ICARDA

Science for resilient livelihoods in dry areas

Rangeland management in southern Tunisia: rest strategies for sustaining rangeland productivity

2018

ILRI
INTERNATIONAL LIVESTOCK RESEARCH INSTITUTE

CGIAR
RESEARCH PROGRAM ON Livestock

WORKING PAPER

ISBN: 9789291275205

Working Papers
Working Papers are one of ICARDA's global public goods; they capture and share knowledge and learning from projects and research partnerships. Each paper is internally reviewed as part of the center's publishing process.

Suggested citation
Rangeland management in southern Tunisia: rest strategies for sustaining rangeland productivity. 2018. Working Paper. Amman, Jordan: International Center for Agricultural Research in the Dry Areas (ICARDA).

About ICARDA
Established in 1977, the International Center for Agricultural Research in the Dry Areas (ICARDA) is a non-profit, CGIAR Research Center that focusses on delivering innovative solutions for sustainable agricultural development in the non-tropical dry areas of the developing world.

We provide innovative, science-based solutions to improve the livelihoods and resilience of resource-poor smallholder farmers. We do this through strategic partnerships, linking research to development, and capacity development, and by taking into account gender equality and the role of youth in transforming the non-tropical dry areas.

Address
Dalia Building, Second Floor, Bashir El Kasser St, Verdun, Beirut, Lebanon 1108–2010.

www.icarda.org

Contents

1. BACKGROUND ... 4
2. METHODOLOGY ... 5
2.1. SITE DESCRIPTION ... 5
2.2. STUDY DESIGN ... 5
2.3. DATA COLLECTION ... 7
2.4. STATISTICAL ANALYSES ... 8
3. RESULTS ... 9
3.1. TOTAL PLANT COVER ... 9
3.2. SOIL SURFACE COVER CHARACTERISTICS ... 9
3.3. PLANT DENSITY ... 10
3.3.1. DENSITY OF PERENNIAL SPECIES ... 10
3.3.2. DENSITY OF ANNUAL SPECIES ... 11
3.4. BIOMASS ... 18
3.5. RANGELAND PRODUCTION ... 19
3.6. CARRYING CAPACITY ... 19
3.7. RICHNESS AND PLANT COMPOSITION ... 19
CONCLUSION ... 30
REFERENCES ... 31

1. Background

Rangelands are a vital source of livestock feed and economic stability for rural communities across the world (Ouled Belgacem and Louhaichi 2013). They provide food security and poverty alleviation to millions of people and are the main feed resource for traditional livestock rearing systems in many parts of the world, as well as providing ecological, environmental and economic functions (Lund 2007). For example, Tunisia has the highest livestock headcount per unit area (Chabay et al. 2016), reflecting the heavy reliance on rangelands for livestock feeding. In Tunisia, about one-quarter of the total territory is rangeland, located mostly in the south (5.5 million ha), and of which 78% falls under arid conditions (Gamoun et al. 2018). Of this 5.5 m ha, almost 64% is collectively owned, 28% privately owned, and 8% is publicly owned (Gamoun et al. 2018). However, the area of natural rangelands has considerably decreased due to continuous degradation caused by, amongst other things, overgrazing and agriculture expansion (Le Houérou 2009; Ouled Belgacem and Louhaichi 2013; Gamoun 2014).

Across the world, rangeland degradation is on the rise, mainly caused by the expanding population which is increasing consumption patterns and placing a higher demand on the land to produce more (Wessels et al. 2004). Degradation is even more apparent in dryland areas, where conditions are harsh due to the scarcity of rainfall and poor soil nutrient status (Ouled Belgacem et al. 2013). The expanding population in these areas has contributed significantly towards overgrazing, threatening the local resource base upon which rural people's communal livelihoods depend on (Wessels et al. 2004). Therefore, managing and manipulating the grazing animal-forage plant-soil complex to rehabilitate degraded rangelands is important towards accomplishing integrated ecological, economic and animal requirements. For instance, grazing approaches must consider both plant growth and animal requirements to yield a balance between long-term ecosystem stability as well as immediate profitability (Thornton et al. 2009).

Halting further rangeland degradation through rehabilitation strategies, such as resting of previously grazed areas, is one of the cost-effective ways of intervening to preserve and maintain productivity in arid rangelands (Reed et al. 2007). Restoring rangelands to a desirable condition from both an ecological and a pastoral perspective ensures continued production of a wide variety of forage species than rangelands in an undesirable condition (e.g. accelerated erosion, bare ground, few perennial grasses, many weeds) (Gamoun et al. 2011). Continuous grazing with high stocking rates has negative impacts on land condition either as patches within a pasture or over whole pasture areas (Zubair et al. 2018). For example, in Tataouine (Southern Tunisia), during the three past decades, about 37% of the natural rangeland (73,695 ha) belonging to 1,410 beneficiaries (CRDA Tataouine 2018) has been the subject of natural restoration efforts. This approach has been implemented through closely involving tribal institutions, with one of the objectives to strengthen communal and private rangeland management, as well as traditional practice of protecting rangeland areas. This sustainable rangeland management approach has been used to protect part of the arid rangelands to reduce the effects of degradation by increasing the vegetation structure and composition, as well as its spatial distribution (Ouled Belgacem et al. 2008; Gamoun et al. 2010; Tarhouni et al. 2015).

However, the role of grazing strategies that provide rest to vegetation at critical times to encourage recovery of decreaser perennial grasses has still not been objectively assessed (Ash et al. 2011). Therefore, under the framework of the CRP Livestock, and in collaboration with the Institute of Arid Lands (IRA), the Forestry Department (DGF) and the Office of Livestock and Pasture (OEP), a research study has been implemented to assess the impact of rangeland resting on plant cover dynamics, biomass and rangeland productivity in Southern Tunisia. The study also targets assessing species richness in relation to vegetation type, duration of implementing this technique, and land tenure to determine the period of rangeland recovery. More specifically, the study seeks to address one main question related to how does resting affect plant community structure (e.g. species richness and density) and function (aboveground biomass and productivity) across vegetation types (spatial scale) and over time (temporal scale) in the arid rangeland? Results obtained from this study are expected to contribute towards developing a suitable management tool for these rangelands to cope with climate change and to also improve resilience of the pastoral and agro-pastoral communities relying on these rangelands (Tarhouni et al. 2017).

2. Methodology

2.1 Site description

The climate of southern Tunisia is arid Mediterranean with a mild rainy season concentrated in autumn–spring (the growth season of September–April) and a dry, rain-free summer lasting about 4 months from May–August (Ammar et al. 2011). In Tataouine, rainfall was 253 mm during the season 2017/18, which was well above the average of 79 mm. Rainfall during the season of this study was very high, characterized by a short rainy season, highly variable throughout the year and largely limited to November–December (Figure 1). The landscape is dominated by Villafranchian limestone crust forming undulating hills. The soil of the area is Regosol, with friable caliches at 10–25 cm depth and gypsum outcrops (Ammar et al. 2011). The agricultural area in southern Tunisia is approximately 17 000 km^2 and is largely dominated by natural rangelands which cover an estimated 15 000 km^2 (Ammar et al. 2011). These rangelands are grazed by an estimate of 5.5 million heads of sheep and goats (10% of the total population in Tunisia) and 25 000 heads for camels (50% of the total population). The traditional agriculture system is livestock farming based on the use of large rangelands and transhumance to Central regions and even neighboring countries (Algeria, Libya). According to the importance of the flock size, its composition, and availability of the family labor, farmers use several systems of shepherding the animals. These range from guardianship by the family, recruitment of a sheepherder or an association agreement within the community for herding the livestock (Ammar et al. 2011).

2.2 Study design

Over the past few years, the OEP has implemented a series of national project-related strategies designed to improve rangeland conditions. One important strategy is a nationwide conservation project targeting rangeland management, which aims to restore degraded rangelands and promote equilibrium between sustainable ecological productivity and socioeconomic development. In March 2018, the program established 20 sites (rested vs. grazed rangeland) in private and communal rangelands to continuously monitor vegetation cover, species richness, productivity, and biomass in the south of Tunisia (Table 1

Figure 1. Amount and distribution of rainfall during 2017/18 in Tataouine (Southern Tunisia).

