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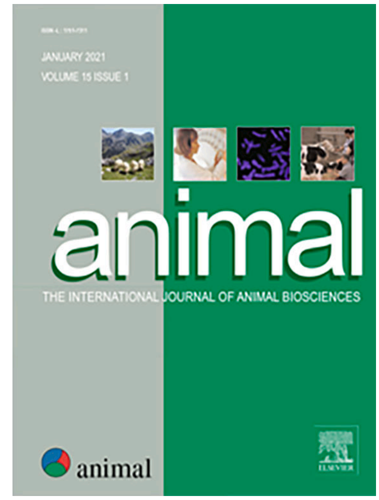

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Evolution of pastoral livestock farming on arid rangelands in the last 15 years

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Abstract

Livestock farming in arid rangelands constitute a key component in the agricultural sector, particularly in developing countries. Farms have rapidly changed in recent decades, which has resulted in the modification of their structure, management and economic performance. Nowadays, livestock production in arid rangelands is threatened by climate change, coupled with the impact of complex interactions among social, economic and political factors. The present study analyses the main changes that have occurred on farms in the arid rangelands of south Tunisia from 2004 to 2019 and discusses the factors that explain the geographical patterns of such changes. Data were collected through face-to-face questionnaires with 73 farmers in two years (2004 and 2019). Information included farm structure and management, resources use and economic performance. Multivariate statistical methods analysed the differences in farms typologies between dates and the different pathways of change. Results showed that most farms increased herd size and cereal area for feeding the sheep, and reduced the time spent in rangelands. These changes could be partly explained as a response to decreasing gross margins per livestock unit and the deployment of policies fostering the use of agriculture-based feed resources. Despite these general trends, the variability among pathways of change was wide. Few farms kept using rangelands by focusing on sheep or camel production. Small sheep farms intensified the use of off-farm feeds in the north of the study area, where ecological conditions favoured agriculture. Feed supplementation allowed herd size and animal production to increase, with a substantial risk of susceptibility to market fluctuations. The economic results showed that camel farming combined with small ruminant species can lead to a similar profitability to, or even higher than, large farms that focus solely on sheep and rely on feed supplementation. We conclude that the current situation of livestock farming in arid rangelands remains fragile and their long-term viability is uncertain.

Keywords: Farm dynamics, temporal dynamics, farm typologies, sheep, camels.

Implications

Feed supplementation has become a common practice in arid regions, but rangelands still constitute an important resource for livestock. Feed supplementation allows herd size and animal productivity to increase but makes farms susceptible to market fluctuations. The optimal balance between the use of rangelands and off-farm feeds depends on local ecological conditions. Camel farming seems a promising strategy to sustainable use of arid rangelands while maintaining farm profitability.

Introduction

Rangelands cover about 79 million km^2 of the Earth's surface, of which 43% is classified as arid or semi-arid (approx. 34 million km^2; International Livestock Research Institute-ILRI-, 2021). Many pastoral communities across the world directly depend on rangelands for their livelihoods, particularly in arid and semi-arid regions that hold 46% of global livestock production on rangelands (ILRI, 2021). Pastoral communities have historically used rangelands while maintaining an equilibrium between stocking rates and the provision of regulating ecosystem services, such as C and N storage and soil retention and formation, among others (Oñatibia et al., 2015; Fan et al., 2019; Khosravi et al., 2019). However, livestock farming systems in these regions have substantially changed in the last decades due to a variety of global, regional and local drivers.

Similarly to other arid and semi-arid Mediterranean countries, livestock feeding in Tunisia was based on rangeland resources until the 1970s (Abaab and Genin, 2004). Since then, farming systems have undergone major changes such as agricultural mechanisation and the expansion of rainfed cereals, fruit, and olive trees. These changes were driven by policy, market, social and climate factors, fostering livestock-agriculture integration (Ben Salem, 2011; Alary et al., 2019; Rigolot et al., 2019). In Central and Southern Tunisia, these integrated systems have partially replaced the traditional rangeland-based pastoral systems, resulting in transhumant farmers adapting to a sedentary lifestyle (Elloumi et al., 2011; Ammar et al., 2011; Gaddour et al., 2013). Despite these general trends, rangelands still remain an important feed resource for livestock (Bencherif, 2013; Neffati, 2020; Steinfeld et al., 2006) and can be key for the future of livestock farming in the Maghreb (i.e. region of North Africa bordering the Mediterranean Sea, including Algeria, Libya, Mauritania, Morocco, Tunisia, and the disputed territory of Western Sahara). Unlike many other world regions (especially Europe), sheep populations has increased in the last few decades in the Maghreb (Deleule, 2016; Belanche et al., 2020). In the particular case of Tunisia, animal numbers have grown from 8.1 million in 1990 to 8.6 million in 2019, mainly due to sheep (FAOSTAT, 2019). Arid rangelands represent two thirds of national rangelands and provide 20-60% of livestock feed requirements (ILRI, 2021; Jaouad et al., 2022).

General overviews of livestock farming evolution are useful for analysing the main development pathways but fail to account for variability across farms. Exploring the diversity of changes provides evidence of farming heterogeneity, which helps understanding the range of farmers' reactions to common and specific drivers of change at different scales (e.g., García-Martínez et al., 2009; Ryschawy et al., 2014; Muñoz-Ulecia et al., 2021). Furthermore, becoming aware of past changes can help designing more effective policies to promote resilient farming in the future (Valbuena et al., 2015). However, studies covering temporal dynamics of farming in arid and semi-arid rangelands are scarce, particularly in Maghreb countries (Falconnier et al., 2015; Vall et al., 2017). In Tunisia, several studies have described livestock farm types at specific times (Nefzi, 2012; Jeder et al., 2013; Ibidhi et al., 2018) but, to our knowledge, no study has analysed the evolution of farming systems, neither the context conditions that may explain evolution patterns (Muñoz-Ulecia et al, 2021). This research bridges this gap by studying changes in livestock farming and geographical patterns of change over a 15-year period.

The objective of this study is twofold: (i) to analyse the main changes that livestock farms in Tunisian arid rangelands have undergone between 2004 and 2019; (ii) to explore potential geographical patterns explaining these changes. We discuss the outcomes of our study in relation to socio-economic and policy factors in the region.

Material and Methods

Study area

The study was conducted in the El Ouara rangelands in SE Tunisia, which cover 564000 ha in the Tataouine (Municipalities of Tataouine South, Tataouine North, Rmada and Smar) and Medenine (Benguarden Municipality) governorates (Supplementary Fig. S1). “El Ouara” means "where it is difficult to live", which reflects the harsh climate conditions in our study area. It is a transition zone between Mediterranean woodlands and scrub and xeric scrubland ecological zones (Olson and Dinerstein, 2002) in a Hot Desert Climate (Köppen climate classification: 175.3 mm annual average rainfall for 2004-2020). The dry season is variable and ranges from 8 to 12 months. Temperatures are mild in winter (January average temperature: 8.4ºC) and very high in summer (August average temperature: 37.2ºC). El Ouara is one of the few common-land rangelands in Tunisia whose main use is still livestock grazing and is, therefore, a relevant example of arid rangelands in Tunisia. The residence place of farmers is generally located in urban areas, 30-120 km away from the rangelands. There are only a few small rural communities near El Ouara, mainly in the Tataouine governorate.

