Revival of traditional best practices for rangeland restoration under climate change in the dry areas

A case study from Southern Tunisia

Received 22 February 2018
Revised 14 January 2019
Accepted 24 April 2019

Azaiez Ouled Belgacem
International Center for Agricultural Research in the Dry Areas, Dubai, United Arab Emirates

Farah Ben Salem
Institut des Regions Arides, Medenine, Tunisia

Mouldi Gamoun
International Center for Agricultural Research in the Dry Areas, Tunis, Tunisia

Roukaya Chibani
Institut des Regions Arides, Medenine, Tunisia, and

Mounir Louhaichi
International Center for Agricultural Research in the Dry Areas, Amman, Jordan

Abstract

Purpose – The purpose of this paper is to illustrate the benefits of reintroducing traditional grazing systems practices for improving arid rangelands. Grazing is the most extensive land use in southern Tunisia, but the rangelands have suffered many decades of severe degradation due to profound socioeconomic changes and the emergence of an agro-pastoral society in place of the former pastoral one. Traditional grazing systems (*gdel* and herd mobility), which had historically allowed for grazing deferment and control of grazing livestock were abandoned. Yet grazing management strategies are important tools to sustain integrated livestock rangeland production systems in dry areas in the face of ongoing climate change and human pressure.

Design/methodology/approach – This study assesses the revival of traditional best practices of rangeland resting in a representative community. Total plant cover, species composition, flora richness and

This work was supported by the International Center for Agricultural research in the Dry Areas (ICARDA), the OPEC Fund for International Development (OFID) and the CGIAR Research Program on Livestock (CRP Livestock). The authors thank several anonymous reviewers for their critical review. The opinions expressed here belong to the authors, and do not necessarily reflect those of CRP Livestock, ICARDA, OFID or CGIAR.

International Journal of Climate Change Strategies and Management
Emerald Publishing Limited
1756-8692
DOI 10.1108/IJCCSM-02-2018-0019

range production were determined in six rangeland sites subjected respectively to one, two and three years of rest; one and two years of light grazing after rest; and free grazing (control).

Findings – Results showed that dry rangelands keep their resilience to the negative effects of climate change once human pressure is controlled. A maximum of two years of rest is enough to sustainably manage the rangelands in southern Tunisia, as this protection showed considerable and positive effects on the parameters scored.

Originality/value – The revival of the traditional best practices under new arrangements adapted to current biophysical and socioeconomic conditions would be an excellent tool to mitigate the negative effects of frequent droughts and reduce the animal feed costs that poor farmers face.

Keywords Arid rangelands, Plant cover, Production, Rest duration, Tunisia

Paper type Research paper

1. Introduction

Rangelands are the dominant land use in southern Tunisia under arid and desert climates. These lands, however, have suffered decades of severe degradation due to profound socioeconomic changes, expressed in the emergence of agro-pastoral societies in place of the former pastoral ones (Hudson *et al.*, 2014). Traditional grazing systems of transhumance and nomadism, which had historically allowed for grazing deferment and control of grazing livestock, have been abandoned (Ouled Belgacem *et al.*, 2008). Almost all rangelands in arid areas of Tunisia (with a mean annual rainfall of less than 200 mm) are now grazed continuously without any restriction on stocking rate. Such changes have led to rangeland deterioration. The degradation of soils and the loss of perennial palatable species, mainly grasses, are two direct results of the increasing anthropic pressure on arid rangelands in Tunisia (Ouled Belgacem *et al.*, 2006a, 2006b; Tarhouni *et al.*, 2007a). The negative effect of overgrazing, the main anthropic factor, is in the excessive removal of the living parts of high range value species, which may lead to their extinction.

Overgrazing is even more harmful when coupled with the climatic aridity effect. In southern Tunisia, drought has become more frequent (Ben Salem *et al.*, 2007). Such drought is different from the cyclic drought phenomena known in the region, and could result from global climatic warming. It has disturbed the normal functioning of ecosystems and exacerbated the impact of human activities. Studies on the quantification of the drought effect on plant cover dynamics are, however, rare (De-Pauw, 2002; Ouled Belgacem *et al.*, 2008; Ouled Belgacem and Louhaichi, 2013).

Covered, essentially, by sparse steppic plant communities, the rangelands of Chenini community, located in Southern Tunisia, are also the dominant land use and cover about 40,000 ha (53 per cent of the community area). They are subjected to continuous heavy grazing. In addition, the balance of ecosystems has been disturbed, during the past decades, by the frequency and severity of droughts. The unpredictability of rains and dry year successions constitute the most prominent features of the climatic aridity of the region (Ouled Belgacem and Louhaichi, 2013). Our knowledge of this phenomenon, its predictability, its intensity and its effects is still incomplete.

In facing degradation and the negative effects of drought on rangelands, local people in arid areas of Tunisia have used the rest technique locally called *gdel* as a common practice for many centuries. In recent years, this practice has been newly established in response to widely fluctuating rainfall and declining productivity in communal rangelands. Such an adaptation of traditional grazing practices provides a balance between the natural and agricultural services that the rangeland ecosystem provides (Mu *et al.*, 2016). *Gdel* is based on the principle of leaving the rangeland in rest (without grazing) to reconstitute its plant cover. Applied in several types of natural environments (for rangeland improvement, dune stabilization, national parks, etc.,), this technique allowed good results in arid and even desert areas of Tunisia (Ouled Belgacem *et al.*, 2008). However, the efficiency of the technique varies according to several factors, which determine the potential of regeneration of the treated area, including rainfall, soil nature and level of degradation reached and period of validity of the technique.

This study was implemented in the arid rangelands of southern Tunisia, aiming at assessing the impact of resting on plant cover dynamics and productivity in relation to the vegetation type and duration of implementing this technique, to develop suitable management tools for these rangelands to cope with climate change and improve the resilience of community livelihoods.

