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# Impact of Long-term fencing on vegetation structure and carbon sequestration in arid areas: case study of Sidi Toui National Park, southern Tunisia

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**Abstract** The degradation of arid rangelands is mainly caused by overgrazing. Fencing is considered as a key management aspect to restore these ecosystems leading to changes in vegetation and soil structure. However, it depends on intensity and duration of protection. The aim of this study was to evaluate the impact of long-term fencing (more than 25 years) on the soil surface state and vegetation structure. Aboveground biomass and carbon contents were also assessed. Measurements were made using the quadrat point method and phytomass sampling in two defined plant communities: (i) G1 dominated by *Anthyllis henoniana* (Coss.) Maire and *Gymnocarpos decander* Forssk. and (ii) G2 dominated by *Rhanterium suaveolens Desf.* and *Stipa lagascae R. et Sch*, inside and outside Sidi Toui National park, during spring 2019. One-way analysis of variance (ANOVA) was performed using SPSS software. The main results indicated that under long-term grazing exclosure the perennials density, total vegetation cover and litter increased significantly in G1 and G2. Likewise, a significant increase in total aerial phytomass and aerial carbon content was observed inside the fenced area for both studied communities. However, a negative effect was stated on the annuals density. These results suggest that long-term grazing exclosure appears to be beneficial in aboveground phytomass expansion of arid rangelands and enhancing their contribution to carbon sequestration.

**Keywords**: arid rangelands, grazing exclosure, protected areas, phytomass, carbon content.

**Résumé** La dégradation des parcours arides est principalement causée par le surpâturage et se manifestent sous forme des changements dans la structure de la végétation et le sol. La mise en défens est considérée comme un aspect clé de la gestion pour restaurer ces écosystèmes. Néanmoins, cela dépend de l'intensité et de la durée de la clôture. Par cette étude on a visé à évaluer l'impact d'une mise en défens à long terme (plus de 25 ans) sur l'état de surface du sol et la structure de la végétation. La biomasse aérienne et les teneurs en carbone ont également été évalués. Les mesures ont été effectuées au printemps 2019, en utilisant la méthode du point quadrat et l'échantillonnage de la phytomasse dans deux groupements végétaux définis : (i) G1 dominé par *Anthyllis henoniana* (Coss.) Maire et *Gymnocarpos decander* Forssk. et (ii) G2 dominé par *Rhanterium suaveolens* Desf. et *Stipa lagascae* R. et Sch, à l'intérieur et à l'extérieur du parc national de Sidi Toui. Une analyse de la variance à un facteur (ANOVA) a été réalisée à l'aide du logiciel SPSS. Les principaux résultats obtenus ont indiqué que sous l'exclusion du pâturage à long terme, la densité des espèces pérennes, la couverture végétale totale et la litière ont augmenté de manière significative au niveau des groupements étudiés, G1 et G2. De même, une augmentation significative de la phytomasse aérienne totale et de la teneur en carbone aérien ont été observées à l'intérieur de la zone protégée pour les deux groupements. Cependant, un effet négatif a été constaté pour la densité des annuelles. Ces résultats suggèrent que l'exclusion du pâturage à long terme semble être bénéfique dans l'expansion de la phytomasse aérienne des parcours arides et l'amélioration de leur contribution à la séquestration du carbone.