Globally, livestock farming in the study area has changed considerably in recent decades. Traditional pastoral farms mainly dependent on rangeland resources evolved to smallholder mixed livestock-agriculture farms. In these mixed farms, rangelands feed resources are usually complemented with rainfed barley crop residue (stubble, straw, etc.) and agro-industrial by-products (mainly olive pomace) (Ben Salem, 2011; Ibidhi et al., 2018; Nefzaoui, 2004). Currently, the area accounts for around 19% of the camels, 6% of the goats, and almost 5% of all the sheep in Tunisia (South Development Office, 2018). The region has a negative migratory balance (approximately -6% of the population from 2004 to 2014; official data of the National Institute of Statistics of Tunisia, 2014). Most migrants were young rural people who moved to coastal cities or abroad to seek employment in sectors that offer better labour opportunities than agriculture (Castagnone et Termine, 2021; REACH and Mercy Corps, 2018).

The evolution of employment, land use and livestock heads during the study period differed among municipalities (Supplementary Fig. S2). Although Tataouine governorate experienced a negative net migration, its population grew by 5%. Its main economic activity moved to services and construction, producing a sharp decrease (approx. -70%) in the percentage of people working in agriculture, also observed (-43 to -86% depending on the municipality) in the total cereal crops area (mainly rainfed).

However, sheep numbers increased in Tataouine South and North municipalities but lowered in Rmada and in Smar, and the total camel numbers decreased. The areas with tree plantations remained constant (Tataouine South and Rmada) or slightly increased (Tataouine North and Smar). Contrarily to the Tataouine governorate, Benguarden municipality in Medenine Governorate underwent very high population growth (49%). Economic activity moved to construction, while the number of people in the agricultural sector lowered (-59%). Nevertheless, the cereal crop area increased by 66% and tree plantations, which were anecdotal in 2006 (i.e., 1110 ha), multiplied fifty-fold by 2019. Conversely, the total sheep numbers lowered (30% and 35% respectively), while the total camel numbers slightly rose (1%).

Farmer survey design and implementation

Data were collected in 2004 and 2019 by a face-to-face survey to farmers. The questionnaire included information about farm structure, management, labour, economic performance, and farmers' socio-economic characteristics. All the farmers using El Ouara rangelands (according to a list drawn up by the Tunisian Union of Agriculture and Fisheries) were surveyed in 2004, totalling 413 farmers (117 for Tataouine South, 90 for Tataouine North, 49 for Rmada, 43 for Smar and 114 for Benguarden). A group of 120 farmers was randomly selected from this sample and contacted again in 2019. Of the 120 farmers, 22 could not be found, 16 had given up livestock farming and nine had passed away without successor. This left a final sample of 73 farmers who were surveyed both in 2004 and 2019: 41 farms in the Tataouine governorate (13 in Tataouine North, 11 in Tataouine South, 11 in Smar, 6 in Rmada) and 32 farms in the Medenine governorate (in the Benguarden municipality).

Data analysis

The analytical methodology is divided into the following four steps:

1. Analysis of the average changes in farms.
2. Analysis of evolution of farms by identifying farm typologies both in 2004 and 2019.
3. Analysis of evolution of farms by identifying the different change pathways followed by farms.
4. Analysis of geographical patterns of typologies and change pathways.

Analysis of the average changes in livestock farms

We determined the changes in livestock farms during the study period by analysing 22 variables that defined: farm structure, farm management and labour, and farm economic performance (Table 1). Variables were either obtained directly from questionnaires or calculated (i.e., ratios per livestock unit (**LU**). The applied LU conversion factors were 1 for camels and 0.15 for both sheep and goats (Agripedia, 2012). All the economic variables were converted into 2019 constant Tunisian dinar (**TD**, local currency). Differences between years were evaluated by ANOVA, Kruskal-Wallis and Chi-square tests depending on the type of variables (i.e., continuous or categorical) and their distribution (i.e., normal or non-normal). These statistical tests were carried out using the R software (R Core Team, 2019).

Analysis of the evolution of livestock farms

We analysed the evolution of farms using the analytical method proposed by Doledec and Chessel (1987) and modified by Gibon et al. (1999). This method has been applied to analyse the evolution of farming systems (e.g., García-Martínez et al., 2009; Muñoz-

Ulecia et al., 2021), since it allows to analyse differences among farms on each study date, as well as differences in the changes that they had experienced between dates (Gibon et al., 1999). We analysed these two types of changes: intrafarm and interfarm changes (terms used by Gibon et al., 1999). In the intrafarm analysis (“farm typologies” henceforward), farms were compared to the average farm separately on each date. This analysis did not account for the effect of time; it can be considered a farm typology analysis on each date. The interfarm analysis (“change pathways” henceforward), explored differences per farm once the average trend of change (time-dependent) had been eliminated. The method is described in detail below.

Definition of variables used

We specifically considered 12 continuous variables of the 22 described in Table 1 to be the key descriptors of farm structure and management, including: farm structure aspects (i.e., Olive tree area, Cereal area, Herd LU, Camel LU, and Sheep LU/Herd LU), farm management and labour aspects (i.e., Work Units (**WU**) hired/LU, Rangeland period, Transhumance period) and input costs (i.e., Feeding cost/LU, Guarding cost/LU, Transport cost/LU, Water cost/LU). Goat LU and Sheep LU were excluded from this analysis because they were highly correlated with Sheep LU/Herd LU, which we considered to be the best proxy to indicate the relative importance of sheep on farms. The three farm economic performance variables: Total output, Gross margin (**GM**), and GM/LU were not considered at this point of the analysis because they do not define farm structure but economic results.

Following Gibon et al. (1999), initially, data were organised in a matrix, which columns included the *p* variables describing farms and which rows included the *s* observations (i.e., farms) on the considered *t* dates. In our case: *p*=12 variables (with normalised values); *s*=73 farms; *t*=2 dates. Starting from this matrix the two analyses were carried out as follows.

Farm typologies in 2004 and 2019. We built a data table per date were the value of each cell was calculated as $x_{tsp} - x_{t.p}$ per variable (in columns) representing the deviation of each farm (in rows) to the average of farms per date. A principal component analysis (**PCA**) was performed on both data tables to determine the factors that best explained differences among farms on each date. Then a K-means cluster analysis (**CA**) was carried out on all the principal components (**PC**) with eigenvalues above 1 to establish a farm typology. The selection of the number of clusters was based on loss of inertia (in a cluster sum of squares) upon each partitioning of clusters. After establishing the farm typology for 2004 and 2019, we compared the features of the types identified on each date and how individual farms changed, or not, their typologies over the study period.

Change pathways. We built a data table with *p* columns (i.e., 12 variables with normalised values) and *s* + *t* rows (i.e., *s* observations – 73 farms, on *t* dates – 2 time points, 2004 and 2019). The value of each cell was defined as $x_{tsp} - x_{.sp}$, which represents the deviation to the average of each farm at the two time points. Similarly to the typologies analysis, a PCA was performed. PCs describe the combination of variables that best explained the changes that occurred in farms on the study dates.