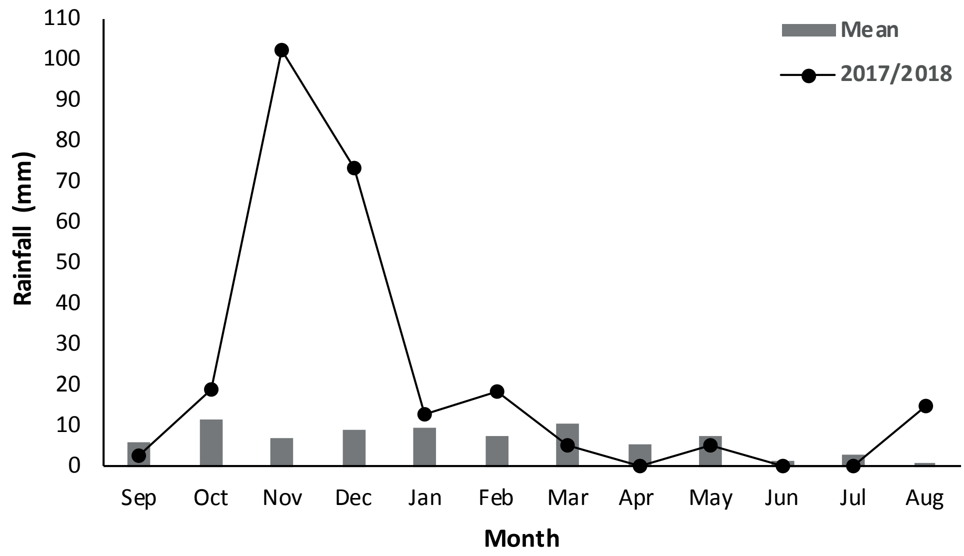
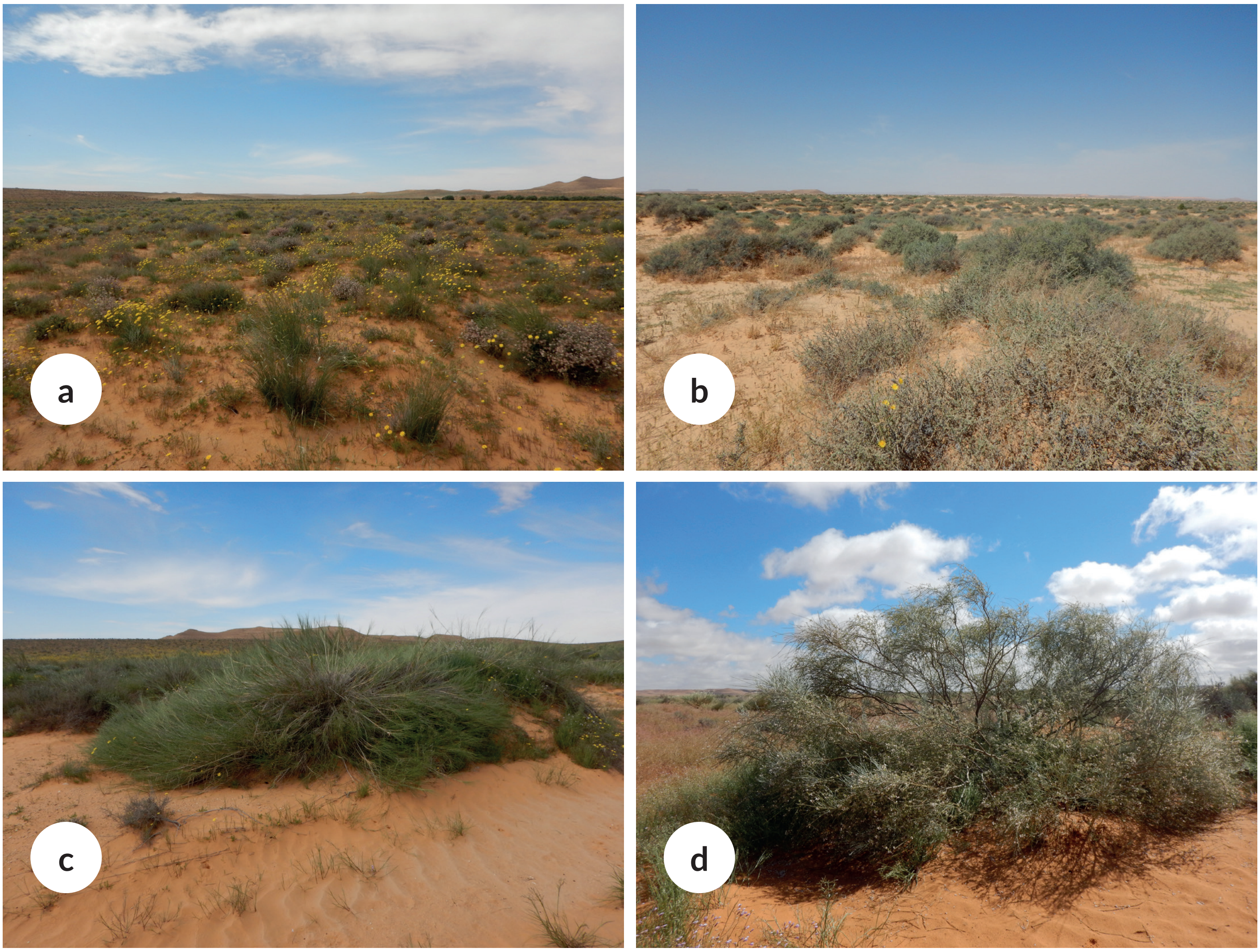


Table 1. Characteristics of the study sites in Tataouine, Tunisia.

Site number	Land tenure	Owner	Area (ha)	Plant community	Management mode
1	Private	Said Boughrara	120	*Anthyllis henoniana*	1-year rest
2	Private	Salem Hadded	30	*Haloxylon schmittianum*	1-year rest
3	Private	Amor ben Jemaa	100	*Stipagrostis pungens*	1-year rest
4	Private	Salem Hadded	30	*Retama raetam*	1-year rest
5	Private	Said Aloui	170	*Anthyllis henoniana*	2 years rest
6	Private	Said Aloui	170	*Haloxylon schmittianum*	2 years rest
7	Private	Said Aloui	170	*Stipagrostis pungens*	2 years rest
8	Private	Amor Maatoug	140	*Retama raetam*	2 years rest
9	Private	Said Aloui	20	*Anthyllis henoniana*	3 years rest
10	Private	Hedi Gomsi	20	*Haloxylon schmittianum*	3 years rest
11	Private	Said Aloui	20	*Stipagrostis pungens*	3 years rest
12	Private	Hedi Gomsi	20	*Retama raetam*	3 years rest
13	Collective	Communal	3000	*Anthyllis henoniana*	1-year rest
14				*Haloxylon schmittianum*	
15				*Stipagrostis pungens*	
16				*Retama raetam*	
17	Collective			Mosaic	Freely grazed
18	Private				
19	Private				
20	Collective				

Figure 2. Photographs showing the different rangelands types: (a) an *Anthyllis henoniana* dominated community in stony terrain, (b) a *Haloxylon schmittianum* dominated community, (c) psammophytes of *Stipagrostis pungens*, and (d) a stand dominated by *Retama raetam*.



and Figure 2). The sites are located in most of Tunisia's arid rangeland types, covering four rangeland types, each dominated by the following species; *Anthyllis henoniana*, *Haloxylon schmittianum*, *Stipagrostis pungens*, and *Retama raetam*.

The study consisted of four management approaches:

i) 1-year resting- the rangeland was given a year of no grazing prior to commencing the study
ii) 2-year resting- the rangeland had been given a period of two years without any grazing prior to commencing the study and was still protected during the period of study,
iii) 3-year resting- the rangeland had been given a period of two years without any grazing prior to commencing the study and was still protected during the period of study, and
iv) Freely grazed – this rangeland has exposed to continuous grazing without any period of rest

Setting up the study this way is important in establishing a comparison of the spatial and temporal responses of community structure and ecosystem function towards rest in the rangelands.

2.3 Data collection

The changes in vegetation characteristics were monitored during the peak of the growing season in spring, March 2018, when growth of annual vegetation is at its prime. The study set up three 50-m long transects in each site. Vegetation cover and species composition were estimated using the using the line intercept method as described by Daget and Poissonet (1971). Each of the 100 hits/line within each transect was recorded according to plant species and type of ground touched (stones, wind veil, crust, or litter). Annual plant density was estimated by establishing three quadrats (1 m^2) per line transect per site. Plant density was then estimated through counting the number of individuals and dividing by the quadrat's area. However, the density of perennial plants was determined by counting the number of tufts of each species within five 1-m^2 quadrats.

Plant density (plants/m^2) and plant species coverage (%) were calculated based on Louhaichi et al. (2012). These same quadrats were also used for estimating total biomass, through clipping vegetation inside quadrats for annual species and by clipping half of the potentially grazeable biomass (according to the rule take half and leave half) of 10 tufts of each species for perennial vegetation estimation. The total biomass of perennial species was estimated by multiplying the mean available biomass/individual by the density of the species.

Two methods were used to determine carrying capacity. The first was based on biomass production and the needs of an animal unit (AU). The second considered the plant species cover and its palatability class or acceptability index according to the following formula (INRA 1978):

$$P = 1.5 \sum_{i=1}^{n} SCi \times PFi \times TPC/100$$

Where P is total rangeland production in Forage Units (FU)/ha/year, SC*i* is cover of species *i* (%), PF*i* is palatability factor of species *i*, and TPC is total plant cover (%).

The carrying capacity was then determined as the ratio of total rangeland production to the annual needs of an animal unit which is estimated to 400 FU/year.[1]

2.4 Statistical analyses

A general linear model, with plant species cover, aboveground biomass and density (annual and perennial species) as continuous variables, was used to evaluate the effects of exposing different areas to resting. The data were analyzed using IBM SPSS-Statistics version 20, while the differences among the means were compared using Tukey's post hoc least significant difference at $P < 0.05$.

[1] **Note:**
1st year rest: private rangeland rested for one year.
2nd year rest: private rangeland rested for two years.
3rd year rest: private rangeland rested for three years.
Collective: communal rangeland subjected to controlled grazing.
Control: rangeland freely grazed during the whole year.

3. Results

3.1 Total plant cover

Patterns of changes in cover after the wet season (2017/18) are presented in Figure 3. When comparing the vegetation characteristic within each resting period, plant cover was lowest in the *A. henoniana* rangeland type (60%; $p<0.05$) compared to the three vegetation types. The same pattern was apparent in the 2-year and 3-year rests, with the *A. henoniana* rangeland type recording the lowest plant cover in (Figure 3). In all these treatments, the freely grazed rangelands recorded the lowest plant cover (40%; $p<0.05$). Within each period of rest, no significant differences ($p>0.05$) were observed amongst the *H. schmittianum*, *S. pungens* and *H. schmittianum* rangeland types. Regarding rangeland tenure, we observed significant differences in plant cover ($F = 4.263$, $P = 0.043$) between private (72%) and collective (62%) rangeland.

Since there were no significant differences between the 1-year and 3-year rests in plant cover, these results appear to suggest that even a year's rest affords time enough for plant cover to be comparable to a period of 3 years rest. Our results do support Ouled Belgacem et al. (2008)'s opinion that resting has been recommended as a restoration strategy to reduce the negative impacts of grazing. However, of importance during the period of resting are factors such as the amount of rainfall during the period because under a favorable climate, short rest periods are sufficient for plants to quickly recover their vigor (Ouled Belgacem et al. 2008). For example, the average rainfall for the year of study was 253 mm, which contributed towards the 1-year rest having the similar effect as a 3-year rest period. As a result, plant growth conditions were conducive during the period of rest (Figure 4).

3.2 Soil surface cover characteristics

When the different vegetation dominated types exposed to the different management strategies were compared, *A. henoniana* in the 1-year rest was dominated by stones (45%) while litter was most abundant in the 2-year rest management approach 42%; (Figure 5). For the 3-year rest, the soil surface cover was dominated by stones and wind veil. In the collectively managed rangelands, wind veil was most apparent (80%) compared to the rest of the soil surface cover characteristics. In the 1-year rest for the *H. schmittianum* dominated community, there was low presence of stone, litter and soil crust, but a dominance of wind veil. The 3-year rest was also slightly

Figure 3. Variation of total plant cover in relation to applied restoration and management mode used in private arid rangelands of southern Tunisia. The plant cover estimates are represented with standard deviation error bars.