**Mots-clés** : parcours arides, clôture, parc national, phytomasse, teneur en carbone.

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# I- Introduction

Rangeland ecosystems are not only a valuable base for livestock production but also perform significant ecological service to tens of millions of people in large urban areas located within or among rangelands (Havstad et al., 2007). These ecosystem services are involved in different environmental sectors, livestock production, water quality and quantity, biodiversity conservation and carbon sequestration (Briske, 2017). Globally, rangelands (including grasslands, savannas, shrub lands, deserts, tundra's, marshes, and meadows) comprise the largest land use, are estimated to cover about 25% of earth's land surface (Liebig et al., 2006). Land degradation, in the form of desertification, woody species encroachment, non-native species invasion and loss of range biodiversity, appears to be the major challenge in the rangelands worldwide (Palmer et al., 1997). Over the past years, excluding livestock in the rangelands by establishing fences has become a common management tool for conserving and restoring native vegetation (Spooner et al., 2002). Some researchers have proven that lightly and moderately degraded rangelands can be restored to their initial state within ten to twenty years by reducing the grazing intensity and establishing fencing. However, for heavily and extremely degraded rangeland, other measures are also necessary (Feng et al., 2010). Grazing exclusion by fencing is an effective ecological management measure that excludes grazing to reverse the negative effects of overgrazing and restore degraded rangeland (Wang et al., 2014) by improving ecosystem functions including vegetation production , species diversity, physical and chemical soil properties and soil fertility (Li et al., 2018). Overgrazing leads to excessive removal of the most palatable species, which are usually perennial grasses (Anderson and Hoffman, 2006). This opens the way for less palatable and faster establishing annual grasses and forbs to take hold. Constant decreasing of the highly palatable species leads to rangeland deterioration (Reda, 2020). However, many authors demonstrated that grazing exclusion have a positive effect on vegetation and soil by enhancing diversity and productivity (Jeddi and chaib, 2010; Moumni et al., 2020), reducing bare soil and increasing plant cover (Yeo, 2005; Mofidi et al., 2013), increasing litter accumulation (Jing et al., 2013) and rising above-ground biomass accumulation (Li et al., 2018; Al-Rowaily et al., 2015).

Rangelands represent a vast store of carbon (C), both in soils and vegetation. Scientists estimated that rangeland and grassland globally contain 306–330 Pg of organic carbon and 470– 550 Pg of inorganic carbon representing 20 to 25 % of the global terrestrial carbon (Havstad et al., 2007), with the potential to store almost 0.3 Gt C/year (Lal, 2004). In Africa, 59% of total carbon storage was estimated in arid areas (Campbell et al. 2008; UNEP 2008). In these regions, where pastoral activities are dominant, most of the sequestered carbon is stored underground, and is therefore relatively stable (FAO 2002). A significant amount of aboveground carbon is stored in trees, bushes, shrubs and grasses, which are not or lightly grazed (IPCC 2007; Vashum and Jayakumar 2012). Indeed, the reduction of livestock in overgrazed areas significantly increases carbon storage in aboveground biomass, litter mass (Xiong et al., 2016) and even in soil (Su et al., 2005). However, some studies revealed that carbon sequestration rates decreased with vegetation restoration (Speed et al., 2014; Deng et al., (2014).

In Tunisia, rangelands constitute the largest land use by 4.5 million hectares (DGF, 2010). However, the estimation of carbon sequestration in vegetation has been concentrated on forest areas located in the north of the country (Zribi et al., 2016) and until now, the dry lands contribution in carbon sequestration through vegetation and soil is not or partially studied.

The restoration of degraded rangelands is currently one of the major focuses of ecologists and land managers. Thereby, national parks and other protected areas have been established to protect biodiversity and maintain ecological stability through long-term restriction of livestock grazing and other human interventions. These techniques revealed restoration of these rangeland ecosystems in terms of aboveground vegetation, biomass production, species composition and soil quality (Wu et al. 2009).

The investigation of the environmental impacts of long-term grazing exclosure on vegetation and soil can be considered as an important tool for policy-makers to better formulate policies to manage natural rangelands.

In the present study, we investigated the effects of long term grazing exclosure (more than 25 years) on the soil surface state, vegetation structure, aboveground biomass and carbon sequestration in Sidi Toui region, southern Tunisia. Also, we would like to test the hypothesis who says that long-term grazing exclusion enhance biomass and carbon sequestration and make changes in the structure of vegetation communities. For that, we have done a comparison of soil surface state, vegetation structure, phytomass accumulation and aboveground carbon contents, in two defined plant communities; (i) G1 dominated by *Anthyllis henoniana* and *Gymnocarpos decander* and (ii) G2 known by *Rhanterium suaveolens* and *Stipa lagascae,* inside (long term protection) and outside (open grazing) the national park of Sidi Toui.