Then a CA was performed on the PCs with eigenvalues above 1. Thus, clusters grouped the farms that followed similar change pathways.

Both farm typologies and change pathways were described using the 12 variables considered in the statistical analysis (see above), and 10 complementary variables; two continuous variables (i.e., Sheep LU and Goat LU), five categorical variables (i.e., second economic activity, and tractors, cars, tanks and wells ownership), and three economic performance variables (i.e., Total output, Gross Margin, Gross Margin/LU). The analyses of typologies and change pathways (including the PCA and CA) were done using version 2013 of the XLSTAT software.

Analysis of geographical patterns

We analysed the geographical pattern of the evolution of livestock farms by exploring the distribution of farms across municipalities according to their typologies in 2004 and 2019 and change pathways. Differences between municipalities were evaluated by a Chi-square test using the R software (R Core Team, 2019).

Results

Average changes in livestock farms

Farms changed considerably throughout the study period (Table 1). Cereal area increased by 66% from 2004 to 2019 (*Average ± SD;* 0.8 ha ± 2.6 ha to 2.3 ha ± 3.2 ha, respectively; $p<0.00$), and Olive tree area also increased (4.5 ha ± 6.2 ha, 5.8 ha ± 13.4 ha; $p<0.03$). Sheep LU doubled (18.4 LU ± 19.8 LU to 34.7 LU ± 40.8 LU; $p<0.07$) during the studied period, while Camel LU and Goat LU remained constant, which led to an increase in sheep LU/Herd LU (54.8% ± 27.6% to 68.1% ± 29.5%; $p<0.00$). Work units (WU) and hired/LU did not significantly change. We observed a decrease in both the Rangeland grazing period (10.0 months ± 2.5 months to 8.7 months ± 3.6 months; $p<0.02$) and the Transhumance period (3.6 months ± 2.6 months to 2.1 months ±1.8 months; $p<0.00$). Due to these changes, the total variable costs increased. Feeding cost/LU (172.7 TD ± 113.5 TD to 250.1 TD ± 86.5 TD; $p<0.00$) and Guarding cost/LU (79.3 TD ± 102.5 TD to 148.4 TD ± 124.2 TD; $p<0.00$), which constituted the larger share of the variable costs, also increased. Transport cost/LU more than halved (24.2 TD ± 34.7 TD to 11.1 TD ± 28.6 TD; $p<0.00$), and Water costs slightly decreased (8.4 TD ± 15.2 TD to 8.0 TD ± 15.6 TD; $p<0.02$). In parallel to the rise in variable costs, Total output almost doubled (15391.7 TD ± 16465.4 TD to 26898.7 TD ± 27187.7 TD; $p<0.06$). However, Gross margin (GM) remained stable during the study period (5012.7 TD ± 8226.7 TD to 5069.5 TD ± 9772.8 TD; $p<0.49$) because the GM/LU halved (119.2 TD ± 149.8 TD to 57.6 TD ± 153.4 TD; $p<0.02$).

Farm typologies in 2004 and 2019

PCA results are provided in the Appendix (Supplementary Table S1). CA resulted at three clusters in both 2004 and 2019 (i.e., “2004 typologies” and “2019 typologies” hereafter). Similar typologies were identified in both dates, although their average features and relative importance evolved over time: a) camel-focused farms with large tree areas (“Camel farms”, hereafter); b) large sheep-focused farms with considerable rangelands use (“Large sheep farms”, hereafter); c) small sheep-focused farms (“Small sheep farms”, hereafter). Typologies are described below according to the 12 variables considered in the analysis of changes (Fig. 1) and 10 other complementary variables (Table 2).

a) *Camel farms.* In 2004, these farms represented 24.7% of the sampled population and their relative importance decreased during the study period; in 2019, they represented 15.0% of the farms. They were characterised by having the highest Camel LU and Olive tree area, and the lowest Sheep LU/Herd LU of the three typologies. They had the longest transhumance period and the lowest feeding and water costs per LU. From 2004 to 2019, these farms had an increased Camel LU ($p<0.01$). GM/LU more than halved during the study period ($p<0.06$), but GM remained constant.

b) Large sheep farms. In 2004, these farms represented 23.3% of the sampled population and their relative importance almost doubled during the study period; in 2019, they represented 49.3% of the farms. They had the highest Sheep and Goat LU and, contrarily to the Small-sheep farms (see below), they usually recruited external labour and practiced transhumance for longer periods than other typologies. Besides these aspects, they were similar to Small-sheep farms in farming system management terms. During the study period, the Cereal area per farm greatly increased ($p<0.0001$). The Rangeland period remained stable, but the Transhumance period significantly reduced ($p<0.00$). Both GM and GM/LU remained constant.

c) *Small sheep farms*. In 2004, these farms represented more than half (52%) the sampled population and their relative importance decreased during the study period; in 2019, they represented 35.6% of the farms. They were characterised for having the lowest Herd LU, Transhumance period, WU hired/LU and Guarding cost/LU of all typologies. Cereal area tripled from 2004 to 2019 (p<0.00) and was the highest of all the typologies in 2019. The Herd size of this farm type almost halved throughout the study period and the number of camels in herds lowered (p<0.05). The Rangeland period also halved (p<0.00) with the consequent increase in Feeding cost/LU (18.7%; p<0.05) and a cut in Transport cost/LU (p<0.00). As in the other two farming system typologies, GM/LU decreased during the study period (p<0.04) but, conversely, GM also reduced (p<0.02).

The fact that similar farm typologies were found in 2004 and 2019 does not mean that individual farms continued with the same typology during that period. Figure 2 shows how individual farms shifted among the typologies between 2004 and 2019. Around half (n=35) of the farms fell in the same typology in both 2004 and 2019, which was more likely to happen in the Large sheep farms than in the other two typologies. Most of the Large sheep farms that did not remain in the same category shifted to the Small sheep farms (24%). On the contrary, half of the Small sheep farms in 2004 became Large sheep farms in 2019, and only a very low percentage (5%) became Camel farms. Finally, a similar proportion (approx. 30%) of the 2004 Camel farms shifted to both the Small sheep farms and Large sheep farms

Farms' change pathways

The PCA resulted in five PCs with an eigenvalue above 1 that explained 69% of total variance and represented the major trends of change in the sampled farms (Supplementary Table S2). Based on these five PCs, the CA resulted in four farms' change pathways, which are described according to the 12 variables used in the analysis of pathways (Fig. 3) and the other 10 complementary variables (Table 3).

Sheep intensification pathway

This pathway was followed by 20.5% of the sampled population. These farms were characterised by the largest increase in Sheep LU/Herd LU and Feeding cost/LU of all the pathways, and by a sharp reduction in the Rangeland period. This reduction in herd movement led both Transport and Water costs/LU to lower. All these changes brought about an increase in Total output, although GM and GM/LU decreased. They also increased the agricultural area, particularly the Olive tree area. Finally, these farms showed the highest decrease in household size (-50%) and the highest increase in practicing a second economic activity (80% of the farms started a second activity besides farming).