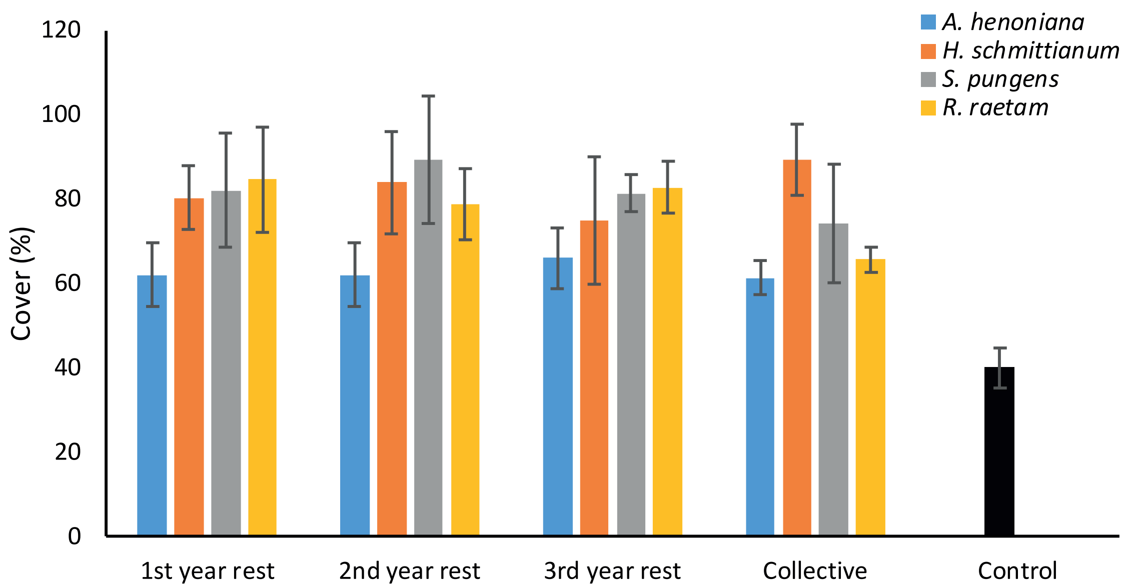


Figure 4. Wildflowers in arid rangeland of southern Tunisia in March 2018, after ideal rain conditions stimulated plant cover to increase.

dominated by wind veil, although all soil characteristics were below 50%. The *S. pungens* community was largely dominated by wind veil for all the rest periods, as well as the collectively managed rangelands. The same pattern was evident in the *R. raetam* community, with the wind veil highest in all rest periods as well as in the collectively managed rangelands.

There was a high proportion of stones characterizing the soil surface (71%) within the freely grazed rangelands. This was not surprising given that there was no controlling the grazing on these rangelands, possibly leading to overgrazing. As expected, the rate of stones was highest in the *A. henoniana* community (31.92%), being a typical shallow soil vegetation type. In most rangeland types, the lack of impact of resting was possibly due to higher than average rainfall amounts received during the study period which contributed to characteristics in 3 years rested rangelands being similar to 1-year rested rangeland types. The short rest period after summer had high infiltration rates and was adequate for rangeland to recover and produce an intermediate litter accumulation (Hart et al. 1988; Taylor et al. 1993).

3.3 Plant density

3.3.1. Density of perennial species

Within the 1-year rested rangelands, the density of perennial plant species was higher ($p<0.05$) in the *S. pungens* plant community (39.2 plants m^{-2}; Figure 6), compared with the three other community types. In the 2-year rested rangelands, perennial plant density was lowest ($p<0.05$) in the *S. pungens* community type. In the 3-year rested rangeland, *A. henoniana* recorded the highest ($p<0.05$) perennial plant species density (14 plants/m^2; Figure 6) when compared with the three rangeland communities. In the collectively managed rangelands, the *H. schmittianum* community recorded the highest perennial plant density (34 plants m^{-2}; $p<0.05$). Surprisingly, the freely grazed rangelands (control) had higher perennial species density when compared with *H. schmittianum*, *S. pungens* and *R. raetam* communities in the 3-year rested rangeland communities. The expectation was that the lack of controlling grazing animals would negatively affect the perennial species density. The reason could be, as already highlighted, because of the higher rainfall received during the season of data collection compared to the long-term average monthly rainfall. The increase in perennial density from the first year of protection was generally due to the high density of species such as *Helianthemum kahiricum* and *Plantago albicans* (Table 2), whose growth is expected following a high rainy season and a grazing disturbance (Tormo et al. 2006; Jeddi and Chaieb 2010). The high density of these species after grazing is attributed to their high reproductive capacity, ability for vegetative multiplication, resistance to drought (Neffati 1994), and seeming to adapt well to frequent rejuvenation following grazing (Poissonet et al. 1980). A rest period of more than one year led to a decreased density of *Plantago albicans* (Table 2) and it did not appear to benefit from protection (Ouled Belgacem et al. 2013).

3.3.2. Density of annual species

Annual species density was strongly positively affected by rangeland protection ($F = 11.984$, $P < 0.05$); and significantly differed among rest periods ($F = 28.950$, $P < 0.05$) but not among plant community types ($F = 2.301$, $P = 0.082$). The interaction of rest period and vegetation type was also significant ($F = 6.123$, $P < 0.05$), indicating that the specific nature of vegetation responses to rest period varied across the four plant communities. The *H. schmittianum* community had the highest density of annual species during the second year of protection (144.77 plants/m^2), the lowest annual plant density in the 3-year rest treatment (17.55 plants/m^2) and the highest density of annual species in the collectively managed rangelands (Figure 7).

Figure 5. Variation of soil surface (%) in relation to the applied restoration and management mode used in private and collectively owned arid rangelands of southern Tunisia.

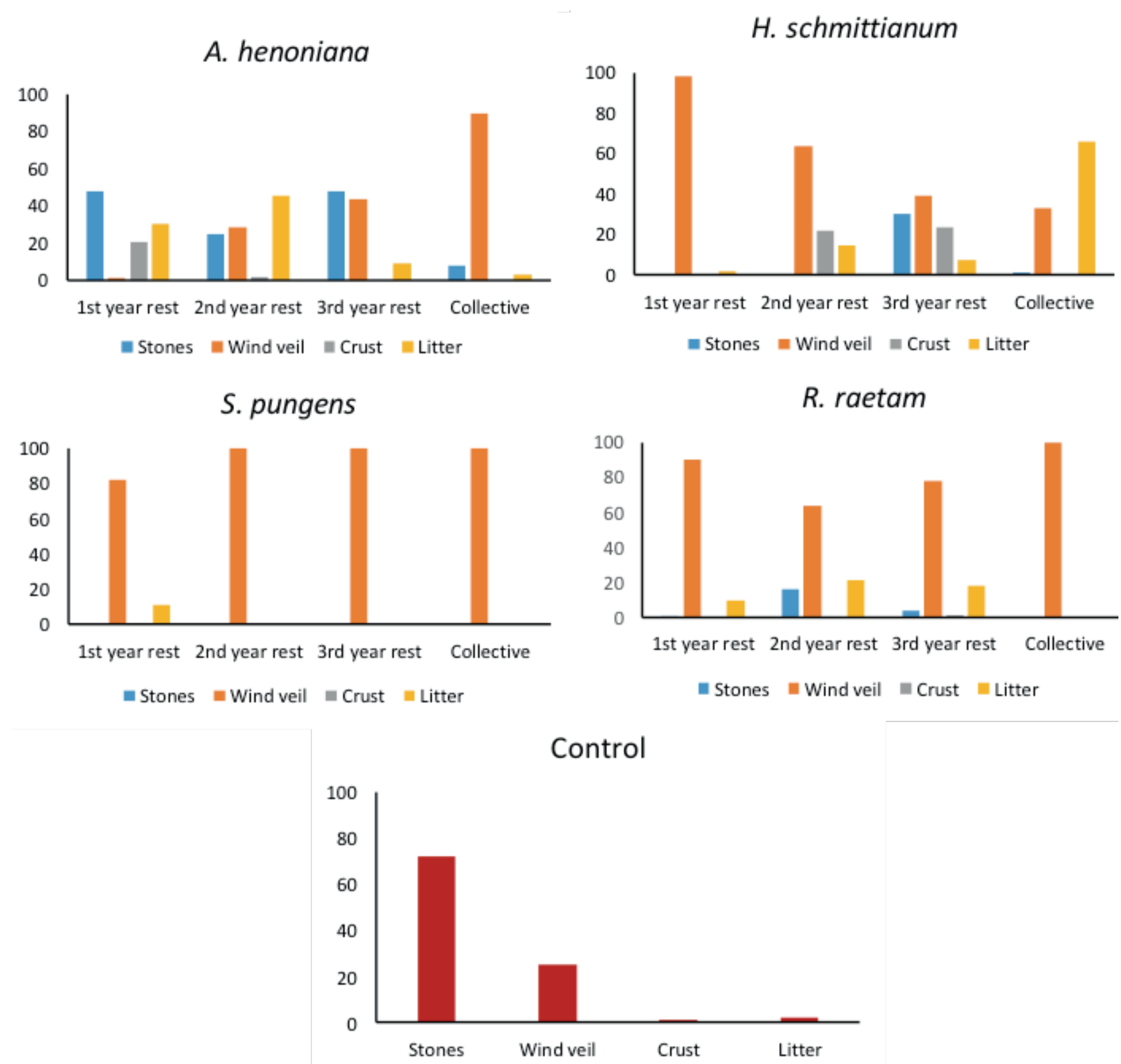
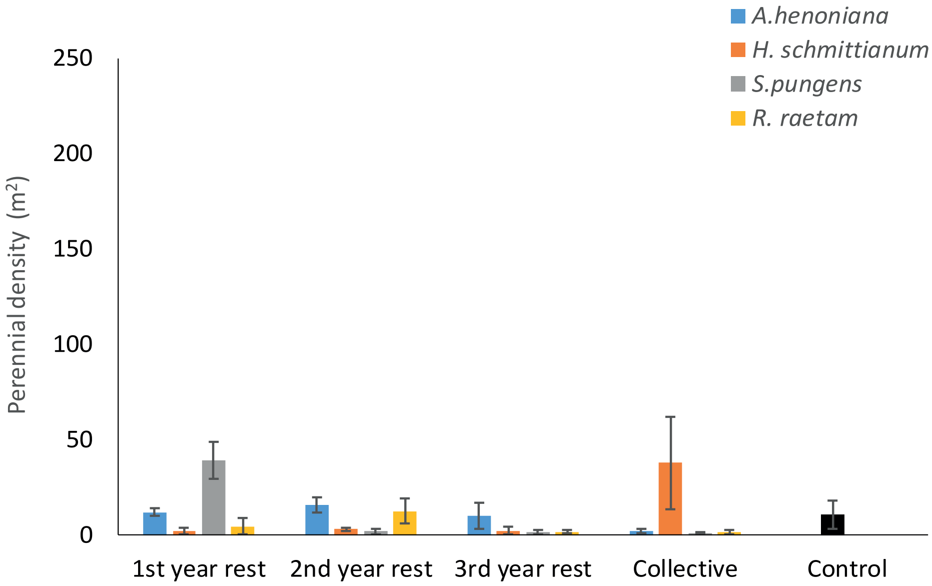


Figure 6. Variation of perennial species density (plants/m²) in relation to applied restoration and management mode used in private and collectively owned arid rangelands of southern Tunisia.