# II- Material and methods

## 2.1 Study site

The present study was carried out inside (long-term protection) and outside (open grazing) the Sidi Toui National Park. This park, is located in El Ouara natural rangeland at 70 km from the Ben Guardene town in south east of Tunisia, having a surface of 6315 ha and created in 1991 (Figure 1). This protected area includes a low hill, Djebel Sidi Toui (172 m), surrounded by an extensive plain composed of small dunes, sebkhas and dry sandy wadis. The vegetation cover is mainly dominated by shrubby chamaephytes. Principal shrubby species include *Anthyllis henoniana* Coss. Ex Batt.*, Gymnocarpos decander* Forssk.*, Rhanterium suaveolens* Desf.*, Haloxylon schimittianum* Pomel. and *Haloxylon scoparium* Pomel. This area is mainly grazed by small ruminants and camels.

Ben Guardene climate is classified as type BWh, according to Köppen-Geiger classification (data for the period 199-2019, available at https:/fr.climate-data.org, accessed on 11 September 2021). The mean annual precipitation is around 195 mm and characterized by low quantity and rainstorm. The average temperature is 20.6 °C. The mean precipitation recorded in the meteorological station of the Sidi Toui National Park during the three last year's previous experimentation (2017-2019) was relatively low (121mm) compared to the mean annual rainfall of the region (Fig 1).

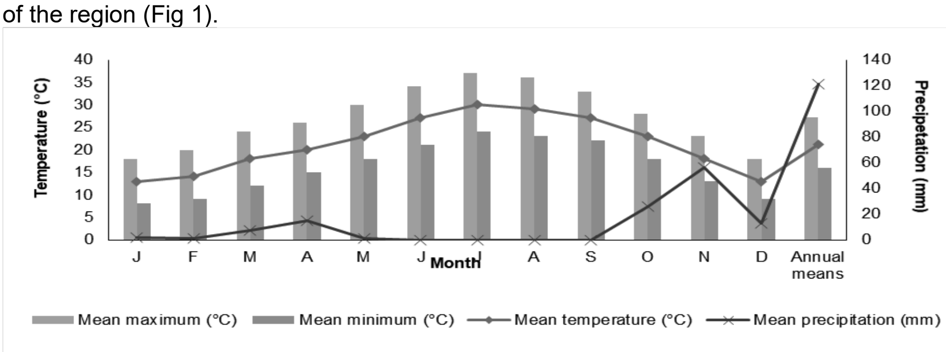


**Figure 1. Climate data for the Sidi Toui National Park 2017–2019 (local meteorological station).**

## 2.2 Vegetation sampling and data collection

Vegetation was monitored during spring 2019. Within each experimental plot, five random transects of 50 m long each were established in two plant communities (i) G1: dominated by *Anthyllis henoniana* and *Gymnocarpos decander* and (ii) G2: dominated by *Rhanterium* *suaveolens* and *Stipa lagascae* of the studied rangeland site and used to determine vegetation structure, according to the quadrat-points method described by Daget and Poissonet (1971). This design permitted the assessment of the regeneration capacity 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 surface structure. In each sampling plot, annual plants densities were measured by counting species individuals inside five randomly established quadrats of 1 m² each. However, the perennial density was measured by counting the tufts of each species within five quadrats of 20 m², each. Species richness was determined by counting all perennial and annual species within the experimental plots. In both, the protected and open grazing (control) areas, biomass production was determined. The aerial phytomass was obtained by clipping all the aerial parts of five measured plots (8 $m^2$) of both studied vegetation communities (G1 and G2).

### 2.3 Vegetation biomass and organic carbon content measurement

In each measured plot, the fresh material was weighed and dried at 105 °C for 24h, to obtain the aerial dry biomass (DM). The carbon content was measured by the loss on ignition method (ash method) (Chavan and Rasal, 2011). Samples from each clipped plot were weighed (fresh matter: M1) then burned in an oven for about 4 hours at 550°C. The obtained ash was weighed (dry matter: M2) after cooling in a desiccator.
The proportion of organic carbon (OC) content for each biomass was calculated using ash weight (M2), primary weight (M1), and the proportion of organic matter (OM), by the following formulas (Allen et al., 1986):

$$\mathbf{OM\ (\%) = (M1 - M2) / M1 * 100} \qquad \mathbf{[1]}$$

$$\mathbf{OC\ (\%) = OM\ (\%) * 0.58} \qquad \mathbf{[2]}$$

### 2.4. Statistical analysis

One-way analysis of variance (ANOVA) was performed using SPSS software 20.0 to test the effect of long term grazing enclosure on (1) the soil surface state, (2) vegetation structure and (3) aboveground biomass and carbon content.

