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Modeling the distribution of *Vachellia tortilis* (forssk.) in Tunisian drylands

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Abstract

Biodiversity conservation, through the creation of national parks, is generally helping to maintain a greater level of resilience within ecosystems and to protect the natural plant cover and threatened plant species. This research was conducted in Bou Hedma National Park, a UNESCO-MAB biosphere reserve containing the unique *Vachellia tortilis* (Forssk.) Gallaso & Banfi steppe with trees in Tunisia. The focus is to explore how the distribution of suitable habitat for *V. tortilis* might shift under climate change scenarios using the MaxEnt modeling algorithm. The Canadian Earth System Model version 5 (CanESM5) was used for projecting the future distribution. The model was run under two Shared Socioeconomic Pathways (SSP245, SSP585) during four time periods (2021-2040, 2041-2060, 2061-2080, and 2081-2100). The tested climate change scenarios seem to be affecting the species' suitable habitat in the park. Three soil variables (Clay, Coarse, WRB Classes) are significant factors in determining *V. tortilis*'s suitable habitat. Distribution modeling provides valuable information for managers to implement suitable strategies to conserve this endemic, rare, and threatened plant tree and the overall ecosystem.

1. INTRODUCTION

Dryland ecosystems are threatened both by climate variations and human disturbance (Millennium Ecosystem Assessment (MEA) 2005). Increased temperature, rainfall, changes in rainfall patterns, and severe droughts are the main climatic conditions threatening the ability of these ecosystems to produce (Yao et al. 2020) and pose significant problems for vegetation dynamics, ecosystem functioning, and biodiversity conservation (Hilbert et al. 2007). These pressures are particularly important in arid regions, where plant species distribution is often influenced by climatic and edaphic conditions. Understanding how environmental changes may affect the distribution of key plant species is therefore essential for developing effective conservation strategies in dryland ecosystems

Active management is increasingly considered the major challenge for maintaining biodiversity, reducing natural resource degradation, and combating desertification (Gamoun and Louhaichi 2021). The establishment of national parks is one of the main strategies to achieve biodiversity conservation and to preserve the natural plant cover as well as the threatened plant species in arid and desert areas of Tunisia and all around the world (Ouled Belgacem et al. 2008; Ouled Belgacem et al. 2019). Predicting how species distributions may respond to future environmental conditions.

Vachellia tortilis (Forssk.) Gallaso & Banfi (Fabaceae) is a “Keystone tree species”, widely distributed in arid and semi-arid ecosystems of North, East and Southern Africa, the Middle East and the Arabian Peninsula (Taha et al. 2022). It is well adapted to harsh environmental conditions and disturbances (drought, fire, and browsing) (Noumi and Chaieb 2012). It is also known for its ability to improve soil fertility and to increase biodiversity (Abdallah et al. 2008).

Previous studies have described the ecological importance of *V. tortilis* (Abdallah et al. 2008; Noumi and Chaieb 2012), but its potential future distribution under different climate change scenarios has not been assessed using a species distribution modelling approach.

Species distribution models (SDMs), including the Maximum Entropy (MaxEnt) approach, provide a useful framework for relating species occurrence data to environmental conditions and projecting potential habitat suitability under current and future scenarios.

This study focuses on modeling the current and projected future distribution of *V. tortilis* in Bou Hedma National Park using MaxEnt. Specifically, we aimed to (i) identify the environmental variables contributing most strongly to the current distribution of the species, and (ii) assess change in the spatial distribution under two future Shared Socioeconomic Pathways (SSP145 and SSP585 and four future periods (2021-2040, 2041-2060, 2061-2080, and 2080-2100). By examining the shifts in suitable habitats, we aim to understand the potential impact of climate change on this vital species and inform conservation strategies to optimize its future safeguarding.