This density was due to the contribution of three species: *Daucus sahariensis*, *Cutandia dichotoma*, *Launaea glomerata*, and *Matthiola longipetala*. After three years of rest these species disappeared completely from the *H. schmittianum* community (Table 3). The importance of these species during the second year of rest was due to the favorable climate conditions of the two previous seasons: 2016/17 and 2017/18. Similarly, edaphic conditions (sandy soil) are also favorable for growth of therophytes. *Daucus sahariensis*, *Cutandia dichotoma*, *Launaea glomerata*, and *Matthiola longipetala* grow in the Saharan territory of Tunisia (Gamoun et al. 2018) with high rates of germination (Aidoud 1989; Neffati and Akrimi 1997). The 3-year resting period did not result in differences ($p>0.05$) in annual plant species density when compared to the control (free grazing).

Figure 7. Variation of annual density in relation to the applied restoration and management mode used in the private arid rangelands of southern Tunisia.

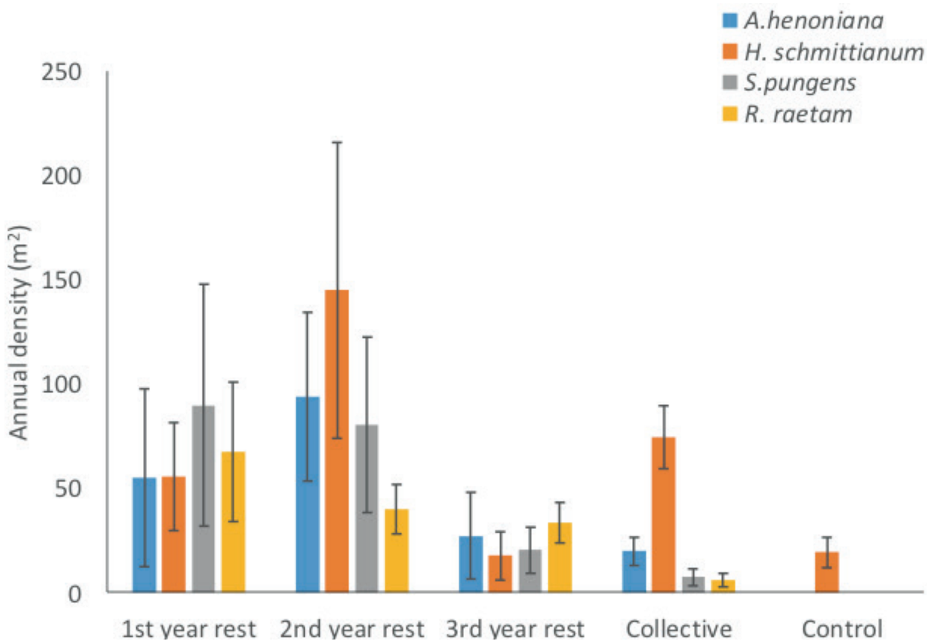


Table 2. Distribution of perennial species (perennial plants/m²) in relation to applied restoration and management mode used in the studied rangelands.

Community	Species	1st year rest	2nd year rest	3rd year rest	Collective
A. henoniana	*Anthyllis henoniana*	2	1	1.4	1.2
	Artemisia herba-alba	0.4	0	0	0
	Atractylis serratuloides	0	4.4	0	0
	Gymnocarpos decander	0.8	4.8	3.2	0.6
	Haloxylon schmittianum	0	0	0	0.4
	Helianthemum kahiricum	8.6	2	5	0
	Helianthemum sessiliflorum	0.2	3.4	0	0
	Kickxia aegyptiaca	0	0	0.6	0
	Rhanterium suaveolens	0	0.4	0	0.2
	Total	**12**	**16**	**10.2**	**2.4**
H. schmittianum	*Anthyllis henoniana*	0.2	0	0	0
	Atractylis serratuloides	0.2	0	0	1.8
	Gymnocarpos decander	0	0.6	0	0
	Haloxylon schmittianum	1.2	1.4	1	1.8
	Helianthemum sessiliflorum	0	0.6	1.4	2.8
	Plantago albicans	0	0	0	31.4
	Rhanterium suaveolens	0	0.2	0	0
	Salsola villosa	0.4	0.2	0	0
	Total	**2**	**3**	**10.2**	**37.8**
S. pungens	*Anthyllis henoniana*	0.2	0	0	0
	Gymnocarpos decander	0.2	0	0.2	0
	Haloxylon schmittianum	0	0	0.4	0
	Helianthemum sessiliflorum	1.2	0.2	0	0
	Plantago albicans	34.8	0	0	0
	Rhanterium suaveolens	0.8	0.6	0	0
	Salsola villosa	0.4	0.2	0	0
	Stipagrostis pungens	1.6	1	1	1.2
	Total	**39.2**	**2**	**1.6**	**1.2**
R. raetam	*Gymnocarpos decander*	0	2	0	0.2
	Haloxylon schmittianum	1.6	0.6	0.4	0.2
	Helianthemum sessiliflorum	0	7.4	0	0
	Herniaria fontanesii	0	0.4	0	0
	Kickxia aegyptiaca	0	0.4	0	0
	Plantago albicans	1.8	0	0	0
	Retama raetam	1.2	1.2	1.4	1
	Rhanterium suaveolens	0	0.6	0	0
	Stipagrostis pungens	0	0	0	0.2
	Total	**4.6**	**12.6**	**1.8**	**1.6**
Control	*Anthyllis henoniana*	0.15			
	Atractylis serratuloides	0.25			
	Gymnocarpos decander	0.35			
	Haloxylon schmittianum	0.3			
	Haloxylon scoparium	0.3			
	Helianthemum kahiricum	8.3			
	Helianthemum sessiliflorum	0.95			
	Herniaria fontanesii	0.05			
	Retama raetam	0.05			
	Salsola villosa	0.1			
	Stipa tenacissima	0.05			
	Total	**10.85**			

Table 3. Distribution of annual species (individuals/m²) in relation to the applied restoration and management mode used in the studied rangelands.

Community	Species	1st year rest	2nd year rest	3rd year rest	Collective
A. henoniana	*Allium roseum*	0	0.111	0	0
	Anacyclus clavatus	5.222	6.111	4.667	0
	Anacyclus monanthos	1.778	0	0.556	1.222
	Asphodelus tenuifolius	0	24.44	0.444	2.444
	Astragalus corrugatus	0.333	0	0	0
	Atractylis cancellata	0.444	0	0	0
	Atractylis carduus	0.111	0.222	0.667	0
	Calendula arvensis	0.333	0.111	1.222	0
	Centaurea furfuracea	0	0.667	0.667	0.222
	Cutandia dichotoma	0.444	5.556	5.556	12.33
	Daucus sahariensis	0	23.78	0.333	0.333
	Enarthrocarpus clavatus	0	0	0	0.111
	Erodium laciniatum	0.889	0	0	0
	Erucaria pinnata	0.333	0	0	0.333
	Fagonia cretica	0	0	0.111	0
	Fagonia glutinosa	0	1.222	0.444	0
	Filago germanica	0	0.111	1	0
	Hedysarum spinosissimum	1.222	0	0.111	0
	Hippocrepis areolata	0.333	5	0	0.889
	Ifloga spicata	0	1.222	0.111	0
	Koelpinia linearis	1.111	3.889	1.556	0.333
	Launaea fragilis	0	0.222	0.111	1.222
	Launaea glomerata	13.11	16.33	1.889	0
	Lotus halophilus	1.222	0	0	0
	Matthiola longipetala	0	0	0	0.111
	Medicago minima	0	0	2.889	0
	Pallenis hierochuntica	0	0	0.222	0
	Plantago coronopus	0	0	0.111	0
	Plantago ovata	0	0	1.333	0
	Rostraria litorea	18	0.111	0	0
	Savignya parviflora	0	4.444	0	0.222
	Scorzonera undulata	1.889	0	2.111	0
	Senecio glaucus	0	0	0.222	0
	Silene villosa	0	0	0.111	0
	Stipa capensis	8	0	0	0
	Thesium humile	0	0	0.444	0
	Total	**54.78**	**93.56**	**26.89**	**19.78**