2. Materials and methods

2.1 Study area

The study was carried out in the Chenini community rangelands of the governorate of Tataouine in south-eastern Tunisia. This area is characterized by an arid Mediterranean bio-climate with a moderate winter. Rainfall is low and sporadic; the mean annual is estimated to be around 100 mm. Temperatures are generally cold in winter and hot in summer with a mean annual of about 20.1°C. The water balance is greatly affected by the low, dense soil cover and exposure to winds. Potential evapotranspiration is estimated around 1,700 mm/year on average (Tataouine weather station, 1949-2000 period). Soils are mostly raw mineral on hard rocks, coarse colluvium or calcareous and gypsum crusts. Of the community's approximately 40,000 ha of rangelands, about 16,000 ha are private and 24,000 ha are communal land tenure and subjected to overgrazing.

2.2 Experimental sites

The first field visits were carried out in March 2017 to identify and classify the sites subjected to resting according to the land tenure system and age of implementation of the technique. During these visits, the main plant communities of the protected rangeland, and the open grazing sites to be used as a control, were characterized and the existing plant communities based on the dominant species were identified and delimited. A total of six sites covering 7,600 ha, including the freely grazed site considered as control, were retained for detailed monitoring and assessment. The natural vegetation of the study area is mostly dominated by degraded steppes of *Stipa tenacissima* (Escadafal, 1989) (Table I).

2.3 Measurements and data collection

Measurements were carried out in March and April 2017 for all sites. To resolve the problem of replications both in space and in time and given the importance of the area of the study sites both within the rested sites and the open grazing control, a total of 28 experimental

Table I. Management practices applied in the studied sites of the Chenini community, Southern Tunisia

Site no.	Area (ha)	Management mode
1	180	1 year rest
2	100	2 years rest
3	100	3 years rest
4	180	1st year grazing after 3 years rest
5	40	2nd year grazing after 3 years rest
6	7,000	Freely grazed (control)

plots within the different representative plant communities were established for collecting data on plant cover attributes and biomass production.

Within each experimental plot, three random transects of 50 m long each were established in the different representative plant communities of the target rangeland site and used to determine plant cover parameters according to the points-quadrats method described by Daget and Poissonet (1971). This design permitted an appreciation of the potential of regeneration and the persistence of plant species by monitoring the evolution of several descriptors (global plant cover, specific frequencies, flora richness and plant density). The state of the soil surface (wind veil, crust, stones and litter) was also studied to monitor and assess changes of soil structure. Both in the rested area and its respective control, biomass production permitting the estimation of the carrying capacity was determined.

In each sampling plot, annual plants densities were measured by counting species individuals inside five randomly established quadrats of 1 m^2 each. However, the density of perennial plants was measured by counting the tufts of each species within five quadrats of 20 m^2 each. Species richness was determined by counting all perennial and annual species within the experimental plots.

Range biomass production was estimated by harvesting the vegetation inside five quadrats of 1 m^2 each for annual species, and by clipping half of the potentially grazeable biomass (according to the rule take half and leave half) of ten tufts of each species for perennial vegetation. The total biomass of perennial species was estimated by multiplying the mean available biomass per individual by the density of the species. The clipped plants were weighed immediately, after which samples were oven-dried for 48 h at 70°C in the laboratory for estimation of dry matter content (DM).

The method used for determining the carrying capacity takes into account the plant species cover and its palatability factor (PF) or acceptability index according to the following formula (INRA, 1978):

$$P = 1.5\sum_{i=1}^{n} SC_i \times PF_i \times \mathrm{TPC}/100$$

With

P = total rangeland production in forage units (FU)/ha/year;
SC_i = species i cover per cent;
PF_i = palatability factor of species i; and
TPC = total plant cover per cent.

The carrying capacity is determined by the ration of P and the annual needs of a sheep unit, which is estimated at 400 FU/year.

3. Results and discussion

3.1 Rainfall quantity and distribution during the year of the experiment

The amount of rainfall recorded in Tataouine, the nearest weather station to the study area (at 15 km), during the biological year 2016-2017 was 153 mm (Table II). This can be considered exceptionally high, as it significantly exceeded the average of 100 mm. Furthermore, the rainfall was well distributed during the season with a good fall amount (30 mm), considered by many authors as very efficient for seedlings emergence and vegetation growth. Table II shows that 51 per cent of the total rainfall occurred in autumn

Month	September	October	November	December	January	February	March	April	May	June	July	August	Total
Rainfall (mm)	30	8	0	40	0	0	0	75	0	0	0	0	153

Source: Weather station of Tataouine

Table II. Amount and distribution of rainfall during the season 2016-2017 in Tataouine (15 km from the study area) and winter and 49 per cent in spring (April). The latter is very beneficial for seed production of C_3 plants and for growth of C_4 plants, particularly chenopodiaceous species.

Previous studies (Miranda *et al.*, 2009; Mathias and Chesson, 2012) have shown that precipitation may affect seed germination, seedling growth and survival and phenology, and thereby, alter the productivity and species richness of annuals in many arid and semiarid ecosystems. Both observational and experimental studies suggest that precipitation may also impact species richness of annuals in dry areas.

3.2 Total plant cover and soil surface conditions

The results of plant cover and soil surface conditions in the studied rangeland sites subjected to different restoration and controlled management modes as compared to the freely grazed sites are presented in Figure 1. The effects of the duration of the rest technique were significant on total plant cover ($P = 0.0253$) and highly significant on bare soil percentage ($P = 0.0002$), but not significant on litter ($P = 0.1591$) or stones ($P = 0.2047$). The highest total plant cover was recorded at the site subject to two years' rest (63 per cent), followed by the first-year grazing (37 per cent). The freely grazed site (control) had the lowest plant cover rate (14.6 per cent) of all the sites. Regarding the other elements of the soil surface, the bare soil was, as expected, very high at the grazed site (78 per cent), expressing a higher threat of desertification.