2. MATERIAL AND METHODS

2.1. Study area

Bou Hedma National Park (34.476102 N, 9.649239 E; Fig. 1), created in 1980, plays a key role in the conservation of flora and fauna biodiversity and contains the unique *V. tortilis* steppe with trees in Tunisia (Tarhouni 2003). It is characterized by an arid Mediterranean bioclimate (Le Houérou 1969). The average annual rainfall varies between 100 and 200 mm. The average annual temperature is about 17.2°C.

2.2. Environmental variables & species distribution modeling

The potential distribution of *Vachellia tortilis* under current and future climatic conditions was modelled using the maximum entropy algorithm implemented in MaxEnt version 3.4.4. Occurrence records of *V. tortilis* were obtained from the field surveys, resulting in 97 occurrence records after data cleaning. The final occurrence records were randomly divided into two subsets, with 75% used for model training and 25% used for model testing and validation.

A total of 34 environmental predictors were considered, including 19 bioclimatic variables (19 bioc), three topographic variables, and 12 soil variables. The 19 bioc variables were obtained from WorldClim version 2.1 at a spatial resolution of 30arc-seconds (approximately 1 km). Future climatic projections were obtained for four periods, 2021-2040, 2041-2060, 2061-2080 and 2081-2100, under two Shared Socioeconomic Pathways (SSP245 and SSP585), using the Canadian Earth System Model version 5 (CanESM5). The latter was selected because its climatic predictions were considered representative of the climatic conditions of the study region. The three topographic variables, namely elevation, slope, and aspect, were derived from a 30m Digital Elevation Model using QGIS. In addition, 12 soil variables were obtained from the SoilGrids database at 250m spatial resolution. The complete list of environmental predictors is provided in Table 1. All environmental layers were harmonized to a common spatial resolution of approximately 30 × 30 m (0.000269°) and

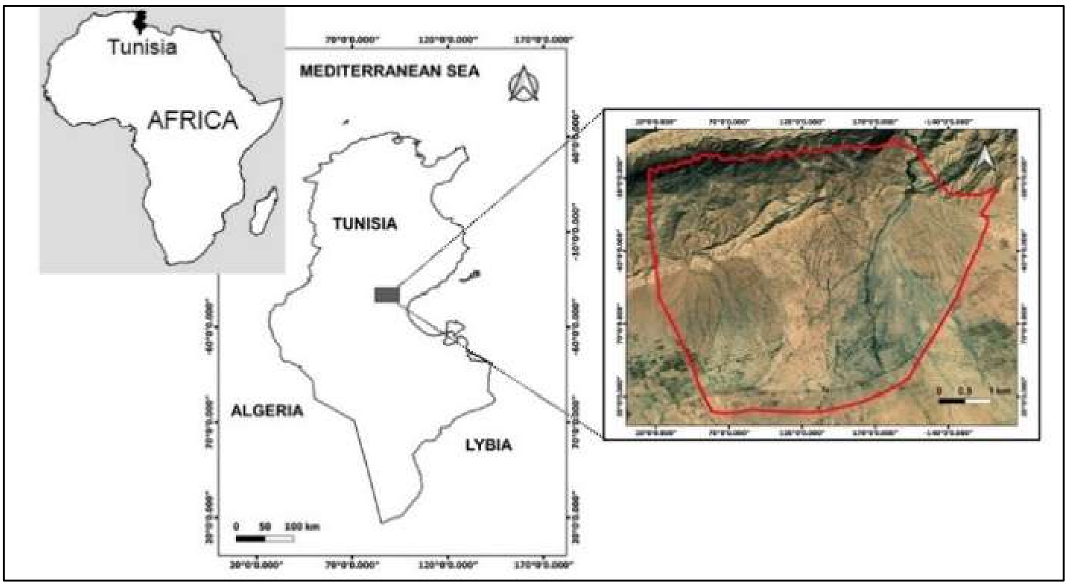

Fig. 1. Geographical location of Bou Hedma National Park

converted to ASCII format for compatibility with MaxEnt.