Table 3. *continued*

Community	Species	1st year rest	2nd year rest	3rd year rest	Collective
	Allium roseum	0	0	0	0.333
	Anacyclus clavatus	1	0	0	0
	Asphodelus tenuifolius	0.556	8.333	0.222	1.222
	Astragalus corrugatus	5	1.333	0	0
	Astragalus asterias	0.778	0.556	0	0
	Atractylis cancellata	0	0.111	0	0
	Atractylis carduus	0	1.333	0	0
	Calendula arvensis	0	0.111	0	0
	Centaurea furfuracea	1.333	0	0	1.556
	Cutandia dichotoma	1.667	29.33	0	38.89
	Daucus sahariensis	0	38.78	0	0.111
	Erodium laciniatum	0	0.111	1.667	0
	Euphorbia retusa	0	0	0.111	0
	Fagonia glutinosa	0.556	0	0.556	0
	Filago germanica	29.33	0.222	1.889	0.444
	Hedysarum spinosissimum	0	6.111	0	0
H. schmittianum	*Hippocrepis areolata*	0.222	1.333	0	0
	Ifloga spicata	0	0.111	0	0
	Koelpinia linearis	0	3.111	0	2.889
	Launaea fragilis	0	0.556	0	1
	Launaea glomerata	0	20.33	0.667	2.667
	Launaea nudicaulis	0.889	0	0	0
	Lotus halophilus	1.556	3.667	2.778	3.333
	Matthiola longipetala	6	19.33	0	0.667
	Medicago minima	0	2.778	0.222	0
	Neurada procumbens	0.889	0	1.444	0
	Pallenis hierochuntica	0	0	0.556	0
	Paronychia arabica	0	0	0.333	0.889
	Plantago ovata	3	6.889	0	1.111
	Savignya parviflora	0.444	0.333	0.111	11.44
	Schismus barbatus	1.778	0	5.222	0
	Silene villosa	0.333	0	0	7.556
	Stipa capensis	0	0	1.778	0
	Total	**55.33**	**144.8**	**17.56**	**74.11**

continued/

Table 3. *continued*

Community	Species	1st year rest	2nd year rest	3rd year rest	Collective
	Arnebia decumbens	0	0.111	0	0
	Asphodelus tenuifolius	3.556	1.222	0.444	0
	Astragalus corrugatus	3.556	0.111	0.222	0
	Atractylis cancellata	0.222	0	0	0
	Atractylis carduus	0.333	0.444	1.111	0
	Calendula arvensis	0.111	0	0	0
	Centaurea furfuracea	0	0.222	0	0
	Cutandia dichotoma	37.67	57.89	12.22	6.444
	Daucus sahariensis	15.22	9.333	2.778	0
	Erodium laciniatum	0	0.222	0.333	0
	Erucaria pinnata	0	0.333	0	0.444
	Fagonia glutinosa	0.333	0	0	0
	Filago germanica	0	0.111	0.222	0
	Glebionis coronaria	0	0.667	0	0
S. pungens	*Hedysarum spinosissimum*	0.556	0	0	0
	Hippocrepis areolata	0.667	0.444	0.111	0
	Ifloga spicata	0	0.222	0	0
	Koelpinia linearis	0.556	3.111	0.556	0
	Launaea angustifolia	0.667	0.778	1.444	0
	Launaea fragilis	2.889	3.222	0	0
	Lotus halophilus	3	1.667	0	0
	Medicago minima	8.222	0	0.444	0
	Paronychia arabica	0.333	0	0.111	0
	Plantago coronopus	0	0	0.222	0
	Plantago ovata	9.556	0	0	0
	Savignya parviflora	0	0	0	0.333
	Silene villosa	2.111	0	0	0
	Total	**89.56**	**80.11**	**20.22**	**7.222**

Table 3. *continued*

Community	Species	1st year rest	2nd year rest	3rd year rest	Collective
R. raetam	*Anacyclus clavatus*	1.333	5.111	0	0
	Asphodelus tenuifolius	0.556	1.889	0.556	0
	Astragalus corrugatus	2.556	0.222	0.111	0
	Atractylis carduus	0.222	0	0	0
	Centaurea furfuracea	0.222	0	0	0
	Convolvulus supinus	0.222	0	0.667	0.333
	Cutandia dichotoma	2.667	12.33	0	4.556
	Daucus sahariensis	0	0.444	0	0
	Erodium laciniatum	0.111	0	1	0
	Erucaria pinnata	0	0	0	0.556
	Fagonia glutinosa	0.444	0	0.667	0
	Filago germanica	45.33	1.556	11.11	0
	Hippocrepis areolata	0	1.333	0.111	0
	Ifloga spicata	0	1.111	0	0
	Koelpinia linearis	0	1.333	0	0
	Launaea angustifolia	0	0	0	0.111
	Launaea fragilis	0	6.889	0.111	0
	Launaea nudicaulis	0.778	0	0.778	0
	Lotus halophilus	2.222	3.444	5.556	0
	Matthiola longipetala	0.444	0	0	0
	Medicago minima	0.111	2	0.333	0
	Neurada procumbens	4.444	0	1	0
	Paronychia arabica	0.889	0	1.222	0
	Plantago ovata	2.778	0	0	0
	Rostraria litorea	0	0.333	0	0
	Savignya parviflora	0	0	0	0.222
	Schismus barbatus	1.444	1.778	9.222	0
	Silene villosa	0.444	0	0	0
	Stipa capensis	0	0	0.778	0
	Total	**65.89**	**34.67**	**33.22**	**5.778**

continued/

Table 3. *continued*

Community	Species	Collective
Control	*Anacyclus clavatus*	1.111
	Asphodelus tenuifolius	0.111
	Astragalus corrugatus	0.306
	Daucus sahariensis	0.028
	Erodium laciniatum	0.028
	Fagonia glutinosa	1.944
	Filago germanica	0.500
	Ifloga spicata	0.389
	Koelpinia linearis	0.028
	Launaea fragilis	0.444
	Medicago minima	0.556
	Pallenis hierochuntica	7.417
	Plantago coronopus	0.472
	Plantago ovata	0.944
	Reseda alba	0.028
	Savignya parviflora	0.861
	Schismus barbatus	3.389
	Scorzonera undulata	0.500
	Total	**19.056**

3.4 Biomass

There were no differences ($p>0.05$) in aboveground biomass production amongst the different plant community types within the 1-year rest (Figure 8). The aboveground biomass in the *A. henoniana* community did not significantly increase because of resting, and the same pattern was observed for the *H. schmittianum* community. Aboveground biomass increased ($p<0.05$) between the 1-year and 2-year resting period but did not increase further for the 3-year rest in the *S. pungens* community. Aboveground biomass did not increase significantly for the *R. raetam* community, with biomass ranging between 7800–8900 kg DM ha^{-1}. While resting appears to have increased aboveground biomass production in most plant communities, this increase was not significant. Biomass production in the freely grazed rangelands (2100 kg DM ha^{-1}) was significantly lower ($p<0.05$) when compared to production in the four plant communities. No significant differences were recorded in the collectively managed rangelands, although the *R. raetum* community had the higher biomass production than the three communities.

There were clear differences in plant community types depending on soil types, because each type of vegetation is represented by soil type (Floret and Pontanier 1982; Gamoun et al. 2011). The most significant effect of rainfall on biomass production was on sandy soil (*R. raetam*, *S. pungens*, and *H. schmittianum*), followed by limestone soil (*A. henoniana*). Soil depth in such coarse sands is a key factor in capacity to store water (1 mm of rain moistens 1 cm of soil depth, and the amount of available water is 0.75 mm/cm) (Le Houérou 2009). In this context, Noy-Meir (1973) emphasized that, in arid and semi-arid regions, coarse, sandy substrates usually favor plant growth because water rapidly percolates through the surface layers.

3.5 Rangeland production

Resting the *A. henoniana* plant community did not significantly increase the rangeland production, with production ranging between 175.25–250.65 FU ha^{-1} $year^{-1}$ ($p>0.05$; Figure 9). Resting the *H. schmittianum* initially increased ($p<0.05$) rangeland production between the 1-year and 2-year rests but the 3-year rest significantly reduced rangeland production (250 FU ha^{-1} $year^{-1}$). Resting the *S. pungens* plant community initially increased rangeland production ($p<0.05$) between the 1-year and 2-year rest but in the 3-year rest, rangeland production decreased ($p<0.05$; 450 FU ha^{-1} $year^{-1}$). No significant differences were observed when the *R. raetam* community was rested up to the third year. Rangeland production was lowest in the freely grazed rangeland (58.373 FU ha^{-1} $year^{-1}$) and this is not surprising, given that the possibility of overgrazing is high in these rangelands. Rangeland production was highest ($p<0.05$) in the *H. schmittianum* community (666.2 FU ha^{-1} $year^{-1}$) There were significant differences between grazed and ungrazed rangeland (F = 45.269, P < 0.001). Productivity was also positively correlated with favorable climate conditions of previous seasons and the period of study. This finding is generally consistent with previous studies in arid rangelands (Le Houérou and Hoste 1977; Gamoun 2016). We observed no significant differences in rangeland production (F = 0.73902, P = 0.394) between private and collective rangelands. The current equilibrium is primarily driven by fluctuating rainfall, which masks the effects of grazing on rangeland production (Stafford Smith 1996).

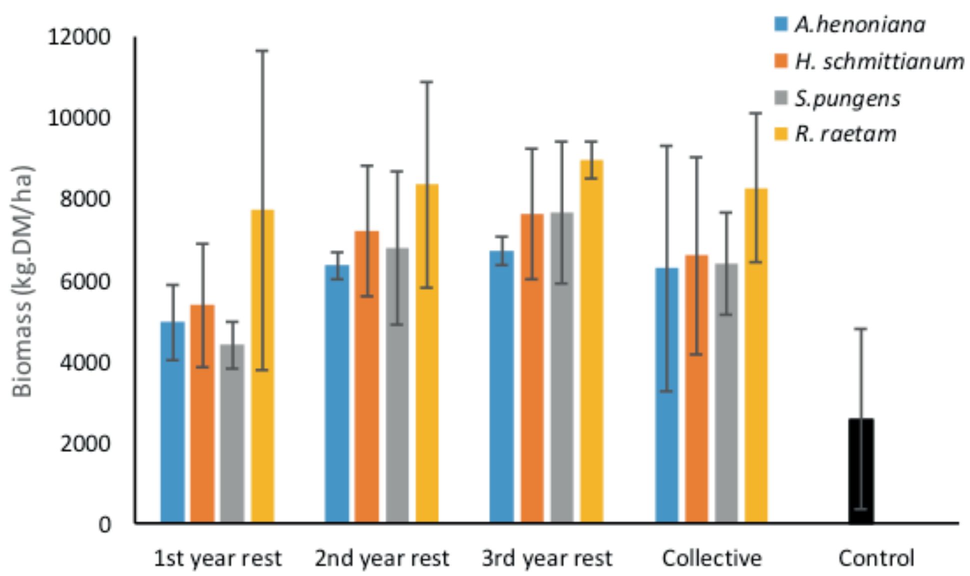
3.6 Carrying capacity

The highest carrying capacity was estimated for *H. schmittianum* (1.665 Sheep Unit/ha) and the lowest for *A. henoniana* communities (0.438 Sheep Unit/ha; Figure 10). The carrying capacity was the lowest in the continuously grazed rangelands (0.145 Sheep Unit/ha; Figure 10). The carrying capacity of each area was not considered as a fixed parameter but rather as a variable dependent on rainfall.