The variations in perennial and annual plants covers in relation to the management mode are presented in Figure 2. Perennials are the most dominant in all treatments including the control, but showed the highest cover in the two-year rested site. The low presence of annuals in the control was also due to early grazing by community herds, as animals and particularly small ruminants prefer to graze on fresher annual species before perennials.

These results corroborate those achieved in other ecologically comparable zones (Gallacher and Hill, 2006; Ouled Belgacem *et al.*, 2006a) that indicate a progressive increase of total plant cover in protected areas, compared to overgrazed ones, which are characterized by bare soil extension. In fact, protection permits soil fixation and the improvement of its structure because of the abundance of litter resulting from trapped dead plant parts (Tarhouni *et al.*, 2007a, 2007b). Even if there was no significant effect of the rest technique on the litter abundance in the present study, dead parts of plants, either from the protected site or outside, are transported by wind, runoff or collected by a good protected plant cover and deposited in new locations. The significant increase of perennial cover in the protected

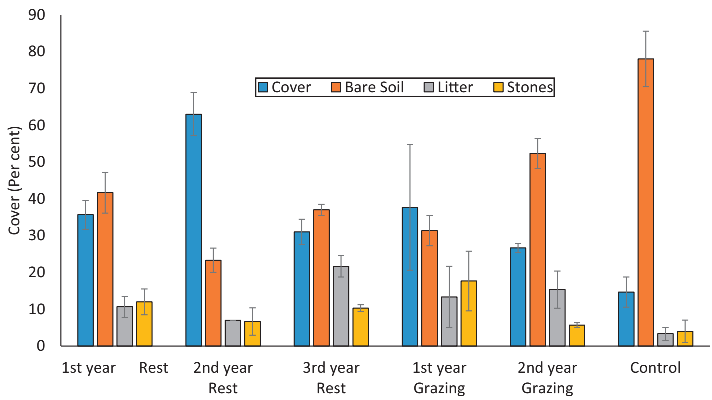

Figure 1.
Variation of total plant cover and other soil surface states in relation to the applied restoration and management modes in the studied rangelands of Chenini community

rangeland sites may be attributed to the improvement of organic matter content in the soil, and thus, the development of the vigor of adult individuals and the good establishment of new seedlings (Ouled Belgacem *et al.*, 2006b; Tarhouni *et al.*, 2007b). The effect of protection on the annual cover is not significant as the abundance of annuals is more dependent on rainfall availability (Westbrooke *et al.*, 2005).

The remarkable increase in bare soil, mostly composed of wind veil, in the freely grazed areas explains the high degree of sensitivity of the whole site to desertification. Under continuous grazing, livestock trampling affects the soil surface and causes the decline of seed retention in the soil (Bertiller and Ares, 2011). Some studies indicated that heavy grazing leads to an increased number of non-palatable plant species, which prevents the establishment of palatable plant species and consequently reduces the palatable species density (Bestelmeyer *et al.*, 2003). Likewise, the fixation of wind veil will lead to the establishment of *psammophile* species such as *Calligonum comosum*, *Rhanterium suaveolens, Plantago albicans* and mainly annual species. Stones, indicators of water erosion, cover a very small area.

3.3 Plant density

The data presented in Table III demonstrates the great variability in plant density according to the applied restoration and management mode and the original condition of the site before applying the resting technique. The highest value (4.43 plants/m^2) was recorded at the site subjected to two years of controlled grazing. This confirms the common belief that adequate grazing can have a beneficial effect over the duration of the vegetative period of certain species, making the alternation of short periods of grazing with periods of vegetative rest generally more favorable than strict or long term protection (Ouled Belgacem *et al.*, 2008). The next highest value was in the site subjected to only one year of rest (2.84 plants/m^2).

The perennial species and their variability as shown in Table III can be summarized as follows:

- species such as *Gymnocarpos decander*, *Salsola vermiculata*, *Stipa lagascae* and *Artemisia herba-alba* recorded higher densities in the protected plots than in the grazed plot. These species' dynamics were supported by protection, and their presence was not recorded in the plots established within sites subjected to other treatments;
- species such as *Argyrolobium uniflorum* and *Helianthemum lippii* appeared notably in the sites subjected to either one year of rest or controlled grazing. It is well-known that these species are characterized by their high dynamics and regeneration under light

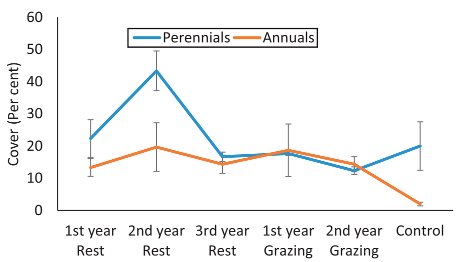

Figure 2. Evolution of percentage cover of perennial and annual species in relation to the applied restoration and management modes in the studied rangelands of Chenini community

Table III. Variation of plant density (individuals.m^{-2}) in relation to the applied restoration and management mode used in the private rangelands of Chenini community