MaxEnt models were developed using the Cloglog output format, which provides predicted occurrence probabilities ranging from 0 to 1. The algorithm was run with a maximum of 500 iterations and a convergence threshold of 0.00001. Model performance was evaluated using the independent 25% testing dataset, and the corresponding AUC values were used to assess predictive performance. The AUC values range from 0 to 1, with AUC ≤ 0.5 indicating performance worse than random chance, 0.5 indicating a predictive discrimination close to random chance, and values ≥ 0.75 suggesting good performance (Elith et al. 2006).

For future projections, climatic variables corresponding to SSP245 and SSP585 were used to estimate potential changes in the suitable habitat of *V. tortilis* for 2021 to 2100. Suitability values were reclassified into four classes: low suitability (LP: 0-0.25), moderate suitability (MP: 0.25-0.50), high suitability (HP: 0.50-0.75), and very high suitability (VHP: 0.75-1). For the analysis of habitat distribution and changes under future climate scenarios, areas classified as HP and VHP were considered suitable habitat, while LP and MP were considered unsuitable habitat. The percentage change in the predicted distribution area between current and future conditions was then calculated for each climate scenario and projection period.

Table 1. General identification and description of the studied environmental variables.

Data source	Variable	Description	Unit
Worldclim (Bioclimatic data)	bio1	Mean annual temperature	°C
	bio2	Mean diurnal range	°C
	bio3	Isothermality	-
	bio4	Temperature seasonality	°C
	bio5	Max temperature of the warmest month	°C
	bio6	Minimum temperature of the coldest month	°C
	bio7	Temperature annual range	°C
	bio8	The mean temperature of the wettest quarter	°C
	bio9	The mean temperature of the driest quarter	°C
	bio10	The mean temperature of the warmest quarter	°C
	bio11	The mean temperature of the coldest quarter	°C
	bio12	Annual precipitation	mm
	bio13	Precipitation of the wettest month	mm
	bio14	Precipitation of the driest month	mm
	bio15	Precipitation seasonality	mm
	bio16	Precipitation of the wettest quarter	mm
	bio17	Precipitation of the driest quarter	mm
	bio18	Precipitation of the warmest quarter	mm
	bio19	Precipitation of the coldest quarter	mm
Soilgrids (Soil data)	Bulk dens	Bulk density	
	Cation	Depth: 0-5	
	Clay content	Depth: 0-5	
	Coarse	Depth: 0-5	
	Nitrogen	Depth: 0-5	
	Organic carbon dens	Organic carbon density	
	pH water	Depth: 0-5	
	Sand	Depth: 0-5	
	Silt	Depth: 0-5	
	Soil Classes_WRB	Depth: 0-5	
	Soil organic carbon	Depth: 0-5	
	Soil organic carbon stock	Depth: 0-3	
Worldclim (Topographic data)	Elevation	Elevation	m
	Slope	Slope	degree
	Aspect	Aspect	degree

3. RESULTS

3.1. Model validation and influencing variables

The predictive performance of the MaxEnt model was evaluated using the Area Under the Curve (AUC) based on the independent testing dataset. In this study, the AUC values are interpreted as an indicator of the discriminatory performance of the models. Values ranged from 0.85 to 0.89, indicating a good ability to discriminate between the environmental conditions associated with observed *V. tortilis* occurrences and the region's conditions (Table 2).

Under both scenarios, it seems that coarse and soil classes-WRB are the strongest predictors of *V. tortilis* distribution with 42.15% and 14.87% respectively under SSP245 and 31.92% and 27.6% under SSP585 (Fig. 2). Bio17 and clay are also important but with lesser contributions (6.47% and 7.92% respectively under SSP245; 5.9% and 6.05% under SSP585).