Non-sheep extensification pathway

This pathway was followed by 20.5% of the sampled population and was the only one to show an extension in both rangelands and transhumance periods. In parallel, feeding costs lowered by an average of 37.6%, whereas Guarding cost/LU increased. Farms in this pathway showed the highest increase in herd size of all the pathways, which was directly related to an increase in both Camel LU and Goat LU which, in turn, led to a decrease in Sheep LU/Herd LU. Average farm output and GM increased despite GM/LU lowering. Olive tree area remained more or less constant but, like the other pathways, Cereal area increased. Finally, more than the half the farms (66.7%) started secondary activities during the study period.

Sheep rangeland pathway

It was followed by 26.1% of the sampled population. These farms restructured their herd by reducing the number of camels and slightly increasing the number of small ruminants (particularly sheep), while keeping the total herd size stable. In parallel, the Rangeland period slightly increased, but the Transhumance period sharply decreased. Workforce hired and, consequently, the Guarding cost/LU, increased. Total output increased slightly, but GM and GM/LU went down. Cereal area increased, but Olive tree area reduced (3.7 ha in 2019). Almost 40% of farms started a secondary activity.

Stable herd structure pathway

This pathway was followed by 32.9% of the sampled population. It grouped the farms that remained relatively stable in terms of herd size and composition. However, unlike the other pathways, Olive tree area showed a major decrease. Herd management changed to a certain extent with a reduction in the Rangeland and Transhumant periods and, consequently, Feeding cost/LU increased and Transport costs/LU lowered. Both Total output and GM increased, and, unlike the other pathways, GM/LU also increased. Finally, the farms had the lowest increase in secondary activities (25%).

Geographical patterns

Our results showed statistical differences across municipalities in the distribution of farms typologies both in 2004 (Chi-square test p-value<0.03) and 2019 (Chi-square test p-value<0.01). In 2004, most Camel farms were located in Benguarden municipality. In the other municipalities, Small sheep farms represented around three quarters of farms, with the remaining quarter being mostly Large Sheep farms (Fig. 4). This picture had changed in 2019. While most Camel farms were still located in Benguarden, Small Sheep farms tended to be located in the Northern part of the study area, and Large Sheep farms in the Southern part. We found no statistical differences in the distribution of farm change pathways across municipalities (Chi-square test p-value=0.28). However, we observed a consistent trend within municipalities where farms following the Sheep intensification pathway were located in the Northern part of each municipality. Note that no Sheep intensification farms were located in Rmada municipality.

Discussion

This study allowed us to explore the general evolution of livestock farms over a 15-year period in a representative arid rangeland of South Tunisia. We also considered the diversity of farms typologies and change pathways, being one of the few studies analysing livestock farming dynamics in arid rangelands (Falconnier et al., 2015). Below we discuss in detail the farm typologies and change pathways, the geographical patterns, and how they might be related to socio-economic factors.

General change: increase in herd size and cereal area, sheep specialisation, and reduction of time spent in rangelands

Most farms evolved in the same direction for four aspects: increase in herd size, increase in cereal area, stronger orientation to sheep production, and (limited) reduction in transhumance and time spent in rangelands. The increase in herd size aligns with a general trend observed in other arid and semi-arid regions of Tunisia, North Africa and elsewhere (Jemaa, 2016; Maatougui, 2000; Mohamed et al., 2021). This is likely a response to the reduction of GM/LU due to the low price of lambs (Bencherif, 2013), and the availability of supplementary feed resources, as discussed below. The increase of herd size was due to sheep numbers while goat numbers decreased. These findings confirm a trend that started one decade before the study was conducted (Ben saad and Bourbouze, 2010). Goats are of lower commercial interest and are mostly kept for milk home-consumption.

In most cases, the increase of herd size was accompanied by supplementary on-farm feeds (i.e., rainfed agriculture by-products, mainly thatch and straw) or purchased, which increased the variable costs per LU and, in turn, further reduced GM/LU. Feed intensification is a common trend observed across farming systems, livestock species and world regions (Powell et al., 2004; Vall et al., 2017; Godde et al., 2018). However, El Ouara farms used less supplementary feeds compared to other regions in Tunisia (e.g., centre of the country: Ibidhi and Ben Salem (2018); Jemaa (2016) and Maghreb areas (Bensmira, 2017). In line with Abdelguerfi and El Hassani (2011) and Hadbaoui et al. (2020), we found a large integration of agriculture and livestock activities which was almost inexistent some decades ago (Abbas, 2014; Nasr, 2004) and very limited at the beginning of the study. Higher use of cereals and agriculture by-products for livestock feeding has improved animal performance but also increased cereal price volatility at national and international levels, and therefore production costs. In Tunisia (Elloumi, 2015) and other developing countries, the dependence on agricultural commodities produced elsewhere has been pointed out as one of the causes of economic instability and social crisis in the recent past (Behnassi and El Haiba, 2022; Jayasuriya et al., 2012; Mittal, 2009), which are likely to be exacerbated in the context of climate change (Vesco et al., 2021).

The average time that herds spend in rangelands was reduced. Previous studies have shown that the contribution of rangelands to small ruminant feeding has decreased in Tunisia in the last three decades (Ibidhi and Ben Salem, 2018, World Bank, 1995 in Elloumi et al., 2001). These studies point to overgrazing and rainfall reduction as key drivers for the reduction of the use of rangelands. We can neither confirm nor deny these drivers. Yet, when analysing the different change pathways, our results revealed that some of them maintained the use of rangelands. In addition, our results showed a general increase of farm machinery and infrastructures (i.e., tractors, cars, wells). Tractors and cars increase might be related to crop production, but they can also be used to transport water and feed, allowing livestock to remain on rangelands during dry periods (Nefzaoui et al., 2012).

In most typologies, guarding costs increased due to rising shepherd salaries (Selmi et al., 2018). According to informal conversations with farmers, this is a consequence of the lack of specialised shepherds. This is probably due to emigration that particularly involves young people (Richard, 2006). Livestock management in harsh environments, such as El Ouara rangelands, requires specialised shepherds with in-depth knowledge of resource distribution across space and time (Bourbouze, 2018; Selmi and Elloumi, 2007). Lack of specialised shepherds is also a common problem in many other world regions, and is generally considered one of the main challenges that future pasture-based systems will face (Morales et al., 2019, Paniagua, 2019).

Finally, the results showed that many farmers (between 25 and 47 out of 120) quit their activity during the study period, which is in line with the decrease in agricultural employment in Tunisia (National Institute of Statistics of Tunisia, 2018). During informal conversations, several farmers pointed out that lack of family labour and/or economic resources to make farm investments are the main reasons for farming abandonment. It is not known to what extent this process will continue in the future, but the current scenario of stagnated profits and young people migration will not help halting the abandonment of farming.