## III - Results and discussion

### 3.1 Soil surface state

The results of soil surface conditions in the studied rangeland sites subjected to two different management regimes (fenced versus open-grazed) for two plant communities ((i) G1 dominated by Anthyllis henoniana and Gymnocarpos decander and (ii) G2 dominated by Rhanterium suaveolens and Stipa lagascae) are presented in Figure 1.

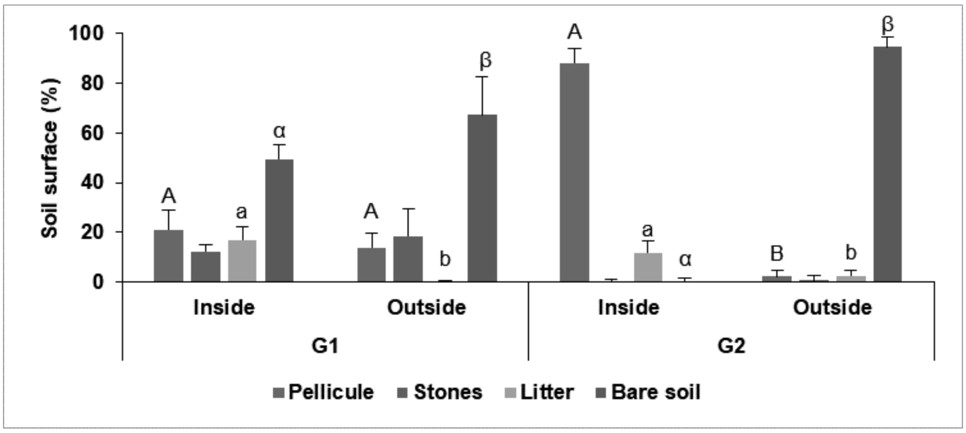


**Figure 2.** Variation of soil surface states for two plant communities (G1 and G2) inside and outside the Sidi Toui National Park. A/B, a/b and α/β indicated the differences between sites inside and outside park for Pellicule, litter and bare soil, respectively. No difference observed for stones for the two communities. Values are means ± SD (n = 5)

For the G1, the effect of protection was significant on the bare soil percentage (p=0.039), highly significant (p<0.001) on the litter percentage and non-significant on the pellicle and stones. The bare soil was higher in the open-grazed site with 67.4% then the protected site with 49.6%. The site inside the park had the highest litter value (17%) while it was very low outside, in order of 0.2%.

In G2, the highest percentage of bare soil was showed in the open-grazing site (94.6%) and lowest was in the protected site (0%). In contrast, the pellicle percentage was very higher inside the park (88.2%) than outside (2.2%). The litter percent too was significantly lower in the grazed area (11.8%) than the fenced area (2.4%).

The long term grazing exclusion reduces significantly the bare ground cover and by evidence the reduction of soil erosion and the sensitivity of the site to desertification (Ouled Belgacem et al., 2019). These results corroborate with those found by Yeo (2005) in east central Idaho in America and by Mofidi et al. (2013) in an Iranian rangelands.

Heavy grazing results in a reduction of plant residues in soil (Litter). Qiu et al. (2013) reported that the accumulation of litter materials on the ground could contribute to the increase of carbon and nitrogen input into soil.

Jing et al. (2013) concluded that excess litter accumulation in long-term fenced sites can inhibit species renewal. This build-up of fresh litter and organic material may also prevent the infiltration of rainfall into the soil. Which accelerates the decomposition of organic matter and renders the rainfall unavailable for infiltration, plant growth and cycling of C and N in semiarid and arid regions (Qiu et al., 2013).

## 3.2 Vegetation Cover

Plant cover percentages in the studied plant communities subjected to two different management regimes (open grazed and protected) are presented in figure 3.

