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Review

Lygeum spartum L.: a review of a candidate for West Mediterranean arid rangeland rehabilitation

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Abstract. *Lygeum spartum* L. (Poaceae) is a perennial native grass grown throughout arid and semi-arid regions around the West Mediterranean basin. In terms of pastoral use, its associations with other annual species and small chamaephytes constitute a valuable source of livestock forage. *L. spartum*, which has an extensive root system, reduces soil erosion and enhances soil stabilisation. The leaves contain many fibres, producing a material suitable for basket manufacture. This plant species can also be used in the phytoremediation of contaminated soils. Published work on the research and development of this species is meagre. This article represents an effort to compile the literature on *L. spartum* and to review the current understanding of this plant and its potential as an alternative source of fodder during periods of forage scarcity, for traditional craftsmen, for phytoremediation and for rangeland rehabilitation purposes.

Additional keywords: basketry, drought, fodder, salinity.

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Introduction

Lygeum spartum L. (Poaceae), commonly known as albardine, esparto grass in Spain and *sennagh*, *gousmir* and *halfa maboula* in North African Arabic, is an important perennial grass in semi-arid and arid areas in the West Mediterranean basin (Le Houérou 2001; Nedjimi and Beladel 2015). This grass provides a natural fence against desert extension. In addition to its ecological role, *L. spartum* is of economic interest to traditional craftsmen and is used in basketry (sparterie) manufacture (Keith 1965). *L. spartum* is a poor-quality fodder, but is nevertheless consumed by small ruminants (sheep and goats) when pastoral pressure is intense and/or as an ultimate forage resource when nothing else is available, a common occurrence in the North African steppes. This article presents an overview of the systematic and botanical characteristics of *L. spartum*, the mechanisms of its adaptation to environmental stresses such as salinity, drought and heavy metals, and its suitability for basket making, pastoral use and soil rehabilitation. *L. spartum* is examined from the point of view of it being a perennial grass of substantial ecological (against erosion; enhanced soil stabilisation) and economic (artisanal activities by pastoral populations) value in West Mediterranean rangelands.

Distribution

L. spartum is widely distributed naturally around the West Mediterranean basin, including Spain, Italy, Malta, Tunisia, Algeria and Morocco (Le Houérou 2001). It is at its extreme eastern limit near Marsa Matruh (extreme east of Marmarica, Libya) in the north-western coastal region of Egypt (Täckholm 1978; Boulos 2005). In Algeria, Aidoud *et al*. (2006) found that *L. spartum* was one of the dominant grasses in the transitional zones between arid steppe and subdesert areas, together with *Stipa tenacissima* and *Artimisia herba alba*. In addition, *L. spartum* can cohabit with halophytes in saline soils (Nedjimi 2009).

L. spartum proliferates in areas of low annual rainfall and high evapotranspiration potential (ETP), and demonstrates better growth in arid (rainfall 150–250 mm, ETP 0.06–0.28) and semi-arid (rainfall 300–450 mm, ETP = 0.28–0.45) steppes than other Mediterranean species (Le Houérou 2001). *L. spartum* predominantly colonises and grows in gypsum terraces covered with sandy soil throughout North Africa and north-west Egypt. In Algeria and Morocco, this species appears to prefer sand-loam soil textures with a calcareous crust. Native populations occur in neutral or alkaline soils (pH 7–11), which are often gypseous soils (Djebaili 1984). In Spain (Iberian Peninsula), *L. spartum* occurs in xeric environments rich in marls and clays, with optimal growth in coastal zones exposed to sea breezes or on gypsum-rich soils (García-Fuentes *et al*. 2001). *L. spartum* is a cold-tolerant plant, with average minimum temperatures in the coldest months of –10 and –12°C (Nedjimi 2011).

Botany and systematics

L. spartum is a perennial tussock grass with erect wiry leaves (30–70 cm long; Fig. 1*a*). Average leaf longevity is 2.5 years and elongation rates range between 0.12 and 4.4 mm day^{-1} (Pugnaire and Haase 1996). The bases of the leaves are protected by a hairy sheath. Dead leaves remain attached to the tussock