Species	1st year rest	2nd year rest	3rd year rest	1st year grazing	2nd year grazing	Control
Anabasis articulata	0	0	0.01 ± 0.02	0.08 ± 0.04	0.01 ± 0.02	0
Anthyllis henoniana	0.14 ± 0.11	0	0.12 ± 0.25	0	0	0.23 ± 0.11
Argyrolobium uniflorum	0.17 ± 0.09	0	0.4 ± 0.47	0.02 ± 0.03	2.23 ± 1.21	0.03 ± 0.06
Artemisia herba alba	0	0.17 ± 0.08	0.08 ± 0.08	0	0	0
Atractylis serratuloides	0.64 ± 0.26	0.01 ± 0.02	0.22 ± 0.12	0	0.28 ± 0.20	0.03 ± 0.02
Gymnocarpos decander	0.5 ± 0.27	0.07 ± 0.10	0.5 ± 0.61	0.2 ± 0.13	0.18 ± 0.10	0.3 ± 0.24
Haloxylon schmittianum	0.04 ± 0.06	0	0	0	0.2 ± 0.05	0.29 ± 0.13
Haloxylon scoparium	0.17 ± 0.11	0	0	0	0	0
Helianthemum kahiricum	0.86 ± 0.52	0	0	1.87 ± 0.48	0.7 ± 0.47	2.7 ± 0.89
Helianthemum lippii	0	0	0.25 ± 0.19	0	0.78 ± 0.77	0.11 ± 0.08
Linaria aegyptiaca	0	0.01 ± 0.008	0	0	0	0
Plantago albicans	0	0	0	0	0	15.33 ± 3.89
Reaumeria vermiculata	0	1.22 ± 0.88	0.11 ± 0.09	0	0	0
Rhanterium suaveolens	0.05 ± 0.08	0.04 ± 0.08	0	0	0	0
Salsola vermiculata	0	0	0	0.02 ± 0.04	0.03 ± 0.02	0.03 ± 0.02
Stipa tenacissima	0	0.2 ± 0.12	0	0	0	0
Stipa lagascae	0.28 ± 0.43	0	0.05 ± 0.10	0	0	0
Teucrium polium	0.01 ± 0.02	0	0.18 ± 0.11	0	0	0
Traganum nudatum	0	0	0.18 ± 1.31	0	0	0
Total Perennials	2.86 ± 1.42	1.72 ± 0.85	2.13 ± 2.01	2.19 ± 2.10	4.43 ± 3.12	19.05 ± 8.42
Anacyclis clavatus	0.5 ± 0.36	0	7.37 ± 4.32	0	0	0
Asphodelus tenuifolius	0.4 ± 0.21	0	1 ± 1.68	0.5 ± 0.86	3.5 ± 1.80	0.8 ± 0.67
Asteriscus pigamaeus	0	0	0	0.6 ± 0.34	0.83 ± 1.04	0
Astragalus corrigatus	0	0	0	0.2 ± 0.14	1.16 ± 1.02	0
Atractylis flava	0.4 ± 0.12	0	0	0.1 ± 0.22	0	0
Centaurea contracta	0	0	0	0.2 ± 0.44	0.16 ± 0.12	0
Cutandia dichotoma	0	0	15.25 ± 8.17	0	0.16 ± 0.10	0
Daucus syrticus	0	16.8 ± 9.47	28.37 ± 11.95	0	0	0
Echium humile	0.5 ± 0.34	0	2.87 ± 1.70	0	0	0
Euricaria pinnata	0	4.6 ± 3.43	0	0	0	0
Fagonia glutinosa	0.2 ± 0.08	0	0.75 ± 0.5	0.6 ± 0.32	0.16 ± 0.09	0
Hernaria fontanesii	0	0	0	0	1.33 ± 0.28	0.4 ± 0.65
Hippocrepis bicontorta	0	0	1.12 ± 1.60	0.1 ± 0.02	1.66 ± 2.02	0

(*continued*)

Table III.

Species	1st year rest	2nd year rest	3rd year rest	1st year grazing	2nd year grazing	Control
Hordeum murinum	0	0	1.37 ± 1.13	0	0	0
Ifloga spicata	0	0	0	0.7 ± 1.3	0	1 ± 2.23
Launaea residifolia	1.1 ± 0.6	0	9.25 ± 3.17	5.2 ± 4.04	2.33 ± 2.51	0
Lotus pisillus	0.8 ± 1.10	0	0	0	0.33 ± 0.57	0
Matthiola lengipetala	0.2 ± 0.06	6.4 ± 6.02	2.5 ± 1.08	0.2 ± 0.24	0.66 ± 1.15	0
Medicago minima	0	0	1.5 ± 1.28	0	0	0
Plantago ovata	0	0	13.5 ± 7.32	0.1 ± 0.08	1.76 ± 2.02	0
Savigna parviflora	0.2 ± 0.08	0	0	2.2 ± 1.81	0.33 ± 0.57	0.2 ± 0.27
Shismus barbatus	0	0	0	0	0	0.2 ± 0.27
Total annuals	4.30 ± 3.12	27.8 ± 16.2	84.87 ± 38.20	10.7 ± 6.41	14.43 ± 8.34	2.6 ± 1.88

grazing. According to Ouled Belgacem *et al.* (2013), the abundance of these species in the grazed area is probably because their germination is stimulated by grazing;