3.7 Richness and plant composition

Variation in species richness and composition are illustrated in Tables 4–9. Species richness ranged within 20–52 species/site and was affected by mode of grazing management (grazed vs ungrazed), rest period, and vegetation type. Species richness was lowest in collective rangeland for the *S. pungens* community (13 species), and highest in private rangeland rested for

Figure 8. Variation of biomass in relation to the applied restoration and management strategies used in studied rangelands of southern Tunisia.



three years for the *R. raetam* community (51 species). Effects of protection from grazing were more complex, with a rest period–vegetation type interaction. On *A. henoniana* communities, richness of perennial species was highest for one year of rest (13 species) than for three years (six species). For annual species of the *R. raetam* community, there were 37 species for one year of rest and 36 species for three years. Thus, protection from grazing for a long period (3 years) had opposite effects on species richness on these two communities. Possibly, the high resource availability, as already highlighted, caused a spike increase in plant response immediately after protection, as compared to the three-year rest period (Figure 11).

Figure 9. Variation of rangeland production in relation to the applied restoration and management strategies used in studied rangelands of southern Tunisia.

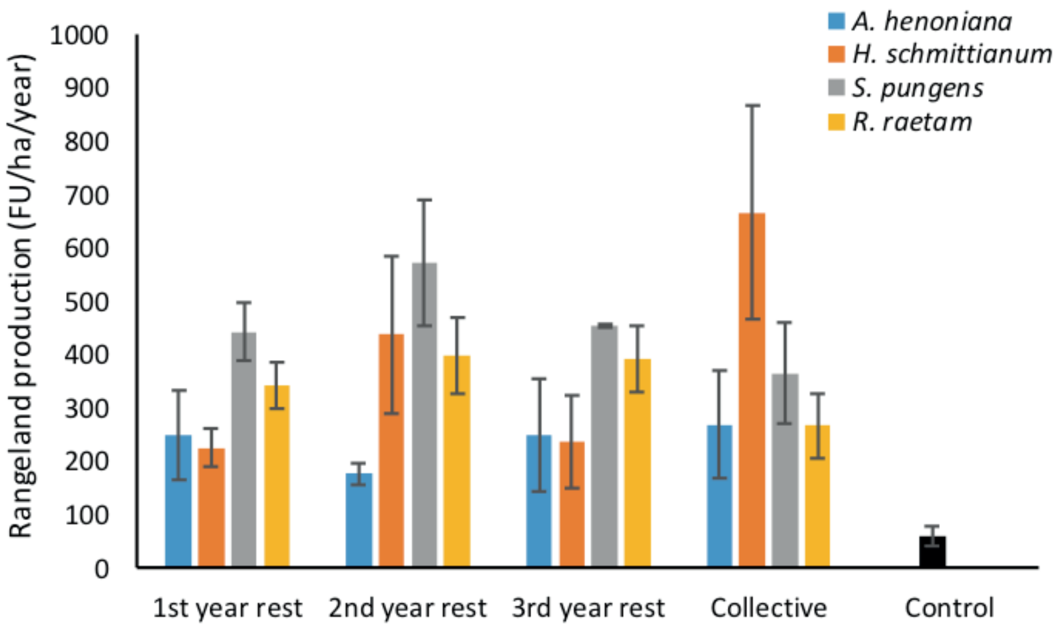


Figure 10. Variation of carrying capacity in relation to the applied restoration and management strategies used in studied rangelands of southern Tunisia.

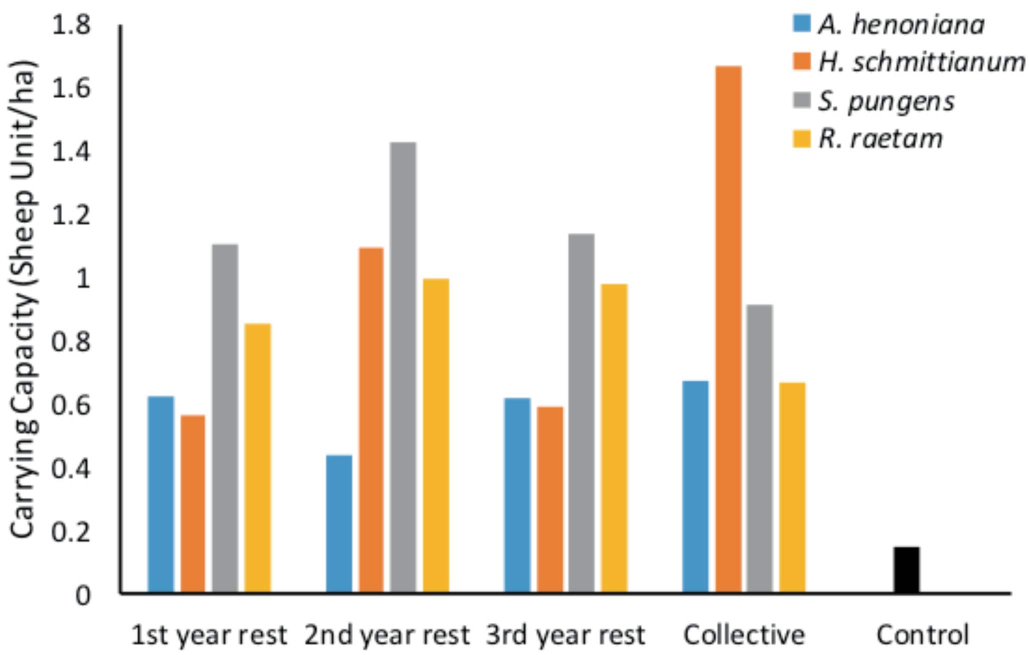


Table 4. Richness of perennial (P) and annual (A) species in relation to the applied restoration and management mode used in the studied rangelands.

Community	1st year rest		2nd year rest		3rd year rest		Collective		Control	
	P	A	P	A	P	A	P	A	P	A
A. henoniana	13	15	11	20	6	11	7	12	7.5	12.5
H. schmittianum	8	33	10	32	10	35	9	20		
S. pungens	10	25	6	21	11	19	4	9		
R. raetam	11	37	15	27	15	36	8	18		
Average	**38**		**35.5**		**35.75**		**21.75**		**20**	

Table 5. Floristic composition in relation to the applied restoration and management mode used in the *A. henoniana* community.

	1st year rest	2nd year rest	3rd year rest	Collective
Perennials				
Anthyllis henoniana	+	+	+	+
Artemisia herba-alba	+	–	–	–
Atractylis serratuloides	–	+	–	–
Echiochilon fruticosum	–	+	–	–
Gymnocarpos decander	+	+	+	+
Haloxylon schmittianum	–	–	+	+
Hedysarum spinosissimum	+	–	–	–
Helianthemum kahiricum	+	+	+	–
Helianthemum nummularium	+	–	–	–
Helianthemum sessiliflorum	+	+	–	+
Herniaria fontanesii	–	+	–	–
Kickxia aegyptiaca	+	–	+	+
Limonium pruinosum	+	+	–	–
Plantago albicans	+	–	–	+
Reaumuria vermiculata	+	+	–	–
Rhanterium suaveolens	–	+	+	–
Salsola villosa	–	+	–	–
Salvia aegyptiaca	+	–	–	+
Stipa tenacissima	+	–	–	–

continued/

Table 5. ***continued***

	1st year rest	2nd year rest	3rd year rest	Collective
Annuals				
Anacyclus clavatus	+	+	+	–
Allium roseum	–	+	–	–
Anacyclus monanthos	+	–	–	–
Arnebia decumbens	–	+	–	–
Asphodelus tenuifolius	–	+	+	–
Atractylis carduus	–	–	–	+
Calendula arvensis	–	–	+	–
Centaurea furfuracea	–	+	–	–
Cutandia dichotoma	–	+	+	+
Daucus sahariensis	–	+	+	+
Dipcadi serotinum	–	+	–	–
Diplotaxis harra	+	–	–	–
Echium humile	+	+	–	–
Enarthrocarpus clavatus	–	–	–	+
Erodium laciniatum	+	–	–	–
Erucaria pinnata	+	–	–	+
Fagonia cretica	–	+	+	–
Fagonia glutinosa	–	+	–	–
Filago germanica	–	+	–	–
Hippocrepis areolata	–	+	+	–
Koelpinia linearis	+	+	–	+
Launaea fragilis	+	–	–	+
Launaea glomerata	+	+	+	–
Launaea nudicaulis	–	–	–	+
Lotus halophilus	+	+	–	–
Matthiola longipetala	–	+	–	–
Medicago minima	+	–	+	–
Muricaria prostrata	–	–	+	–
Nolletia chrysocomoides	–	–	–	+
Plantago coronopus	+	–	–	–
Reseda alba	+	–	–	+
Rostraria litorea	+	–	–	–
Savignya parviflora	–	+	–	+
Scorzonera undulata	+	+	+	+

Table 6. Floristic composition in relation to the applied restoration and management mode used in the *H. schmittianum* community.