3.2. Habitat suitability for *Vachellia tortilis*

The results of MaxEnt are represented in Table 2 and Fig. 3. Under current climate conditions, the MaxEnt model indicated that 864.71 ha is suitable (HP + VHP) for *V. tortilis* to grow. The remaining 2297.47 ha were classified as unsuitable habitat (LP + MP) (Table 3). Future projections showed variable changes in the total suitable habitat depending on the climate scenario and projection period. Under SSP245, suitable habitat decreased from 864.71 ha under current conditions to 846.10 ha in 2021-2040, 630.52 ha in 2041-2060, and 626.22 ha in 2061-2080, before reaching 825.55 ha in 2080-2100. SSP585 showed a great increase in suitable habitat to 901.72 ha in 2021-2040, but then a decrease to 793.92 ha in 2041-2060, 692.97 ha in 2061-2080, and 615.52 ha in2081-2100.The area classified as very highly suitable (VHP) increases under several projections. For example, VHP increased from 214.30 ha under current conditions to 241.66 ha (+12.77%) under SSP245 and 280.82 ha (+31.04%) under SSP585 during 2021-2040. VHP also remained above the current value during several later periods, including 2041-2060 and 2061-2080 under both pathways.(Table 3). The area classified as unsuitable habitat increased under most future projections. Under SSP245, unsuitable habitat increased from 2297.47 ha under current conditions to 2316.07 ha in 2021-2040, 2531.66 ha in 2041-2060, and 2535.95 ha in 2061-2080, before decreasing slightly to 2336.63 ha in 2081-2100. Under SSP585, unsuitable habitat decreased slightly to 2260.45 ha in 2021-2040, but increased to 2368.26 ha,

Table 2. AUC of the distribution of *Vachellia tortilis* under current (2018) and future climate scenarios (SSP245, SSP585) in Bou Hedma National Park.

	Current	SSP245				SSP585			
	2018	**2021-2040**	**2041-2060**	**2061-2080**	**2081-2100**	**2021-2040**	**2041-2060**	**2061-2080**	**2081-2100**
AUC	0.855	0.866	0.871	0.888	0.862	0.854	0.877	0.894	0.855

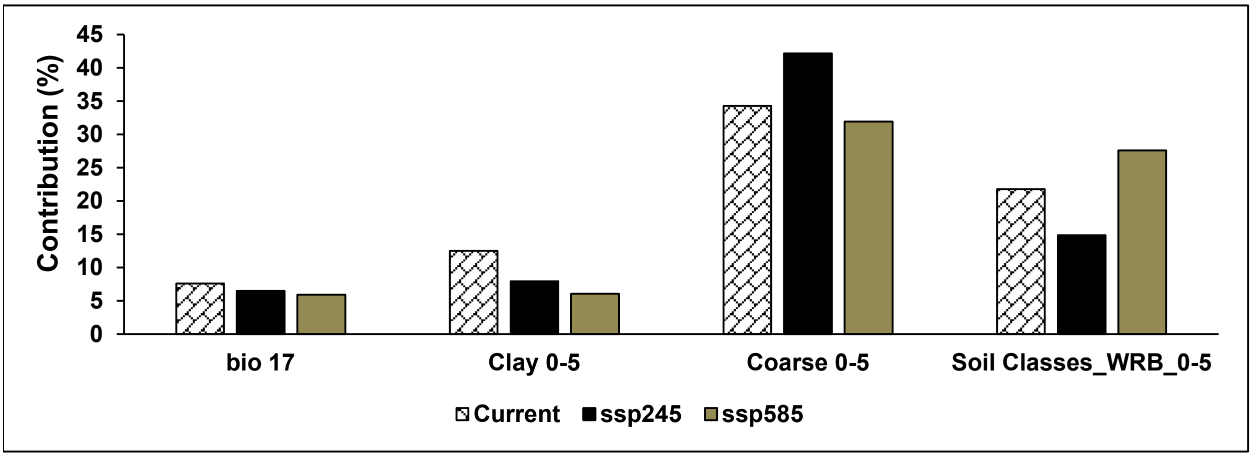

Fig. 2. Contribution (%) of bioclimatic and soil variables when predicting the distribution of *Vachellia tortilis* in Bou Hedma National Park using the MaxEnt model.