- species such as *Haloxylon schmittianum*, *Anthyllis henoniana* and *Atractylis serratuloides* seem to be indifferent to the management mode in term of their densities. These species also constitute indicators of desertification: sites invaded by *Haloxylon spp*. are generally characterized by an accumulation of moving sand while sites colonized by *Anthyllis henoniana* and *Atractylis serratuloides* are generally characterized by gypsum-bearing sierozems. Whatever the soil conditions, these species react rapidly to early rainfall even in small quantities. In this context, Ouled Belgacem and Louhaichi (2013) have shown that the low susceptibility or even invulnerability of *Haloxylon schmittianum* to projected climate change is mainly due to the low grazing pressure exerted on these species given their very low palatability and range value, and concluded that species with low range value and broad ecological niches were favored by the impacts of climate change and seemed to be able to survive under future environmental conditions of their adaptation range.
- *Stipa tenacissima*, which would be the key species of the plant communities in the studied sites, recorded very low density. This means that a rest period of three years is not sufficient in an arid zone for the species to appear in sites from which it has disappeared. In addition to human pressures on the species, it is known to be highly vulnerable to climate variability. Ben Mariem and Chaieb (2017) have emphasized a negative impact of climate change on *Stipa* ecosystems for the next 50 years, with a severe loss of suitable habitats.
- *Plantago albicans* was negatively affected by the protection and presented a higher density in the disturbed area (control). It is a very good pastoral species, which grows naturally in arid habitats. Its abundance is to be well expected following an exceptionally wet rainy season, as the amount of rainfall in one season greatly affects its growth. This very high density of the species seedlings does not in any way express a significant contribution to biomass or rangeland production. In all cases, this high density of *Plantago albicans* can be attributed to its high reproductive capacity, its ability to multiply vegetatively, its resistance to drought (Henchi *et al.*, 1986) and its seeming adaptability to frequent rejuvenation under the effects of grazing (Poissonet *et al.*, 1980). Moreover, Barbosa and García (2014) found that the presence of mucilage on *Plantago albicans* seeds can enhance germination in arid environments with both drought and salt stress.
- The density of annual plants varied greatly not only as a function of the annual precipitation distribution but also the degradation stage reached before applying the resting technique and controlled grazing. A value of 4.3 plants/m^2 was reached in the first year of rest, and this could rise as high as 84 plants/m^2 after three years of rest. However, this parameter showed a very high variability depending on soil conditions, disturbance stage and rainfall consistency. With the exceptions of *Daucus syrticus* and *Echium humile*, there did not seem to be a tendency for particular annual species to develop the following protection. It is important to note, however, that perennial plants in arid areas can help the annual plant by creating a suitable microclimate and soil environment and by trapping seeds (Su *et al.*, 2004; Rathore *et al.*, 2015).

3.4 Species richness

Variation in species richness and composition across rangeland management of sampled sites are illustrated in Table IV. A total of 49 species were identified in the study areas.

Perennials species	1st year rest	2nd year rest	3rd year rest	1st year grazing	2nd year grazing	Control
Anabasis articulata	−	+	+	+	+	−
Anarrhinum brevifolium	−	−	−	+	−	−
Anthylis henoniana	+	+	+	+	+	+
Argyrolobium uniflorum	+	−	+	+	+	+
Artemisia herba alba	−	+	+	−	−	−
Atractylis serratuloides	+	+	+	−	+	+
Gymnocapos decander	+	+	+	+	+	+
Haloxylon schimittianum	+	−	+	−	+	+
Haloxylona scoparium	+	−	−	−		−
Heliantemun kahiricum	+	−	−	+	+	+
Heliantemun lippii	+	+	+	+	+	+
Helianthemum cinereum	−	−	−	+	−	−
Helianthemum nummularium	−	+	−	−	−	−
Linaria aegyptiaca	−	+	−	−	−	−
Plantago albicans	+	−	+	−	−	+
Rantherium suaveolens	+	+	−	−	+	−
Reaumuria vermiculata	−	+	+	−	−	−
Salsola vermiculata	+	+	+	+	+	+
Stipa lagascae	+	−	+	+	−	−
Stipa tenacissima	−	+	−	−	−	−
Teucrium polium	+	−	+	−	−	−
Traganum nudatum	−	−	+	−	−	−
Total perennials	13	12	14	10	10	9
Annuals species						
Anacyclis clavatus	+	−	+	+	+	−
Asphodeus tenuifolius	+	−	+	+	+	+
Asteriscus pigamaeus	−	−	+	+	+	−
Astragalus corrigatus	−	−	+	+	+	−
Atractylis flava	+	−	−	+	−	−
Centaurea contracta	−	−	−	+	+	−
Centauria dimorpha	−	+	+	−	−	−
Cutandia dichotoma	−	−	+	−	+	−
Daucus syrticus	−	+	+	−	−	−
Echium humile	+	+	+	−	−	−
Erucaria pinnata	−	+	−	+	−	−
Fagonia glutinosa	+	−	+	+	+	+
Hernaria fontanesii	+	−	−	−	+	+
Hippocrepis bicontorta	−	−	+	+	+	−
Hordeum murinum	−	−	+	−	−	−
Hordeum murinum	−	−	+	−	−	−
Ifloga spicata	−	−	−	+	−	+
Koelipinia liniaris	+	+	−	+	−	−
Launaea resedifolia	+	+	+	+	+	−
Lotus pisillus	+	−	−	−	+	−
Matthiola longipetala	+	+	+	+	+	+
Medicago minima	−	−	+	−	−	−
Plantago ovata	−	−	+	+	+	−
Savigna parviflora	+	−	+	+	+	+
Scorzonera undulata	−	+	−	−	−	−
Shismus barbatus	−	−	−	−	−	+
Stipa capensis	−	−	+	−	−	−
Total annuals	11	8	18	15	14	7

Table IV. Species richness in relation to the applied restoration and management mode used in the rangelands of Chenini community

There were 22 perennials and 27 annuals. The annual species represent 55 per cent of the surveyed areas. These annual species appear shortly after the first rains and persist for a few months, depending on the amount and distribution of rainfall (Osem *et al.*, 2002). The variation in species richness is clearly evident, with the most species recorded in the site subjected to three years' rest (32 species; 14 perennials; and 18 annuals) and the fewest species recorded in the freely grazed site (16 species; 9 perennials; and 7 annuals). By contrast, the effects of one and two years of controlled grazing on species richness were distinguishable from those of one and two years of rest by only a few (maximum of five) species. Species richness remained almost constant in the controlled grazing, but it declined in the free grazed treatment. Grazing for one year can enhance the establishment and growth of some species, such as *Helianthemum cinereum*, *Ifloga spicata* and *Centaurea contracta*. Therefore, it seems that moderate grazing would be effective in promoting plant diversity in vegetation in dry areas (Holechek, 1991). In keeping with previous regional studies on the impacts of grazing on species richness, we found that the impacts of grazing on plant diversity can be sometimes negative and sometimes positive according to the degree of pressure and trampling can increase the incidence of some species such as *Ifloga spicata* (Ouled Belgacem *et al.*, 2008; Gamoun *et al.*, 2012). High annual species richness correlates to high perennial species richness, with 18 annuals and 14 perennials recorded in the site subjected to three years' rest. This correlation may be due to perennial plants accumulating the seeds of annuals, and consequently, helping increase the species richness and plant cover in arid lands (Khosravi *et al.*, 2017).