	1st year rest	2nd year rest	3rd year rest	Collective
Perennials				
Anabasis oropediorum	–	–	–	+
Anthyllis henoniana	+	+	+	+
Argyrolobium uniflorum	–	+	+	+
Artemisia herba-alba	+	–	–	–
Atractylis serratuloides	–	+	–	+
Cleome amblyocarpa	+	–	+	–
Gymnocarpos decander	+	+	+	+
Haloxylon schmittianum	+	+	+	+
Helianthemum kahiricum	+	+	+	–
Helianthemum sessiliflorum	+	+	+	+
Kickxia aegyptiaca	–	–	+	–
Plantago albicans	+	–	+	+
Rhanterium suaveolens	–	+	–	–
Salsola villosa	–	+	–	–
Salvia aegyptiaca	–	–	+	–
Stipa tenacissima	–	+	–	+
Annuals				
Allium roseum	+	+	–	–
Anacyclus clavatus	+	+	+	–
Anacyclus monanthos	+	–	+	+
Asphodelus tenuifolius	+	+	+	+
Astragalus corrugatus	+	+	+	+
Astragalus asterias	+	–	–	–
Atractylis cancellata	+	–	–	–
Atractylis carduus	+	+	+	+
Bassia muricata	+	–	–	+
Calendula arvensis	+	+	+	–
Centaurea bimorpha	–	+	–	–
Centaurea furfuracea	+	+	+	+
Cistanche violacea	–	+	–	+
Convolvulus supinus	–	–	+	–
Cutandia dichotoma	+	+	+	+
Daucus sahariensis	–	+	+	+
Dipcadi serotinum	–	+	–	–
Diplotaxis harra	–	–	+	–
Echium humile	–	+	–	–

continued/

Table 6. ***continued***

	1st year rest	2nd year rest	3rd year rest	Collective
Annuals				
Enarthrocarpus clavatus	–	–	–	+
Erodium laciniatum	+	+	+	–
Erucaria pinnata	+	+	–	+
Euphorbia retusa	–	–	+	–
Fagonia cretica	–	–	+	+
Fagonia glutinosa	+	+	+	–
Filago germanica	+	+	+	–
Hedysarum spinosissimum	+	+	+	–
Hippocrepis areolata	+	+	–	+
Ifloga spicata	–	+	+	–
Koelpinia linearis	+	+	+	+
Launaea capitata	–	+	–	–
Launaea fragilis	–	+	+	+
Launaea glomerata	+	+	+	–
Launaea nudicaulis	+	–	–	–
Linaria laxiflora	+	–	+	–
Lotus halophilus	+	+	+	+
Matthiola longipetala	+	–	–	+
Medicago minima	+	+	+	–
Neurada procumbens	+	–	+	–
Nolletia chrysocomoides	–	–	–	+
Pallenis hierochuntica	–	–	+	–
Paronychia arabica	+	–	–	–
Plantago coronopus	–	–	+	–
Plantago ovata	–	+	+	–
Reseda alba	–	+	–	–
Rostraria litorea	+	+	–	–
Savignya parviflora	+	+	+	+
Schismus barbatus	+	–	+	–
Scorzonera undulata	+	+	+	–
Senecio glaucus	–	–	+	–
Silene villosa	+	–	+	+
Stipa capensis	+	–	+	–
Thesium humile	–	–	+	–
Trigonella stellata	–	+	–	–

Table 7. Floristic composition in relation to the applied restoration and management mode used in the *S. pungens* community.

	1st year rest	2nd year rest	3rd year rest	Collective
Perennials				
Anthyllis henoniana	+	–	+	–
Argyrolobium uniflorum	+	–	+	–
Artemisia campestris	+	–	+	–
Atractylis serratuloides	–	+	+	–
Calligonum polygonoides	–	–	+	+
Gymnocarpos decander	+	–	+	–
Haloxylon schmittianum	+	–	+	+
Helianthemum sessiliflorum	+	+	–	–
Plantago albicans	+	–	–	–
Polygonum equisetiforme	–	+	+	–
Retama raetam	+	–	+	+
Rhanterium suaveolens	+	+	+	–
Salsola villosa	+	+	–	–
Stipagrostis pungens	+	+	+	+
Annuals				
Anacyclus clavatus	–	+	–	–
Arnebia decumbens	–	+	–	–
Asphodelus tenuifolius	+	+	+	–
Astragalus corrugatus	+	+	+	–
Astragalus caprinus	+	–	–	–
Atractylis cancellata	+	–	–	–
Atractylis carduus	+	+	+	–
Bassia muricata	–	+	–	–
Calendula arvensis	+	–	–	–
Centaurea furfuracea	–	+	–	+
Cistanche violacea	–	–	–	+
Cutandia dichotoma	+	+	+	+
Cynara cardunculus	–	–	–	+
Cynomorium coccineum	–	–	–	+
Daucus sahariensis	+	+	+	–
Diplotaxis simpelx	+	–	–	–
Echium humile	+	–	–	–
Erodium laciniatum	+	+	+	–
Erucaria pinnata	–	+	+	+
Fagonia glutinosa	+	–	–	–

continued/

Table 7. ***continued***

	1st year rest	2nd year rest	3rd year rest	Collective
Annuals				
Filago germanica	–	+	+	–
Glebionis coronaria	–	+	–	–
Hedysarum spinosissimum	+	–	–	–
Hippocrepis areolata	+	+	+	–
Ifloga spicata	–	+	–	–
Koelpinia linearis	+	+	+	–
Launaea angustifolia	+	+	+	–
Launaea fragilis	+	+	+	+
Lotus halophilus	+	+	+	–
Matthiola longipetala	+	–	–	+
Medicago minima	+	–	+	–
Paronychia arabica	+	–	+	–
Plantago albicans	+	–	–	–
Plantago coronopus	–	–	+	–
Plantago ovata	+	–	–	–
Reseda alba	+	+	–	–
Savignya parviflora	–	–	–	+
Scorzonera undulata	–	–	+	–
Senecio glaucus	–	+	–	–
Silene villosa	+	–	–	–
Teucrium polium	–	–	+	–
Trigonella stellata	–	–	+	–

Table 8. Floristic composition in relation to the applied restoration and management mode used in the *R. raetam* community.

	1st year rest	2nd year rest	3rd year rest	Collective
Perennials				
Anthyllis henoniana	+	+	+	+
Argyrolobium uniflorum	+	+	+	–
Aristida plumosa	+	–	–	–
Artemisia herba-alba	+	+	–	–
Atractylis serratuloides	–	+	–	–
Calligonum polygonoides	–	–	–	+
Cleome amblyocarpa	–	–	+	+
Cynodon dactylon	–	–	+	–
Deverra tortuosa	–	–	+	–
Echiochilon fruticosum	+	–	–	–
Gymnocarpos decander	+	+	+	+
Haloxylon schmittianum	+	+	+	+
Helianthemum kahiricum	+	+	+	–
Helianthemum sessiliflorum	+	+	+	–
Kickxia aegyptiaca	–	–	+	–
Plantago albicans	+	+	+	–
Retama raetam	+	+	+	+
Rhanterium suaveolens	–	+	–	+
Salvia aegyptiaca	–	+	+	–
Stipa lagascae	–	+	+	–
Stipa tenacissima	–	–	+	–
Stipagrostis pungens	–	–	–	+
Herniaria fontanesii	–	+	–	–
Salsola villosa	–	+	–	–
Annuals				
Allium roseum	–	+	–	–
Anacyclus clavatus	+	+	+	+
Anacyclus monanthos	+	+	+	+
Arnebia decumbens	–	–	+	–
Asphodelus tenuifolius	+	+	+	+
Astragalus corrugatus	+	–	+	–
Astragalus asterias	+	–	–	–
Atractylis cancellata	+	–	–	–
Atractylis carduus	+	+	+	–
Bassia muricata	+	–	+	+
Calendula arvensis	+	+	+	–
Centaurea furfuracea	+	+	+	+
Cistanche violacea	–	+	–	–
Convolvulus supinus	–	–	+	–

continued/

Table 8. ***continued***

	1st year rest	2nd year rest	3rd year rest	Collective
Annuals				
Cutandia dichotoma	+	+	+	+
Cynomorium coccineum	–	–	–	+
Daucus sahariensis	–	+	+	+
Echium humile	+	–	–	–
Emex spinosa	+	–	–	–
Enarthrocarpus clavatus	–	–	–	+
Erodium laciniatum	+	+	+	+
Erucaria pinnata	+	–	–	+
Fagonia cretica	–	–	+	–
Fagonia glutinosa	+	+	+	–
Filago germanica	+	+	+	–
Hedysarum spinosissimum	+	–	+	–
Hippocrepis areolata	+	+	–	+
Ifloga spicata	–	+	+	–
Kickxia aegyptiaca	–	+	+	–
Koelpinia linearis	+	+	+	+
Launaea fragilis	+	+	+	+
Launaea glomerata	+	+	+	–
Launaea nudicaulis	–	–	+	–
Linaria laxiflora	+	–	–	–
Lobularia libyca	+	–	–	–
Lotus halophilus	+	+	+	–
Matthiola longipetala	+	+	+	+
Medicago minima	+	+	+	–
Neurada procumbens	+	–	+	–
Nolletia chrysocomoides	+	–	–	–
Pallenis hierochuntica	–	–	+	–
Paronychia arabica	+	+	+	–
Plantago coronopus	–	–	+	–
Plantago ovata	+	–	+	–
Reseda alba	–	–	–	+
Rostraria litorea	+	+	–	–
Savignya parviflora	–	+	–	+
Schismus barbatus	+	+	+	+
Scorzonera undulata	+	–	+	–
Senecio glaucus	–	–	+	–
Silene villosa	+	–	+	–
Stipa capensis	+	–	–	–
Stipagrostis ciliata	+	–	–	–
Thesium humile	–	+	+	–

Table 9. Floristic composition in continuously grazed rangeland.

	Control
Perennials	
Anthyllis henoniana	+
Argyrolobium uniflorum	+
Atractylis serratuloides	+
Gymnocarpos decander	+
Haloxylon schmittianum	+
Haloxylon scoparium	+
Helianthemum kahiricum	+
Helianthemum sessiliflorum	+
Herniaria fontanesii	+
Kickxia aegyptiaca	+
Limonium pruinosum	+
Plantago albicans	+
Retama raetam	+
Salsola villosa	+
Stipa tenacissima	+
Annuals	
Anacyclus clavatus	+
Anacyclus monanthos	+
Asphodelus tenuifolius	+
Astragalus corrugatus	+
Catananche arenaria	+

	Control
Annuals	
Daucus sahariensis	+
Diplotaxis simplex	+
Erodium laciniatum	+
Fagonia cretica	+
Fagonia glutinosa	+
Filago germanica	+
Ifloga spicata	+
Koelpinia linearis	+
Launaea fragilis	+
Limonium pruinosum	+
Lotus halophilus	+
Matthiola longipetala	+
Medicago minima	+
Muricaria prostrata	+
Pallenis hierochuntica	+
Paronychia arabica	+
Plantago coronopus	+
Plantago ovata	+
Reseda alba	+
Savignya parviflora	+
Schismus barbatus	+
Scorzonera undulata	+

Figure 11. Rangeland in southern Tunisia. This species-rich rangeland type became a new frame of reference for grazing management in arid rangeland of Tunisia.