Farm typologies and change pathways

Regardless of the pathway followed by farms, feeding costs per LU increased mainly due to purchased supplementary feed. In two pathways, this increase was accompanied by a reduction in the use of rangeland (regardless of the evolution of the number of sheep). The economic performance analysis showed that the strategy which focused on sheep maintaining rangeland use led to a sharp drop in GM, which was not observed in other pathways. This result should be confirmed with more accurate farm economic assessments, including other factors affecting household economic performance such as labour and access to land. However, if it holds true, it does not bode well for the future of rangeland-based sheep farming in El Ouara.

On the contrary, the non-sheep extensification pathway, which focused on camels with a limited number of sheep and maintained transhumance practices in rangelands, was the most profitable pathway. This result suggests that mixed camel-sheep farming could obtain similar or higher profitability than large sheep farms relying on feed supplementation. Studies in other African drylands have found this combination profitable (Behnke, 2021; Faye and Bonnet, 2012; Ratemo et al., 2020). Although the Tunisian government has set up a national program for camel research and development, production remains a traditional activity that relies on arid rangelands with low reproductive efficiency (Moslah et al., 2004; Jemli et al., 2018). Hence, according to some experts (Faye et al., 2014), future camel farming will depend on the sector's ability to improve herd productivity and market channels, which still are largely informal.

Geographical patterns

Our study shows a clear relation between farms' geographical location and pathways of change, which became stronger in 2019 and showed a North-South gradient. This pattern might be explained by several interrelated socio-economic and ecological factors. On the one hand, the fact that small sheep farms (in 2019) and the intensification pathway were located mainly in the north might respond to differential ecological features of El Ouara, i.e., *"Jeffara"* plains in the north far more favourable for agriculture (Guillaume, 2009). Therefore, in favourable agricultural areas small sheep farms may intensify by utilizing agriculture-based feeds, supported by specific sectoral policies (Elloumi, 2006). The harder ecological conditions in the south do not allow the development of crop farming, which explain why farmers increase herd size and rangeland use. On the other hand, camel farms were almost exclusively located in Benguarden municipality both 2004 and 2019. Benguarden holds the largest camel population of all the municipalities in Tunisia (ODS, 2018). This is linked with socio-cultural factors: the “Twazin” tribe, mainly located in the Medenine governorate (Benguarden municipality), has historically raised camels (Moslam and Megdiche, 1989). In addition, camel farming is supported by higher consumption and demand of camel meat in southern regions (Moslah et al., 2004; Trabelsi, 2016).

Limitations

Survey-based results have limitations that should be considered. Collecting accurate on-farm data from face-to-face questionnaires applied to smallholder farmers in developing countries is challenging. Farmers do not record any animal or farm performance data and, therefore, aspects related to animal productivity, feed intake or feed production could not be analysed. Hence, we should acknowledge that the economic data is based on farmers’ estimations, not on accurate accounting. In addition, few official data are available on the socio-economic and environmental factors at the municipality level (where our study focuses on). Therefore, we cannot establish the causal relations between socio-economic and environmental drivers, as other studies do (e.g. Brown et al., 2019; Caron and Hubert, 2000; Muñoz-Ulecia et al., 2021). For these reasons, we decided to limit our discussion to general aspects, for which we point out plausible explanations for the observed changes.

The above-mentioned limitations are common in developing countries and might be one of the reasons why studies of temporal dynamics are scarce in many world regions. This does not limit the interest of our study, which offers relevant information about the changes taking place in poorly known farming systems.

Implications for the future of livestock farms in arid rangelands

Two main implications for the future of livestock farms in arid rangelands derive from our study. Firstly, feed supplementation has become widespread, and additional feed resources (produced on or off farm) will very likely drive the future development of livestock farms in El Ouara and other arid rangelands elsewhere. Feed supplementation might allow herd size, animal productivity and farm profitability to increase, which is particularly key in a climate change context, where reduced primary production in rangelands is expected (Godde et al., 2019). However, this very much depends on feed production costs and market prices. Intensification of feed management makes farms more susceptible to external markets and commodity prices, which will be a key issue for farm sustainability and resilience in developing countries (e.g., Lorent et al., 2009; Cortner et al., 2019) and elsewhere. Moreover, increasing herd sizes may bring about further rangeland overexploitation, which has been observed in different areas of the Maghreb (Bechchari et al., 2014; Bencherif, 2018). The optimum balance between sustainable use of rangelands and of additional feed resources will also depend on herd structure, management, and location, according to ecological conditions. Field studies are needed to determine the stocking rate that can allow natural rangeland regeneration.

Secondly, diversification of livestock species appears to be a promising strategy. Specifically, adaptation capacity to harsh environments can make camels crucial in the climate change context of arid regions. However, the introduction of camels on small ruminant farms poses many challenges because it requires expensive upfront investments and knowledge (Volpato and King, 2019). The camel sector is still weak and disorganised, and the valorisation of camel products (milk, meat) is still below its potential, despite some improvements observed in recent years (Faye, 2013; Jemli et al., 2018).

Finally, even if farms have evolved during the study period in response to changing socio-economic conditions, their current situation (i.e., old farmers, decreasing household size and declining farm profits) remains fragile and their long-term viability is uncertain.

Ethics approval

Not applicable.

Data and model availability statement

None of the data were deposited in an official repository. The data that support the findings of this study are available upon reasonable request to the corresponding author.

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Declaration of interests

None.

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Tables

Table 1

Pastoral livestock farm variables considered in the analysis, their nature, description, average values, and SD across years.

Category	Variable ([1]Cont./Cat.)	Description	2004	2019
			Mean ± SD	Mean ± SD
Farm structure				
	Olive tree area (Cont.)	Farm area used for olive trees (ha).	4.5^{a} ± 6.2	5.8^{b} ± 13.4
	Cereal area (Cont.)	Farm area used for cereal crops (ha).	0.8^{A} ± 2.6	2.3^{B} ± 3.2
	Herd LU (Cont.)	Total livestock units (incl. sheep, goat and camels). Livestock Units (LU) coefficients were 1 for camels and 0.15 for sheep and goats.	41.0 ± 41.5	58.1 ± 67.1
	Camel LU (Cont.)	Number of LU of camels.	17.4^{A} ± 30.4	16.1^{B} ± 36.4
	Sheep LU (Cont.)	Number of LU of sheep.	18.4 ± 19.8	34.7 ± 40.8
	Goat LU (Cont.)	Number of LU of goats.	5.2 ± 5.4	7.3 ± 10.3
	Sheep LU/Herd LU (Cont.)	LU of sheep per total herd LU (%).	54.8^{A} ± 27.6	68.1^{B} ± 29.5
	Tractor ownership (Cat.)	Tractor ownership (yes/no).	23.8%	23.8%
	Wells ownership (Cat.)	Wells ownership (yes/no).	20.5%	21.9%
	Car's ownership (Cat.)	Car's ownership (yes/no).	68.5%	84.9%
	Tank ownership (Cat.)	Tank ownership (yes/no).	23.3%	19.2%
Farm management and labour				
	WU hired/LU (Cont.)	Non-family work units hired per total livestock units. A work unit (WU) is equivalent to the work of one person, full time, for one year.	0.0 ± 0.0	0.0 ± 0.0
	Rangeland's period (Cont.)	Number of months per year that the herd grazes in rangelands.	10.0^{a} ± 2.5	8.7^{b} ± 3.6
	Transhumance period (Cont.)	Number of months per year that the herd is in transhumance.	3.6^{A} ± 2.6	2.1^{B} ± 1.8
	Second activity	Farmer has other economic activity than farming (yes/no).	28.8%	50.7%
Farm economic performance				
	Feeding cost/LU (Cont.)	Sum of costs of grains, concentrates, forages and straw use per year per livestock unit (in Tunisian Dinar-TD).	172.7^{A} ± 113.5	250.1^{B} ± 86.5
	Guarding cost/LU (Cont.)	Costs of non-family hired labour for herd guarding per LU.	79.3^{A} ± 102.5	148.4^{B} ± 124.2
	Transport cost/LU (Cont.)	Costs of hired transport to transport feed to the herd when it is in the rangelands and to move animals to	24.2^{A} ± 34.7	11.1^{B} ± 28.6