3.5 Biomass, rangeland production and carrying capacity

Trends in biomass, rangeland production and carrying capacity, according to management options and in the continuously grazed site, are presented in Table V. Grazing effects on some rangeland properties, such as total biomass, may appear erratic, as other factors including precipitation patterns and previous disturbances play important roles in the responses (Skinner *et al.*, 2002; Koerner and Collins, 2014).

Regarding biomass, results show that grazing does not harm total biomass in the private or the communal rangelands. The highest value (6,457 kg DM/ha) was recorded under free grazing. Under the restoration technique based on strategic resting of rangelands and controlled grazing, biomass varied between 3,000 and 5,000 kg DM/ha. In term of biomass, the conservation status of the rangeland is, however, weaker under protection. As mentioned above, arid rangeland plants that are freely grazed may have a lower cover. Yet they may also have greater biomass and better survival than ungrazed plants (Oba *et al.*, 2000). Consequently, grazing, rather than being destructive, is necessary for proper

Table V. Variation of the biomass, rangeland production and carrying capacity of the studied private rangeland sites in relation to the restoration and management mode

Management mode	1 year rest	2 years rest	3 years rest	1st year grazing	2nd year grazing	Control
Biomass (Kg DM.ha-1)	5,336	3,775	3,587	3,808	3,441	6,457
Rangeland production (FU/ha/year)	667	2,250	667	680	451	120
Carrying capacity (Sheep Unit/ha)	1.6675	5.625	1.6675	1.7	1.1275	0.3

management of arid rangeland. On the other hand, as livestock grazing movement is seasonally regulated in traditional grazing systems, no heavy grazing is observed. This implies a deferred grazing system in which some areas are left ungrazed for long periods of time.

The freely grazed rangeland is dominated by *Anthyllis henoniana, Atractylis serratuloides, Gymnocarpos decander, Helianthemum kahiricum* and *Haloxylon schmittianum*. Ourcival *et al.* (1994), by measuring predawn water potential of *Anthyllis henoniana* in presaharian Tunisia, suggest that this species is able to directly absorb atmospheric water through its leaves and stems. The water is apparently taken up by the vascular system. This ability would allow *Anthyllis henoniana* to benefit from the many dew days observed in its area of distribution and would improve its water balance. The abundance of the large-sized species *Haloxylon schmittianum* greatly contributes to rangeland biomass while the other shrub species are highly adapted to grazing and respond to persistent sheep and goat browsing by growing interlocking twigs. The woody twigs serve as a defense against herbivory, and sometimes flowering is not hindered by heavy browsing. This can also explain the high density of perennial species recorded in the freely grazed site. Their low biomass in rested rangeland may be influenced more by historical than by current grazing pressures and low biomass does not necessarily imply low production or vice versa. These chamaephytes have significantly benefited by grazing (Kahmen and Poschlod, 2008) and can make up 60 to 80 per cent of fodder production (Floret and Pontanier, 1978). Therefore, grazing pressure alone cannot explain the current differences in biomass. In arid areas, the principal driver is precipitation, with its variability having a direct impact on the variability of biomass.

Conversely, results showed that rangeland productivity is more limited in managed rangelands. The site subject to two years' rest provided the highest production (2,250 FU/ha/year) followed by the first-year grazing (680 FU/ha/year) while the lowest was recorded in the freely grazed site (120 FU/ha/year). Allowing a rest from grazing for less than three years led to improved rangeland production over what was seen under free grazing. Resting from grazing for more than two years, however, did not increase rangeland production any more than two years of rest or short-duration grazing (one year). Two years of rest showed rapid recovery of the rangeland production once rains occurred. In addition, light to moderate grazing of one year may stimulate plant production, leading to rangeland production that is more effective than that generated by longer periods of protection (two or three years' rest) or free grazing. In Sahelian areas, Novikoff (1976) found that when exclusion from grazing exceeds one year, grazing is possible during periods when vegetation is dormant. This applied to sandy soil in experimental plots, which were excluded from grazing for two years and became covered by vegetation. These rangelands were then grazed during the autumn by a mixed flock of sheep and goats, and vegetation recovery appeared the same as before.

Livestock grazing affects rangeland function and critical stock forage, particularly when total grazing pressure remains high in years of lower seasonal quality (Bastin, G. and ACRIS Management Committee, 2008). Widespread degradation has made more urgent than ever the need to restore rangelands degraded from overgrazing and keep livestock populations within carrying capacity (Xiong *et al.*, 2016). In southern Tunisia, stocking rates usually exceed the safe carrying capacity. They can be regulated according to potential carrying capacity. The results of this study showed a considerable improvement in rangeland condition and gains in grazing capacity after two years of rest. The highest carrying capacity of livestock is estimated at 5.625 sheep units/ha in the site subject to two years' rest, followed by the site subject to one years' grazing at 1.7 sheep units/ha. Under free grazing, meanwhile, the carrying capacity is estimated at only 0.3 sheep units/ha. Rangeland production was below average, stocking rates were far beyond the carrying capacity and vegetation was badly overgrazed (Ouled Belgacem *et al.*, 2013). Two years of rest can improve carrying the capacity to 18 times that seen under free grazing.