2469.21 ha, and 2546.67 ha during 2041-2060, 2061-2080, and 2081-2100, respectively.

Using the future MaxEnt layers, the predicted distribution map (Fig.3) indicates a decrease in suitable habitat over the longer projection periods. These changes were accompanied by a corresponding expansion of unsuitable habitat, indicating a potential shift from suitable to unsuitable conditions for V. tortilis under future conditions.

was used to evaluate the potential habitat suitability of *Vachellia tortilis* in Bou Hedma National Park under two future SSP pathways. The total suitable habitat, defined here as the combination of high and very high suitability classes (HP + VHP), generally decreases over longer future periods. Similar results are shown by Anthelme and Michalet (2009), who demonstrated the absence of regeneration of *V. tortilis* in the Air-Tenere Nature Reserve (Sahara, Niger). The low regeneration of *V. tortilis* in Bou

Table 3. Changes in suitability of *Vachellia tortilis* habitat (ha, %) from the current situation to 2100 according to SSP245 and SSP585 scenarios.

		Area (ha)				Percent of change (%)			
		LP	**MP**	**HP**	**VHP**	**LP**	**MP**	**HP**	**VHP**
2018	**Current**	1386.23	911.24	650.41	214.30	-	-	-	-
2021-2040	**SSP245**	1438.74	877.33	604.44	241.66	3.79	-3.72	-7.07	12.77
	SSP585	1483.95	776.50	620.90	280.82	7.05	-14.79	-4.54	31.04
2041-2060	**SSP245**	1563.42	968.24	400.14	230.38	12.78	6.25	-38.48	7.50
	SSP585	1532.24	836.02	529.69	264.23	10.53	-8.25	-18.56	23.30
2061-2080	**SSP245**	1770.51	765.44	385.30	240.92	27.72	-15.10	-40.76	12.42
	SSP585	1579.14	890.07	470.93	222.04	13.92	-2.32	-27.60	3.61
2081-2100	**SSP245**	1350.39	986.24	620.32	205.23	-2.58	8.23	-4.63	-4.23
	SSP585	1579.47	967.20	386.48	229.04	13.94	6.14	-40.58	6.88

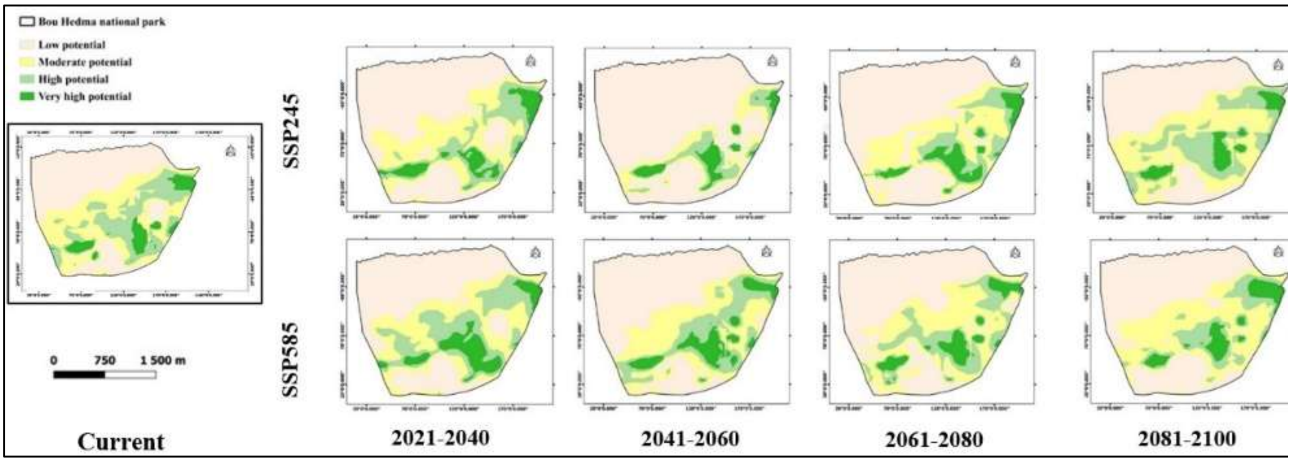

Fig. 3. Changes in suitability of *Vachellia tortilis* habitat under SSP245 and SSP585 climate change scenarios of the CanESM5 model.

