different ($p \leq 0.05$).

ratio under different climatic conditions shows that it is relatively stable at around 1.5, with a slight downward trend under favorable rainfall conditions, and that the use efficiency of marginal land under stressful conditions can double when this fallow is combined with *Atriplex nummularia Lindl.*

CONCLUSION

Conservation agriculture based on agroforestry forage cropping systems is more beneficial than conventional barley monocultures in Morocco's arid marginal zones. Intercropping showed a more balanced botanical composition, relatively low but stable shrub densities, and greater canopy height. Biomass and grain yields were significantly improved in agroforestry systems, with substantial gains over traditional practices. In addition, the interaction between cropping seasons and agroforestry demonstrated that intercropping systems were more resilient to difficult climatic conditions. Irrespective of crop year and cropping method, alley cropping proved superior to conventional farming practices, with greater water use efficiency, better use of agricultural inputs, more soil protection and conservation, and greater productivity of the arid farmland. It's a promising alternative that combines agricultural production with the preservation of the environment and biodiversity. It offers economic, agronomic and environmental benefits, making it a sustainable solution for small farmers in the arid marginalized agricultural areas. These results support the adoption of agroforestry as a sustainable and productive approach to conservation agriculture and agroecology for marginal arid Mediterranean climate areas, for better drought adaptation of livestock-based farming systems.

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