4. Conclusion

In areas such as the arid rangelands of Tunisia, agro-pastoral communities are working with the government to manage rangelands for improved livestock production and conservation. Rangeland vegetation in our study area was able to respond positively in terms of a range of desirable attributes following rational grazing. Even if the results have shown that a protection period of three years is neither sufficient for disappeared species to return, nor for succession to reach a new stage, particularly in the degraded *Stipa tenacissima* community, the reintroduction of the rest practice of *gdel* seems to be beneficial and a suitable tool to sustainably restore the arid rangelands under a changing climate. The evidence suggests that during short-term rest from grazing (two years), vegetation cover, density, rangeland production and carrying capacity can be improved. During relatively rainy years, grazing for short periods (one year or less) is apparently not harmful for rangeland vegetation in the dry areas. In this context, if rangelands are grazed by a number of animals lower than the carrying capacity, there will be no risk of rangeland degradation. Adequate grazing can have a beneficial effect over the duration of the vegetative period of certain species and alternation of short periods of grazing with periods of vegetative rest is generally more favorable than strict or long-term protection.

This study shows that dryland rangelands may keep their resilience to the negative effects of climate change once human pressures on them is controlled. A maximum of two years of rest would be enough to sustainably manage the rangelands in southern Tunisia, as this protection showed considerable positive effects on the parameters scored. Viewed from the perspective of agro-pastoralists, there were positive changes in plant cover, density, biomass and rangeland productivity.

A deferred grazing system based on two years of rest would also resolve social barriers and increase the awareness of the agro-pastoral communities and farmers to readopt this disappeared traditional practice. The revival of the traditional best practices under new arrangements adapted to current biophysical and socioeconomic conditions would be an excellent tool to mitigate the negative effects of frequent droughts and reduce the animal feed costs that poor farmers are facing.

References

Barbosa, L.V. and García, F.P. (2014), "Germination of mucilaginous seeds of *Plantago albicans* (Plantaginaceae): effects of temperature, light, pre-sowing treatments, osmotic stress and salinity", *Australian Journal of Botany*, Vol. 62, pp. 141-149.

Bastin, G. and ACRIS Management Committee (2008), *Rangelands 2008 – Taking the Pulse*, National Land and Water Resources Audit, Canberra.

Ben Mariem, H. and Chaieb, M. (2017), "Climate change impacts on the distribution of *Stipa tenacissima* L. ecosystems in North African arid zone – a case study in Tunisia", *Applied Ecology and Environmental Research*, Vol. 15 No. 3, pp. 67-82.

Ben Salem, F., Tarhouni, M., Ouled Belgacem, A. and Neffati, M. (2007), "Impact of drought on plant cover dynamics in two natural areas of Southern Tunisia", *Journal of Biological Sciences*, Vol. 7 No. 8, pp. 1539-1544.

Bertiller, M.B. and Ares, J.O. (2011), "Does sheep selectivity along grazing paths negatively affect biological crusts and soil seed banks in arid shrub lands? A case study in the Patagonian Monte, Argentina", *Journal of Environmental Management*, Vol. 92 No. 8, pp. 2091-2096.

Bestelmeyer, B.T., Brown, J.R., Havstad, K.M., Alexander, R., Chavez, R. and Herrick, J.E. (2003), "Development and use of state and transition models for rangelands", *Journal of Range Management*, Vol. 56 No. 2, pp. 114-126.

Daget, P. and Poissonet, J. (1971), "Une méthode d'analyse phytologique des prairies. Critères d'application", *Annales Agronomiques*, Vol. 22, pp. 5-41.

De-Pauw, E. (2002), "Drought in WANA: six frequently asked questions", *ICARDA Caravan*, Vol. 17 No. 2, pp. 12-17.

Escadafal, R. (1989), *Caractérisation de la Surface Des Sols Arides Par Observations de Terrain et Par Télédétection*, *Applications: Exemple de la région de Tataouine (Tunisie)*, Etudes et Thèses ORSTOM, Paris.

Floret, C. and Pontanier, R. (1978), *Relations Climat-Sol-Végétation Dans Quelques Formations Végétales Spontanées du Sud Tunisien*, CNRS/CEPE, Montpellier and ORSTOM, Paris.

Gallacher, D. and Hill, J. (2006), "Effects of camel grazing on the ecology of small perennial plants in the Dubai (UAE) inland desert", *Journal of Arid Environments*, Vol. 66 No. 4, pp. 738-750.

Gamoun, M., Ouled Belgacem, A., Hanchi, B., Neffati, M. and Gillet, F. (2012), "Effet du pâturage sur la diversité floristique des parcours arides du Sud tunisien", *Revue D'Ecologie (Terre Vie)*, Vol. 67, pp. 271-282.

Henchi, B., Louguet, P. and Viera Di Silva, J.B. (1986), "Evitement ou tolérance dans l'adaptation à l'aridité du plantain blanchâtre: Plantago albican ssp albicans L", paper presented at Colloque sur les végétaux en milieu aride Tunisie, Djerba, 8-10 September.

Holechek, J.L. (1991), "Chihuahuan desert rangeland, livestock grazing, and sustainability", *Rangelands*, Vol. 13, pp. 115-120.

Hudson, L.N., Newbold, T., Contu, S., Hill, S.L.L., Lysenko, I., De Palma, A., . . . Purvis, A. (2014), "The PREDICTS database: a global database of how local terrestrial biodiversity responds to human impacts", *Ecology and Evolution*, Vol. 4 No. 24, pp. 4701-4735.

INRA (1978), *Alimentation Des Ruminants*, Publications Versailles, Paris.

Kahmen, S. and Poschlod, P. (2008), "Effects of grassland management on plant functional trait composition", *Agriculture, Ecosystems and Environment*, Vol. 128, pp. 137-145.

Khosravi, H., Ebrahimi, M. and Rigi, M. (2017), "Effects of rangeland exclusion on plant cover and soil properties in a steppe rangeland of Southeastern Iran", *Arid Land Research and Management*, Vol. 31 No. 3, pp. 352-371.

Koerner, S.E. and Collins, S.L. (2014), "Interactive effects of grazing, drought, and fire on grassland plant communities in North America and South Africa", *Ecology*, Vol. 95 No. 1, pp. 98-109.