	rangelands and markets per LU.		
Water cost/LU (Cont.)	Costs of purchased water and the transport cost (when the well is far from the farm) per LU.	8.4^{a} ± 15.2	6.6^{b} ± 13.0
Total output (Cont.)	Total income obtained from livestock products in TD.	15391.7 ± 16465.4	26898.7 ± 27187.7
GM (Cont.)	Gross margin. It is total output minus livestock costs (feeding, guarding, transport, water and veterinary) in TD.	5012.7 ± 8226.7	5069.5 ± 9772.8
GM/LU (Cont.)	Gross margin per livestock unit in TD.	119.2^{a} ± 149.8	57.6^{b} ± 153.4

Abbreviations: LU= Livestock Unit; WU=: Work Unit; GM= Gross Margin; TD= Tunisian Dinar (local currency).

[1] Continuous (Cont.) variables are described for each year with average values and SD. Categorical (Cat.) variables are described with the percentage of the sample answering "yes" each year. The same farmers were interviewed in 2004 and 2019 (n=73).

^{A,B} refer to significant differences (P<0.01) between different change pathways during the study period according to ANOVA, Kruskal-Wallis, or χ^2tests depending on the type of variables; ^{a,b} depict trends (P<0.05).

All the economic figures expressed as 2019 constant Tunisian Dinar (1TD=€0.34, 2019).

Table 2

Description of pastoral livestock farm typologies, average values, and SD across farm typologies for each year.

Category	Variable	2004			2019		
		Camel farms (n=18)	Large sheep farms (n=17)	Small sheep-farms (n=38)	Camel farms (n=11)	Large sheep farms (n=36)	Small sheep farms (n=26)
Farm structure							
	Sheep LU (LU)	21.1^{AB} ±34.8	33.5^{A} ±25.1	10.4^{B} ±9.4	55.3^{AB} ±67.0	48.5^{A} ± 5.8	6.8^{B} ± 22.0
	Goat LU (LU)	3.7^{A} ±12.2	9.8^{B} ±4.4	3.8^{A} ±3.9	8.1^{AB} ±9.9	11.0^{A} ±2.8	2.0^{B} ±6.7
	Tractor ownership[1] (% of farmers)	27.8	23.5	21.0	54.6^{a}	22.2^{ab}	11.5^{b}
	Cars ownership[1] (% of farmers)	88.9^{a}	76.5^{ab}	55.3^{b}	100.0	83.3	80.8
	Tank ownership[1] (% of farmers)	29.4	33.3	15.8	45.5	16.7	11.5
	Wells ownership[1] (% of farmers)	17.7	22.2	21.1	27.3	16.7	26.9
Farm management and labour (% of farmers)							
	Second Activity[1]	11.8	38.9	34.2	63.6	47.2	57.7
Farm economic performance (TD)							
	Total output	24812.1^{A} ±26371.7	22705.2^{A} ±20107.6	7657.6^{B} ±21478.6	50182.7^{A} ±29438.7	36095.3^{A} ±23668.3	4314.0^{B} ±7531.0
	GM	7905.5	6571.5	2945.0	8410.0^{AB}	7101.4^{A}	842.7^{B}

		±10085.0	±9681.4	±8008.2	± 11400.4	± 10354.1	±3749.7
	GM/LU	99.1 ±104.7	94.8 ±177.7	139.0 ±164.6	36.4 ±118.3	69.5 ±161.6	50.2 ±154.8

Abbreviations: LU= Livestock Unit; GM= gross margin; TD= Tunisian Dinar (local currency).
[1]Categorical variables are described with the percentage of the sample answering “yes” each year.
[A,B] refer to significant differences (P<0.01) between different change pathways during the study period according to ANOVA, Kruskal-Wallis, or χ^2tests depending on the type of variables; [a,b] depict trends (P<0.05).
All the economic figures expressed as 2019 constant Tunisian Dinar (1TD=€0.34, 2019).

846 **Table 3**

847 Trends of changes observed in pastoral livestock farm pathways. Average values and 848 SD of the value of each variable in 2019, minus the average of this variable in the two 849 years across pathways.

Category	Variable	Sheep intensification pathway (n=15)	Non-sheep extensification pathway (n=15)	Sheep rangelands pathway (n=19)	Stable herd structure pathway (n=24)
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Farm structure					
	Sheep LU (LU)	10.7^{ab} ±16.9	20.2^{a}±27.0	5.4^{ab} ±14.8	1.2^{b}±15.7
	Goat LU (LU)	0.0^{a}±2.7	4.3^{B}±6.1	2.1^{AB} ±7.8	-1.1^{A}±2.8
	Tractor ownership[1] (% of farmers)	33.3	33.3	47.4	29.2
	Cars ownership[1] (% of farmers)	40.0	46.7	36.8	33.3
	Tank ownership[1] (% of farmers)	40.0	33.3	26.3	33.3
	Wells ownership[1] (% of farmers)	46.7	26.7	31.6	25.0
Farm management and labour (% of farmers)					
	Second Activity[1]	80.0	66.7	36.8	25.0
Farm economic performance (TD)					

Total output	6468.4 ± 12534.3	14613.2 ± 16875.5	2463.0 ± 10571.1	2374.3 ± 9650.6
GM	-604.1^{ab} ±3709.7	2694.8^{a} ±7059.1	-3001.3^{b} ±4410.6	1155.7^{a} ±5278.9
GM/LU	-36.9^{ab} ±101.0	-70.9^{a}±120.6	-59.2^{A} ±63.6	20.7^{B} ±90.6

Abbreviations: LU= Livestock Unit; GM= gross margin; TD= Tunisian Dinar (local currency).
[1]Categorical variables are expressed as the percentage of farms that changed.
^{A,B} refer to significant differences ($P<0.01$) between different change pathways during the study period according to ANOVA, Kruskal-Wallis, or χ^2tests depending on the type of variables; ^{a,b} depict trends ($P<0.05$).
All the economic figures are expressed in 2019 constant Tunisian Dinar (1TD=€0.34, 2019).