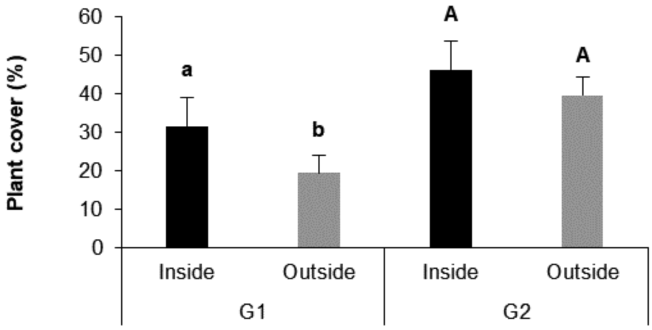


**Figure 3.** Plant cover variation on two plant communities (G1 and G2) inside and outside Sidi Toui National Park. Letters above (a,b and A) indicated the differences between sites inside and outside park for G1 and G2, respectively. Values are means ± SD (n = 5).

The mean values were 31.6% and 46.4% inside and 19.4% and 36.9% outside for G1 and G2, respectively. For the G1 community, plant cover percentage increased significantly inside the protected area. Whereas, no difference was detected between the protected and grazed rangelands for the G2 community.

The increase of the total plant cover inside the protected areas can be explained by the improvement of soil conditions (temperature, moisture, nutrient cycling) inside the protected sites promoting the regeneration and the development of plants. Our statements are in accordance with those reported by (Jeddi and Chaib, 2010) and (Ludwig and Tongway, 1997), which they reported that bigger patch size with more litter content provided specific microclimate, prevented resource loss, and improved structural and functional characteristics of the protected sites.

These results confirm those found by many authors (Yeo (2005); Mofidi et al. (2013); Zhang et al., 2017). However, the findings stated by Song et al. (2020) on the effect of long term grazing exclusion on plant traits in China, oppose our results and conclude that long-term grazing exclusion significantly reduce the total plant coverage.

## 3.3 Plant density

The annuals and perennials densities for the two vegetation groups were presented in table1. As shown in this table, the perennials density was higher in the protected area for the two studied plant communities. These increases were significate and in order to 22% for G1 but non-significate for G2. The highest perennials density was measured inside the park for the G2. Our results corroborate the results stated by Tang et al. (2016), Li et al. (2018), China and Jeddi et al. (2010) and Moumni et al. (2020), in Southern Tunisia. These authors reported that grazing exclusion increases the number of species in sandy lands. In addition, Ouled Belgacem et al. (2019) concluded that some perennial dynamics are supported by protection.

**Table 1.** Annuals and perennials densities for the two vegetation communities (G1 and G2) inside and outside Sidi Toui National Park. Values are means ± SD (A/B and a/b indicated the differences between sites inside and outside park for annuals and perennials, respectively).

| Individuals plants $m^{-2}$ | *Group 1 (G1)* | | *Group 2 (G2)* | |
|---|---|---|---|---|
| | **Inside** | **Outside** | **Inside** | **Outside** |
| **Annuals (n=10)** | 4.5 ± 3.6 (A) | 16.5 ± 9.7 (B) | 9 ± 2.5 (A) | 25.2 ± 7.8 (B) |
| **Perennials (n=5)** | 2.24 ± 0.1 (a) | 1.75 ± 0.1(b) | 3.16 ± 0.7 (a) | 2.58 ± 0.6 (a) |

The highest value of annuals densities (25.2 plts $m^{-2}$) was recorded in G2, in the open grazing site. However, this density was 9 plants $m^{-2}$ for the same community subjected to the protection regime. Similar results were observed for the G1, where the annuals density was significantly higher in the grazed site (16.5 plants $m^{-2}$).

The annuals densities are generally depending on soil conditions, disturbance stage and rainfall consistency (Ouled Belgacem et al., 2019). Our results showed that annuals were increased by grazing pressure. These results corroborate the findings of Tai et al. (2021) and Diaz et al. (2007) considering that grazing exclusion decreased annuals density and species diversity. Su et al. (2005) found that in grazed communities, the proportion of annuals density reached 70%, which was coupled with lower productivity. The abundance of these species in the grazed area is probably explained by germination capacity that stimulated by grazing and rainfall. In the fenced area, the large coverage of the studied communities and the accumulation of litter can reduce the access to light for seedlings of other species (Ungar, 1998).

## 3.4 Species richness

Species richness variations across rangeland management of sampled sites are illustrated in table 2. For the two plant communities, there are more perennials species (three additional species) in the protected area than the open grazing zone. However, no effect of the protection was observed on the annual richness. These results demonstrated that no significant effect of long term grazing exclusion on the species richness.