Conclusion

Research on sustainable rangeland management has received much attention in southern Tunisia due to the interest in animal production and biological conservation. Combining all this information gives a more precise picture of rangeland restoration, potentiality, and carrying capacity, and is therefore crucial for delivery of adequate management actions aiming for more sustainable exploitation of resources. These results from our study thus far reflect a significant effect of disturbances, through browsing and grazing, on vegetation characteristics and rangeland production in the freely grazed rangelands compared with the rangelands protected for different periods. While resting the rangelands for longer than a 3-year period does restore the plant growth, our results also indicate that under ideal climatic conditions, resting a previously grazed rangeland for one year is adequate for it to recover its vigor and productivity. As a result, the current study substantiates other findings which suggest that using resting previously grazed areas is one of several strategies that need to be adopted to facilitate and restore lost biodiversity (Aguiar and Sala 1999; Metzger et al. 2005). For the study site, the results contribute insight toward ensuring the achievement of conservation measures outside the rested areas and to rehabilitate degraded habitats. Findings are also critical in improving our understanding of grazing effects on vegetation, and how continuous grazing impacts potential vegetation recovery in the study area and beyond.

References

Aguiar, M.R. and O.E. Sala. 1999. Patch structure, dynamics and implications for the functioning of arid ecosystems. *Trends in Ecology & Evolution* 14(7): 273–277.

Aidoud, A. 1989. Contribution à l'étude des écosystèmes pâturés des haute plaines Algéro-oranaises. Fonctionnement, évaluation, et évolution des ressources végétales. Thèse doct. USTHB, Alger.

Ammar, H., R. Bodas, M.B. Younes and S. López. 2011. Goat breeding systems in the South of Tunisia (Tataouine). Economic, social and environmental sustainability in sheep and goat production systems. Zaragoza CIHEAM/FAO/CITADGA. *Options Méditerranéennes* A100: 283–288.

Ash, A.J., J.P. Corfield, J.G. McIvor and T.S. Ksiksi. 2011. Grazing management in tropical savannas: utilization and rest strategies to manipulate rangeland condition. *Rangeland Ecology & Management* 64(3): 223–239.

Chabay, I., M. Frick and J. Helgeson. 2016. Land Restoration. Reclaiming Landscapes for a Sustainable Future. Elsevier.

CRDA Tataouine. 2018. Atelier national sur l'amélioration des parcours par la mise en repos *'Gdel'* et la bonne gouvernance dans le contexte du changement climatique. 17–19 Juillet 2018, Hammamet sud, Tunisie.

Daget, P. and J. Poissonet. 1971. Une méthode d'analyse phytologique des prairies. Critères d'application. *Annales Agronomiques* 22: 5–41.

Floret, C. and R. Pontanier. 1982. L'aridité en Tunisie présaharienne: Climat – sol – végétation et aménagement. Trav. et Doc. ORSTOM, n° 150, Paris.

Gamoun, M. 2014. Grazing intensity effects on the vegetation in desert rangelands of Southern Tunisia. *Journal of Arid Land* 6: 324–333.

Gamoun, M. 2016. Rain use efficiency, primary production and rainfall relationships in desert rangelands of Tunisia. *Land Degradation and Development* 27: 738–747.

Gamoun, M., A. Ouled Belgacem and M. Louhaichi. 2018. Diversity of desert rangelands of Tunisia. *Plant Diversity* 40: 217–225.

Gamoun, M., M. Chaieb and A. Ouled Belgacem. 2010. Evolution of ecological characteristics along a gradient of soil degradation in the South Tunisian rangelands. *Ecologia Mediterranea* 36: 5–16.

Gamoun, M., M. Tarhouni, A. Ouled Belgacem, B. Hanchi and M. Neffati. 2011. Response of different arid rangelands to protection and drought. *Arid Land Research and Management* 25: 372–378.

Hart, R.H., M.J. Samuel, P.S. Test and M.A. Smith. 1988. Cattle, vegetation, and economic responses to grazing systems and grazing pressure. *Journal of Range Management* 41: 282–286.

INRA. 1978. Alimentation des Ruminants. Publications Versailles, Paris.

Jeddi, K. and M. Chaieb. 2010. Changes in soil properties and vegetation following livestock grazing exclusion in degraded arid environments of South Tunisia. *Flora-Morphology, Distribution, Functional Ecology of Plants* 205(3): 184–189.

Le Houérou, H.N. 2009. Bioclimatology and Biogeography of Africa. Springer-Verlag, Berlin, Heidelberg.

Le Houérou, H.N. and C. Hoste. 1977. Rangeland production and annual rainfall relations in the Mediterranean basin and in the African Sahelo-Sudanian zone. *Journal of Range Management* 30: 181–189.

Louhaichi, M., F. Ghassali, A.K. Salkini and S.L. Petersen. 2012. Effect of sheep grazing on rangeland plant communities: case study of landscape depressions within Syrian arid steppes. *Journal of Arid Environments* 79: 101–106.

Lund, H.G. 2007. Accounting for the world's rangelands. *Rangelands* 29: 3–10.

Metzger, K.L., M.B. Coughenour, R.M. Reich and R.B. Boone. 2005. Effects of seasonal grazing on plant species diversity and vegetation structure in a semi-arid ecosystem. *Journal of Arid Environments* 61(1): 147–160.

Neffati, M. 1994. Caractérisation morphologique de certaines espèces végétales nord-africaines: implication pour l'amélioration pastorale. Thèse Doct., Univ. Gent: Belgium.

Neffati, M. and N. Akrimi. 1991. Etude des caractéristiques germinatives des semences de quelques légumineuses spontanées de la Tunisie steppique. Séminaire international «acquis scientifiques et perspectives pour un développement durable des zones arides «Parcours et amélioration pastorale». Pages 272–287.

Noy-Meir, I. 1993. Compensating growth of grazed plants and its relevance to the use of rangelands. *Ecological Applications* 3: 32–34.

Ouled Belgacem, A. and M. Louhaichi. 2013. The vulnerability of native rangeland plant species to global climate change in the West Asia and North African regions. *Climatic Change* 119: 451–463.

Ouled Belgacem, A., H. Ben Salem, A. Bouaicha and M. El Mourid. 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* 8: 822–825.

Ouled Belgacem, A., M. Tarhouni and M. Louhaichi. 2013. Effect of protection on plant community dynamics in the Mediterranean arid zone of southern Tunisia: a case study from Bou Hedma National Park. *Land Degradation and Development* 24: 57–62.

Poissonet, P., F. Romane, M.A. Austin, E. van der Maarel and W. Schmidt. 1980. Vegetation dynamics in grasslands, healthlands and Mediterranean ligneous formations. Symposium of the Working Groups for Succession research on permanent plots, and Data-processing in phytosociology of the International Society for Vegetation Science, Montpellier, France.

Reed, M.S., A.J. Dougill and M.J. Taylor. 2007. Integrating local and scientific knowledge for adaptation to land degradation: Kalahari rangeland management options. *Land Degradation & Development* 18(3): 249–268.

Stafford Smith, D.M. 1996. Management of rangelands: paradigms at their limits. Pages 325–357 *in* The Ecology and Management of Grazing Systems (J. Hodgson and A. Illius, eds). CAB International, Wallingford, UK.

Tarhouni, M., W. Ben Hmida and M. Neffati. 2015. Long-term changes in plant life forms as a consequence of grazing exclusion under arid climatic conditions. *Land Degradation and Development* 28: 1199–1211.

Tarhouni, M., W. Ben Hmida, A. Ouled Belgacem, M. Louhaichi and M. Neffati. 2017. Is long-term protection useful for the regeneration of disturbed plant communities in dry areas? *African Journal of Ecology* 55: 509–517. doi: 10.1111/aje.12381

Taylor, C.A., T.D. Brooks and N.E. Garza. 1993. Effect of short duration and high-intensity, low frequency grazing systems on forage production and composition. *Journal of Range Management* 46: 118–121.

Thornton, P.K., J. van de Steeg, A. Notenbaert and M. Herrero. 2009. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural systems* 101(3): 113-127.

Tormo, J., E. Bochet and P. García-Fayos. 2006. Is seed availability enough to ensure colonization success? An experimental study in road embankments. *Ecological Engineering* 26(3): 224–230.

Van Andel, J. and J. Aronson. 2012. Restoration ecology: the new frontier. 2nd ed. Blackwell Publishing Ltd.

Wessels, K.J., S.D. Prince, P.E. Frost and D. Van Zyl. 2004. Assessing the effects of human-induced land degradation in the former homelands of northern South Africa with a 1 km AVHRR NDVI time-series. *Remote Sensing of Environment* 91(1): 47–67.

Zubair M., A. Saleem, M.A. Baig, M. Islam, A. Razzaq, S. Gul, S. Ahmad, H.P. Moyo, S. Hassan, B. Rischkowsky, M.N.M. Ibrahim and M. Louhaichi. 2018. The influence of protection from grazing on Cholistan Desert vegetation, Pakistan. *Rangelands* 40(5): 136–145. doi 10.1016/j.rala.2018.05.005

Established in 1977, the International Center for Agricultural Research in the Dry Areas (ICARDA) is a non-profit, CGIAR Research Center that focusses on delivering innovative solutions for sustainable agricultural development in the non-tropical dry areas of the developing world. We provide innovative, science-based solutions to improve the livelihoods and resilience of resource-poor smallholder farmers. We do this through strategic partnerships, linking research to development, and capacity development, and by taking into account gender equality and the role of youth in transforming the non-tropical dry areas.
www.icarda.org

CGIAR is a global research partnership for a food-secure future. CGIAR science is dedicated to reducing poverty, enhancing food and nutrition security, and improving natural resources and ecosystem services. Its research is carried out by 15 CGIAR centers in close collaboration with hundreds of partners, including national and regional research institutes, civil society organizations, academia, development organizations and the private sector.
www.cgiar.org