List of figure captions

Fig. 1. Changes observed in the variables used to define pastoral livestock farm typologies across years. Boxplots represent the median (solid horizontal lines), the first and third quartiles (contained in boxes) and outliers (black points). Different letters refer to significant differences between farm typologies per year according to ANOVA.
Abbreviations: LU= Livestock Unit; WU= work unit; TD= Tunisian Dinar (local currency).

Fig. 2. Shifting among pastoral livestock farm typologies between 2004 and 2019. The width of the grey linking lines is proportional to the number of farms.

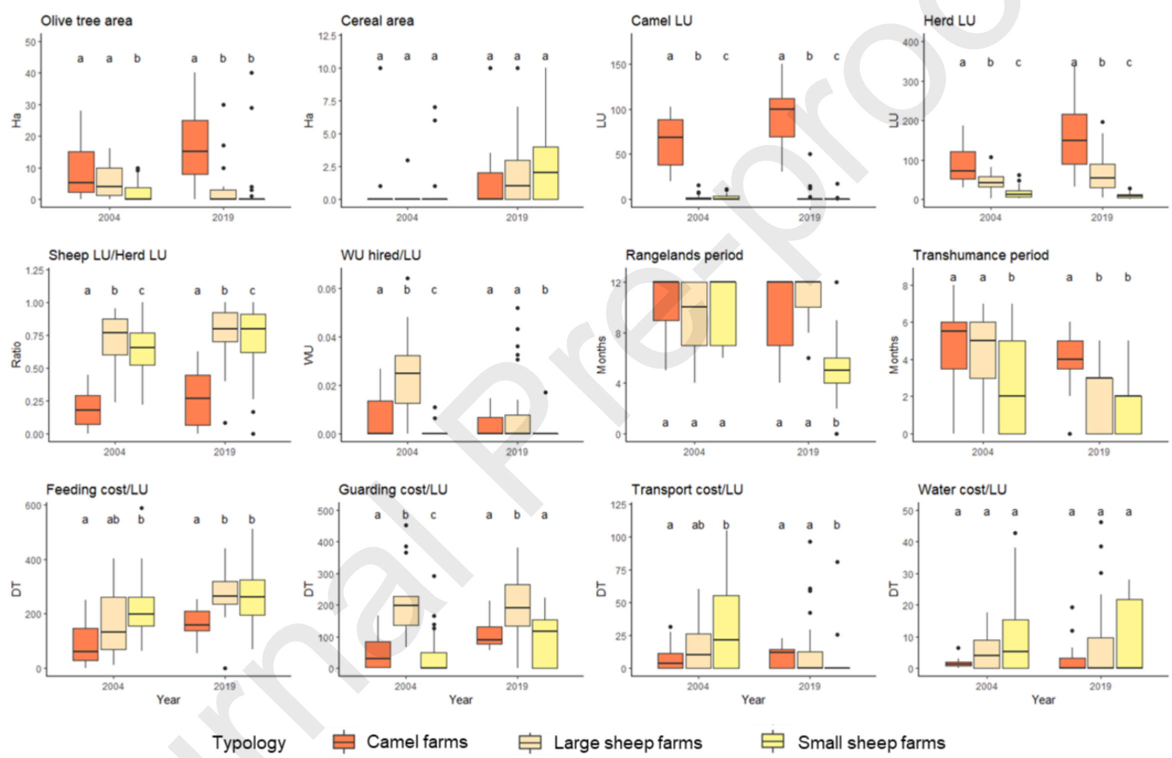
Fig. 3. Trends of change observed in the variables defining pastoral livestock farm change pathways during the study period. Boxplots represent the median (solid horizontal lines), the first and third quartiles (contained in boxes) and outliers (black points) of the distribution of the variables. Different letters refer to significant differences between pathways for each variable according to ANOVA.
Abbreviations: LU= Livestock Unit; WU= work unit; TD= Tunisian Dinar (local currency)

Fig. 4. Geographical distribution of pastoral livestock farms according to their typologies in 2004 and 2019 and their change pathways. For each municipality, pie charts represent the proportion of farms in each typology across years and in each pathway.

Highlights

- Off-farm feed supplementation has become widespread in arid rangelands.

- Farms in harsh ecological conditions areas increased herd size and rangeland use.
- Balancing rangelands use and off-farm feed is benefits can help farm continuity.
- Diversification of livestock species including camels constitutes a promising strategy.
- Long-term viability of pastoral farming in arid rangelands is uncertain.