4. DISCUSSION

To guide conservation priorities and management planning, predictive vegetation models could help to identify hotspots of environmental change or plant habitat suitability (Bedair et al. 2023; Capera et al. 2023). In the present study MaxEnt model, which requires datasets of actual presence called "Occurrences",

Hedma could be explained by the dominance of large and aged individuals on the one hand (Noumi and Chaieb 2012) and by the negative interaction between *V. tortilis* and other plant species on the other hand (Noumi et al. 2023). The area classified as very highly suitable (VHP) increases under several projections. This increase in VHP does not necessarily contradict the overall decline in suitable habitat. Rather, it suggests a redistribution of suitability within the study area, with some areas becoming more favorable while other areas shift toward lower suitability classes. For example, the increase in VHP during 2021-2040 occurs simultaneously with a reduction in the HP class. So, part of the change may reflect a shift from high to very high suitability in some locations.

The obtained results also indicate that the distribution of *V. tortilis* is significantly influenced by soil conditions, especially the presence of clay and coarse particles. Several studies emphasized the crucial role of edaphic factors in enhancing the accuracy of projection (Buri et al. 2017). Clay soils, known for their water retention capabilities (Romero et al. 2011), may provide necessary moisture during dry periods, while Coarse particles can enhance soil aeration and drainage (Bigelow et al. 2001). This combination of soil properties creates an optimal environment for establishing *V. tortilis* in arid and semi-arid ecosystems (Ludwing et al. 2003; Yadeta et al. 2018). The relatively high contribution of edaphic variables may be related to the limited spatial extent of the study area. Within a geographically restricted area, climatic conditions may show relatively limited spatial variation. This does not imply that climate does not influence the projected distribution.

5. CONCLUSION

The MaxEnt model provided an assessment of the potential habitat suitability of *V. tortilis* in Bou Hedma National Park under current conditions and under two future climate pathways. The projections generally indicated a reduction in the total area classified as suitable habitat over several future periods. The results also highlighted the strong role of soil conditions in determining habitat suitability, particularly coarse particles, WRB soil classes, and clay. Therefore, the projected changes cannot be attributed to climate change alone. Despite this, the results can help identify areas of potentially changing suitability, future monitoring, conservation, and management of *V. tortilis* habitats in Bou Hedma National Park.

REFERENCES

Abdallah, F., Noumi, Z., Touzard, B., Belgacem, A. O., Neffati, M., & Chaieb, M. (2008). The influence of *Acacia tortilis* (Forssk.) subsp. *raddiana* (Savi) and livestock grazing on grass species composition, yield and soil nutrients in arid environments of South Tunisia. *Flora-Morphology, Distribution, Functional Ecology of Plants*, *203*(2), 116–125.

Anthelme, F., & Michalet, R. (2009). Grass-to-tree facilitation in an arid grazed environment (Aïr Mountains, Sahara). *Basic and Applied Ecology*, *10*(5), 437–446.

Bedair, H., Shaltout, K., & Halmy, M. W. A. (2023). Stacked machine learning models for predicting species richness and endemism for Mediterranean endemic plants in the Mareotis subsector in Egypt. *Plant Ecology*, *224*(12), 1113–1126.

Bigelow, C. A., Bowman, D. C., Cassel, D. K., & Rufty, J. T. W. (2001). Creeping bentgrass response to inorganic soil amendments and mechanically induced subsurface drainage and aeration. *Crop Science*, *41*(3), 797–805.