**Table 2.** Perennials and annuals species richness for the two vegetation communities (G1 and G2) inside and outside Sidi Toui National Park.

| | G1 | | G2 | |
|---|---|---|---|---|
| | **Inside** | **Outside** | **Inside** | **Outside** |
| **Annuals** | 9 | 9 | 9 | 8 |
| **Perennials** | 8 | 5 | 10 | 7 |

Wu et al. (2009) reported that long-term fencing decreased species diversity. Jing et al. (2013) suggested that species diversity and biomass reached a peak values in the 20th year then decreased with time of restoration due to the litter accumulation. The same for Deng et al. (2014) who reported that peak species richness appeared under moderate and light grazing but not long-term fenced. This occurrence can be explained by plant competition and reproduction, the large coverage and the accumulation of litter caused by long term grazing exclusion (Schultz et al., 2011).

Tang et al. (2016) and Moumni et al. (2020) reported that grazing exclusion increased the number of species, as well as Li et al. (2018) who mentioned that the total number of species exhibited a hump-shaped pattern in response to the length of the grazing exclusion, with a threshold of 6 years. Yet, Schultz et al. (2011) reported that the species richness decline in fenced area by phytomass accumulation. These authors mentioned that Species richness decreased in the absence of grazing only at the high productivity sites (i.e. when phytomass accumulation was > 500 g $m^{-2}$).

## 3.5 Aerial Biomass

The aerial dry biomass (kg $ha^{-1}$), for G1 and G2 both in the grazed rangeland and inside the park, was presented in figure 4. The analysis of this figure show that the aerial biomass value varies from 1855 kg $ha^{-1}$ to 3537.5 kg $ha^{-1}$ for all plant communities. This biomass was significantly higher in the protected area for the two studied plant communities. An increase of 44% and 42% were observed in the protected area of G1 and G2, respectively.

Continuous grazing accelerated aboveground biomass loss by herbivore and leads to less phytomass accumulation. This is in agreement with results obtained by Yong-Zhong et al. (2005) in Inner Mongolia (China), Jeddi and Chaib (2010) and Moumni et al. (2020) in southern Tunisia and Mofidi et al. (2013) in Iran. These authors stated that increased vegetation production in the exclusion could be due to soil conditions improvement (temperature, moisture, and nutrient cycling). However, Yet et al. (2018) reported that the remarkable improvement in pasture yield in the fenced plots was mainly related to decrease of herbivore consumption, whereas the improvement in soil properties was beneficial to the restoration of the vegetation.

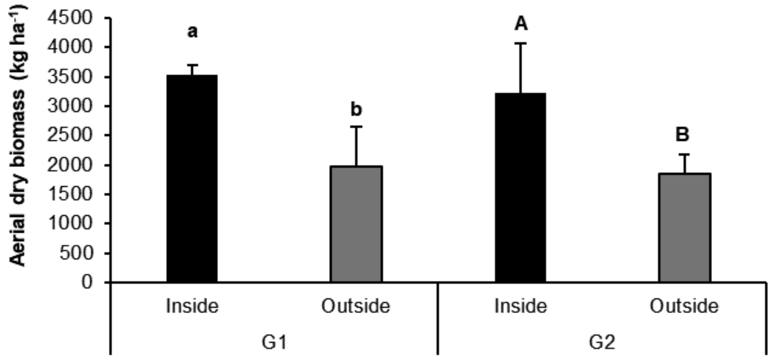


**Figure 4. Variation of aerial biomass for the two vegetation communities (G1 and G2) inside and outside Sidi Toui National Park. a/b and A/B indicated the differences between sites inside and outside park for G1 and G2, respectively. Values are means ± SD (n = 5)**

## 3.6 Aerial carbon content

The carbon content in aerial biomass for the two studied communities inside and outside the park was presented in figure 5. The amount of carbon was significantly higher in protected area for the two studied communities. There were 1918 kg ha$^{-1}$ and 1355 kg ha$^{-1}$ in protected and grazed area, respectively, for the G1 community. In the second studied community (G2), there were 1727 kg ha$^{-1}$ in protected area and 846 kg ha$^{-1}$ in open grazing area.