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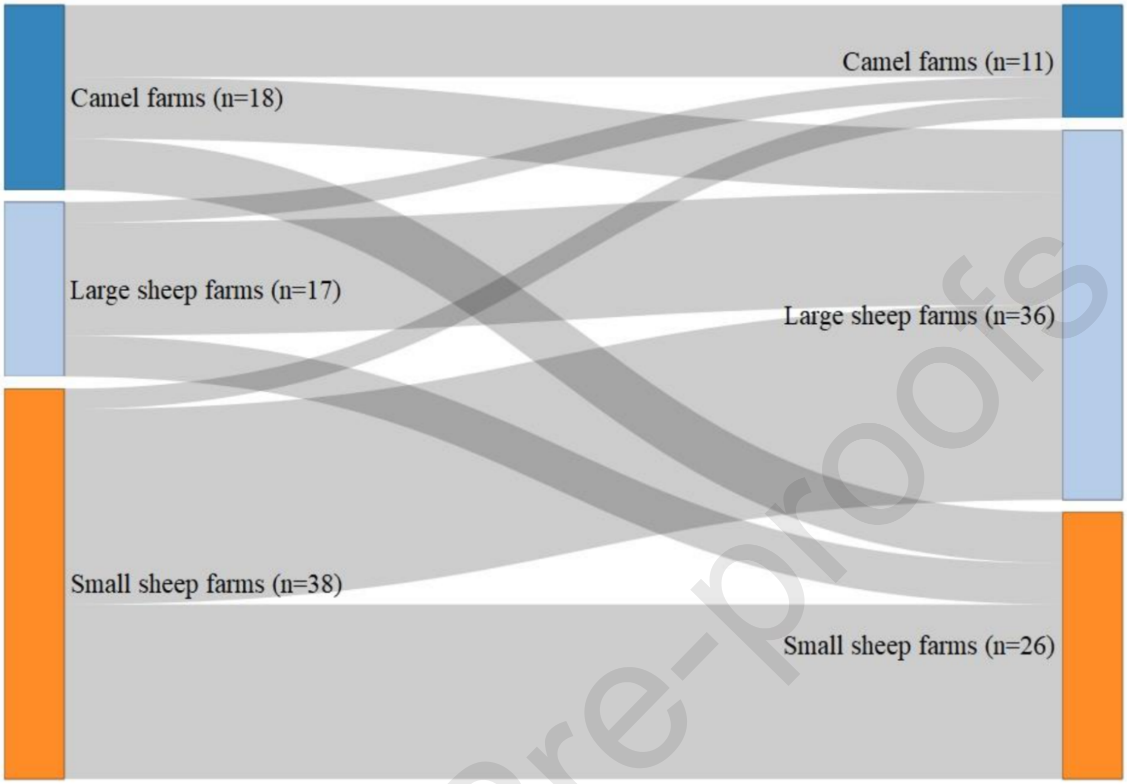
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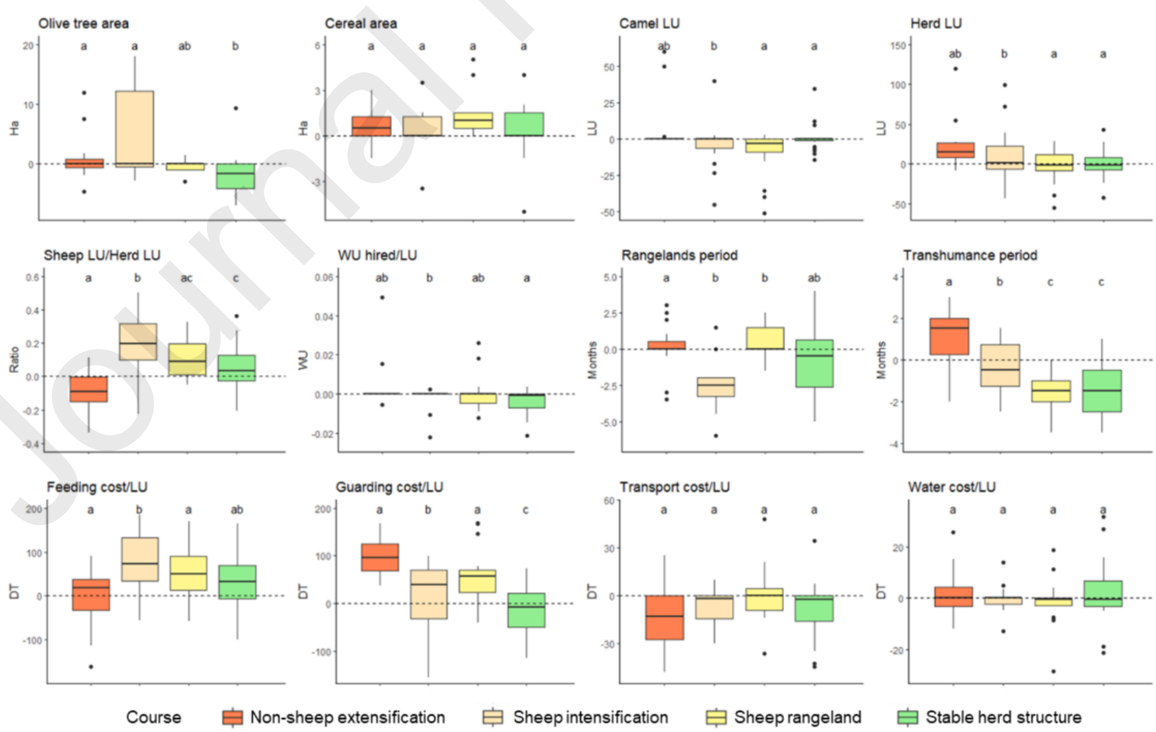
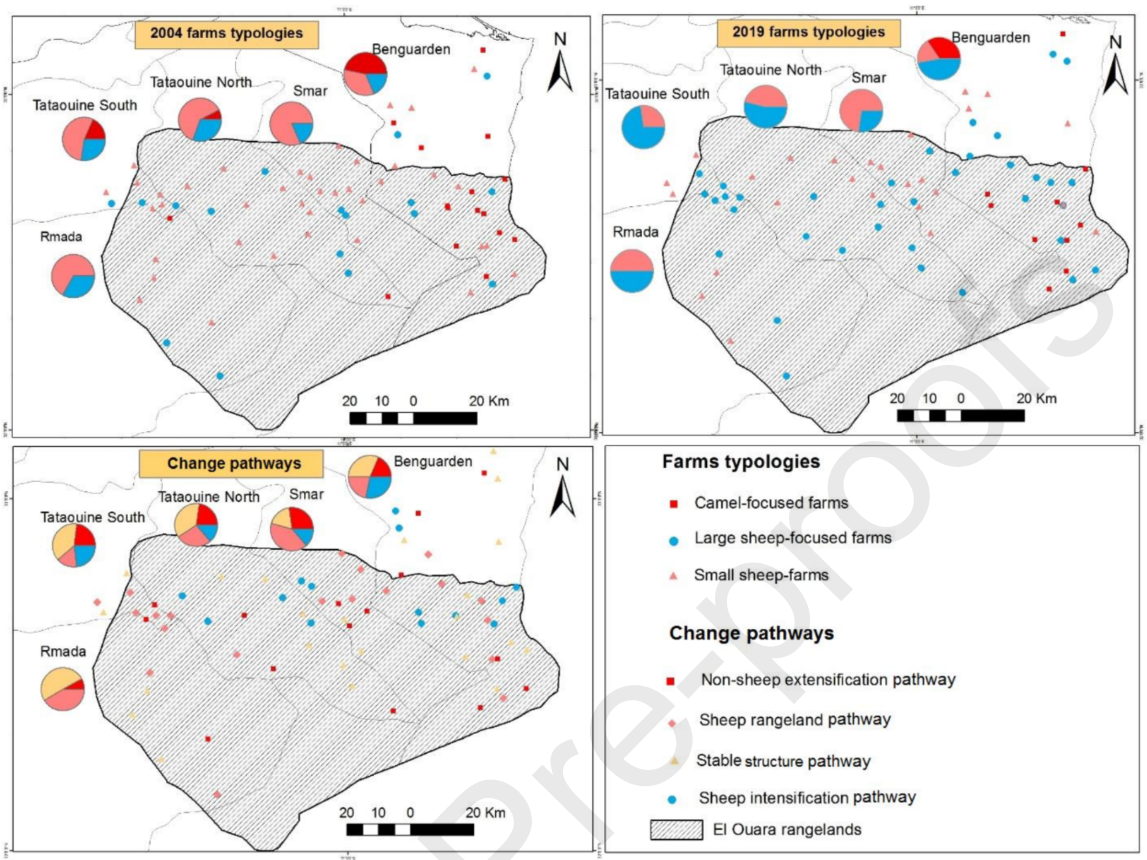
Large sheep farms (n=17)
Small sheep farms (n=38)
Camel farms (n=11)
Large sheep farms (n=36)
Small sheep farms (n=26)


Olive tree area
Cereal area
Camel LU
Herd LU
Sheep LU/Herd LU
WU hired/LU
Rangelands period
Transhumance period
Feeding cost/LU
Guarding cost/LU
Transport cost/LU
Water cost/LU
Course
Non-sheep extensification
Sheep intensification
Sheep rangeland
Stable herd structure


2004 farms typologies
Benguarden
Tataouine North
Smar
Tataouine South
Rmada
N
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2019 farms typologies
Benguarden
Tataouine North
Smar
Tataouine South
Rmada
N
20 10 0 20 Km
Change pathways
Benguarden
Tataouine North
Smar
Tataouine South
Rmada
N
20 10 0 20 Km
Farms typologies
Camel-focused farms
Large sheep-focused farms
Small sheep-farms
Change pathways
Non-sheep extensification pathway
Sheep rangeland pathway
Stable structure pathway
Sheep intensification pathway
El Ouara rangelands

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