Mathias, A. and Chesson, P. (2012), "Coexistence and evolutionary dynamics mediated by seasonal environmental variation in annual plant communities", *Theoretical Population Biology*, Vol. 84, pp. 56-71.

Miranda, J., Padilla, F.M., Lázaro, R. and Pugnaire, F.I. (2009), "Do changes in rainfall patterns affect semiarid annual plant communities?", *Journal of Vegetation Science*, Vol. 20 No. 2, pp. 269-276.

Mu, J., Zeng, Y., Wu, Q., Niklas, K.J. and Niu, K. (2016), "Traditional grazing regimes promote biodiversity and increase nectar", *Agriculture, Ecosystems and Environment*, Vol. 233, pp. 336-342.

Novikoff, C. (1976), "Traditional grazing practices and their adaptation to modern conditions in Tunisia and the Sahelian countries", in Rapp, A., Le Houérou, H.N. and Lundholm, B. (Eds), *Can Desert Encroachment Be Stopped? A Study with Emphasis on Africa, Ecological Bulletins No. 24*, Swedish Natural Science Research Council, Stockholm, pp. 55-69.

Oba, G., Stenseth, N.C. and Lusigi, W.J. (2000), "New perspectives on sustainable grazing management in arid zones of sub-Saharan Africa", *BioScience*, Vol. 50 No. 1, pp. 35-51.

Osem, Y., Perevolotsky, A. and Kigel, J. (2002), "Grazing effect on diversity of annual plant communities in a semi-arid rangeland: interactions with small-scale spatial and temporal variation in primary productivity", *Journal of Ecology*, Vol. 90 No. 6, pp. 936-946.

Ouled Belgacem, A. and Louhaichi, M. (2013), "The vulnerability of native rangeland plant species to global climate change in the West Asia and North African regions", *Climatic Change*, Vol. 119 No. 2, pp. 451-463.

Ouled Belgacem, A., Tarhouni, M. and Louhaichi, M. (2013), "Effect of protection on plant community dynamics in the Mediterranean arid zone of Southern Tunisia: a case study from Bouhedma national park", *Land Degradation and Development*, Vol. 24, pp. 57-62.

Ouled Belgacem, A., Ben Salem, H., Bouaicha, A. and El Mourid, M. (2008), "Communal rangeland rest in arid area, a tool for facing animal feed costs and drought mitigation: the case of Chenini community, Southern Tunisia", *Journal of Biological Sciences*, Vol. 8 No. 4, pp. 822-825.

Ouled Belgacem, A., Chaieb, M., Neffati, M. and Tiedeman, J. (2006a), "Response of *Stipa lagascae* R. and sch. to protection under arid condition of Southern Tunisia", *Pakistan Journal of Biological Science*, Vol. 9, pp. 465-469.

Ouled Belgacem, A., Neffati, M., Papanastasis, V. and Chaieb, M. (2006b), "Effects of seed age and seeding depth on growth of *Stipa lagascae* R. and sch. seedlings", *Journal of Arid Environments*, Vol. 65, pp. 682-687.

Ourcival, J.M., Berger, A. and Le Floc'h, É. (1994), "Absorption de l'eau atmosphérique par la partie aérienne d'un chaméphyte de la Tunisie présaharienne: l'*Anthyllis henoniana* (fabaceae)", *Canadian Journal of Botany*, Vol. 72 No. 8, pp. 1222-1227.

Poissonet, P., Romane, F., Austin, M.A., Van der Maarel, E. and Schmidt, W. (1980), ""Vegetation dynamics in grasslands, heathlands, and Mediterranean ligneous formations", paper presented at the Symposium of the Working Groups for Succession Research on Permanent Plots and Data-Processing in Phytosociology of the International Society for Vegetation Science, Montpellier, September.

Rathore, V.S., Singh, J.P., Bhardwaj, S., Nathawat, N.S., Kumar, M. and Roy, M. (2015), "Potential of native shrubs *Haloxylon salicornicum* and *Calligonum polygonoides* for restoration of degraded lands in arid Western Rajasthan, India", *Journal of Environmental Management*, Vol. 55, pp. 205-216.

Skinner, R.H., Hanson, J.D., Hutchinson, G.L. and Shuman, G.E. (2002), "Response of C3 and C4 grasses to supplemental summer precipitation", *Journal of Range Management*, Vol. 55 No. 5, pp. 517-522.

Su, Y.Z., Zhao, H.L., Zhang, T.H. and Li, Y.L. (2004), "Characteristics of plant community and soil properties in the plantation choronosequence of *Caragana microphylla* in Horqin sandy land", *Acta Phytoecologica Sinica*, Vol. 28 No. 1, pp. 93-100.

Tarhouni, M., Ouled Belgacem, A., Neffati, M. and Henchi, B. (2007a), "Validation of some ecosystem structural attributes under the effect of seasonal drought and animal pressure around watering points in the arid area of Tunisia", *Belgian Journal of Botany*, Vol. 139 No. 2, pp. 188-202.

Tarhouni, T., Ben Salem, F., Ouled Belgacem, A., Henchi, B. and Neffati, M. (2007b), "Variation of flora richness according to the grazing gradient around watering points in pre-Saharan Tunisia", *Sécheresse*, Vol. 18, pp. 234-239.

Westbrooke, M.E., Florentine, S.K. and Milberg, P. (2005), "Arid land vegetation dynamics after a rare flooding event: influence of fire and grazing", *Journal of Arid Environments*, Vol. 61 No. 2, pp. 249-260.

Xiong, D., Shi, P., Zhang, X. and Zou, C.B. (2016), "Effects of grazing exclusion on carbon sequestration and plant diversity in grasslands of China: a meta-analysis", *Ecological Engineering*, Vol. 94, pp. 647-655.

Corresponding author
Azaiez Ouled Belgacem can be contacted at: a.belgacem@cgiar.org