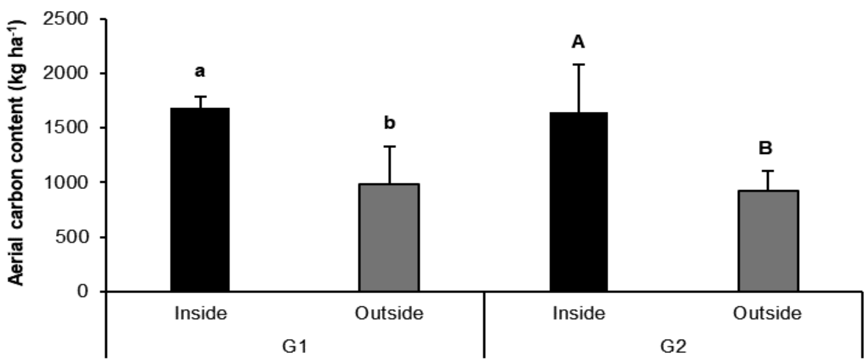


**Figure 5.** Variation of areal carbon content for the two plant communities (G1 and G2) inside and outside Sidi Toui National Park. a/b and A/B indicated the differences between sites inside and outside park for G1 and G2, respectively. Values are means ± SD (n = 5)

Our results showed that grazing exclosure had a significant effect in the phytomass carbon content. Continuous grazing can decrease the level of vegetation cover, resulting in the loss of aboveground biomass and carbon content and even the loss of SOC (Su et al., 2005). Reda (2020) suggest that grazing exclusion has the potential to enhance carbon store (on average 192.70%) in aboveground biomass in different grazing ecosystems. Deng et al., (2014) explain the increase of carbon stock in grazing exclusion by the fact that it reduces output of carbon from the ecosystem to livestock and increase productivity. In addition, Xiong et al. (2016) stated that grazing exclusion significantly increased carbon storage in aboveground biomass (84.7%) and litter mass (111.6%). A study in the alpine ecosystem in China revealed that aboveground carbon stocks are higher in long-term absence of grazers than in continual grazing due to the reduction of herbivores populations. Deng et al. (2014) confirmed that aboveground carbon stock of the grazed grassland was lower than that of the restored grassland, while carbon sequestration rates decreased with vegetation restoration.

However, Nosetto et al. (2006) disagree with the above conclusions and checked that there was no significant difference in carbon store between exclosure and adjacent free grazing areas in a study in north western Patagonia. Likewise, Chibani et al. (2021) reported that the Comparison of the aerial biomass and carbon content of some key woody species inside and outside the Sidi Toui National Park indicated a non-significant effect of long-term protection on shrub biomass production and carbon content, except for the big canopies of the low range value chenopods (i.e. *Haloxylon schmittianum* and *Haloxylon scoparium*).

Tanentzap and Coomes (2012) considered that Plants which are adapted to high-intensity grazing regimes may be more capable to recover rapidly from herbivory (can re-grow to an equal or greater biomass (overcompensation) than their pre-defoliation levels). They explained this by the fact that grazing can be associated by increases in soil nitrogen availability, which promote growth, herbivore consumption of litter fall that shades young plants and/or reductions in the competitive ability of neighbors. They concluded that carbon stocks increased in many circumstances because of the influence of herbivores on litter decomposition and nitrogen mineralization.

Generally, continuous grazing is very disastrous to carbon sequestration in vegetation and soil. Then, appropriate grazing intensity will stimulate vegetation and soil carbon sequestration and subsequent carbon storage considering precipitation gradient and vegetation type.

## IV - Conclusion

Grazing exclusion has been reported as one of the effective methods to restore the degraded rangelands. The study of the impact of long-term fencing on vegetation and aboveground carbon sequestration amount contribute to the assessment of this management technique. The results of this study showed that grazing exclusion is a beneficial ecosystem restoration approach to reduce significantly the bare ground cover and improve sensitivity of the site to desertification and soil erosion. Moreover, long-term protection contribute to restore overgrazed rangelands and to increase phytomass and carbon sequestration in El Ouara natural rangeland in Southern Tunisia. However, this study did not investigate the effect of fencing on rangeland production and soil nutriment improvement and soil carbon sequestration.

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