Buri, A., Cianfrani, C., Pinto-Figueroa, E., Yashiro, E., Spangenberg, J. E., Adatte, T., Verrecchia, E., Guisan, A., & Pradervand, J. N. (2017). Soil factors improve predictions of plant species distribution in a mountain environment. *Progress in Physical Geography*, *41*, 703–722.

Capera-Aragones, P., Tyson, R. C., & Foxall, E. (2023). The maximum entropy principle to predict forager spatial distributions: An alternate perspective for movement ecology. *Theoretical Ecology*, *16*, 21–34.

Elith, J. H., Graham, C. P., Anderson, R., Dudík, M., Ferrier, S., Guisan, A. E., & Zimmermann, N. (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, *29*(2), 129–151.

Gamoun, M., & Louhaichi, M. (2021). Botanical composition and species diversity of arid and desert rangelands in Tataouine, Tunisia. *Land*, *10*(3), 313.

Hilbert, D. W., Hughes, L., Johnson, J., Lough, J. M., Low, T., Pearson, R. G., Sutherst, R. W., & Whittaker, S. (2007). *Biodiversity conservation research in a changing climate*. Commonwealth of Australia, Canberra, 74 pp.

Le Houérou, H. N. (1969). La végétation de la Tunisie steppique. *Annales de l'Institut National de la Recherche Agronomique de Tunisie*, *42*(5).

Ludwig, F., Dawson, T. E., de Kroon, H., Berendse, F., & Prins, H. H. (2003). Hydraulic lift in *Acacia tortilis* trees on an East African savanna. *Oecologia*, *134*, 293–300.

Millennium Ecosystem Assessment (MEA). (2005). *Ecosystems and human well-being: Desertification synthesis*. World Resources Institute.

Noumi, Z., & Chaieb, M. (2012). Dynamics of *Acacia tortilis* (Forssk.) Hayne subsp. *raddiana*

(Savi) Brenan in arid zones of Tunisia. *Acta Botanica Gallica*, *159*(1), 121–126.

Noumi, Z., Mezghani, I., & Mseddi, K. (2023). Relative contributions of short-term canopy and long-term soil effects of a native shrub under arid bioclimate: A case study from Tunisia. *Wood Research*, *68*(1), 141–153.

Ouled Belgacem, A., Ben Salem, H., Bouaicha, A., & 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*, *8*(4), 822–825.

Ouled Belgacem, A., Ben Salem, F., Gamoun, M., Chibani, R., & Louhaichi, M. (2019). Revival of traditional best practices for rangeland restoration under climate change in the dry areas: A case study from Southern Tunisia. *International Journal of Climate Change Strategies and Management*, *11*(5), 643–659.

Romero, E., Della Vecchia, G., & Jommi, C. (2011). An insight into the water retention properties of compacted clayey soils. *Géotechnique*, *61*(4), 313–328.

Taha, D., El Hajjaji, S., Mourabit, Y., Bouyahya, A., Lee, L. H., El Menyiy, N., & Bourais, I. (2022). Traditional knowledge, phytochemistry, and biological properties of *Vachellia tortilis*. *Plants*, *11*(23), 3348.

Tarhouni, M. (2003). *Cartographie des systèmes écologiques et étude de la dynamique de l'occupation des terres dans le parc national de Bou Hedma*. DEA thesis, Université de Sfax, Faculté des Sciences de Sfax, Tunisia, 73 pp. + annexes.

Yadeta, T., Veenendaal, E., Sykora, K., Tessema, Z. K., & Asefa, A. (2018). Effect of *Vachellia tortilis* on understory vegetation, herbaceous biomass and soil nutrients along a grazing gradient in a semi-arid African savanna. *Journal of Forestry Research*, *29*, 1601–1609.

Yao, J., Liu, H., Huang, J., Gao, Z., Wang, G., Li, D., & Chen, X. (2020). Accelerated dryland expansion regulates future variability in dryland gross primary production. *Nature Communications*, *11*(1), 1665.