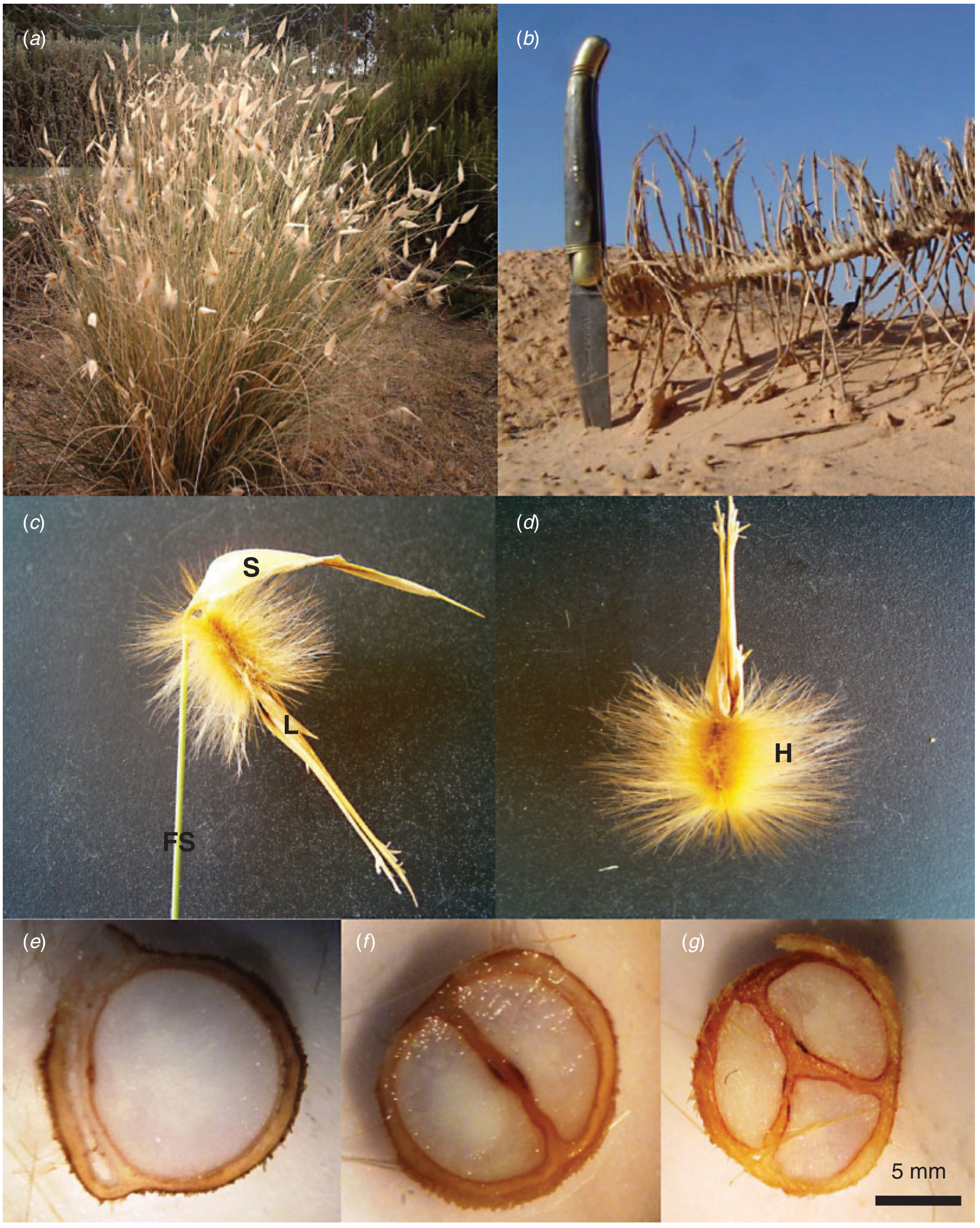

Fig. 1. (*a*) *Lygeum spartum* L. tussock (Poaceae) from Djelfa region (Algeria). Total height = 80 cm. (*b*) *L. spartum* rhizome with short internodes. (*c*) *L. spartum* seed with spathe or glume (S), lemma (L) and floral stalk (FS). (*d*) Mature seed of *L. spartum* (1 × 3 cm) with numerous unicellular hairs (H). (*e–g*) Transverse sections of mature spikelets with one (*e*), two (*f*) or three caryopses (*g*).

for many years, forming dense tufts that contribute to sand stabilisation. Rhizomes are short and covered by tough scales (Quézel and Santa 1963). The leaves of *L. spartum* are often confused with those of *S. tenacissima* (Halfa) and *Aristida pungens* (Drinn), but they can be distinguished by their long ligule (Nedjimi *et al*. 2011). The shallow roots of *L. spartum* constitute 75% of the whole plant biomass (rooting depth 50 cm). This shallow rooting system enables *L. spartum* to react rapidly to small changes in soil moisture (Aidoud 1989). Mattia *et al*. (2005) compared the characteristics of the root systems of three Mediterranean species, indicating that the root reinforcement used by *L. spartum* is stronger than the reinforcement exerted by *Atriplex halimus* and *Pistacia lentiscus* in the upper layers of the soil. The inflorescence of *L. spartum* is formed by a single spikelet with one to four flowers. After maturation, each mature spikelet presents between one and three caryopses (Fig. 1*e–g*).

The genus *Lygeum* is represented only by one species, *L. spartum* (Quézel and Santa 1963). The presence of two distinct cytotypes has been suggested (Benmansour and Kaid-Harche 2001; Djabeur *et al*. 2008); the first cytotype, growing in semi-arid coastal regions, is tetraploid (2n = 4x = 40), whereas the second, growing in arid steppes, is diploid (2n = 2x = 16).

The principal soil colonisation strategy of *L. spartum* is based on vegetative multiplication (rhizomes). This mechanism is used during the aging phase of the tussock. During this stage, the old plant produces new tussocks in the periphery of the mother plant (Nedjimi *et al*. 2011). The rhizomes of *L. spartum* are mostly linear, with a very dense rooting system developing almost vertically at each internode under the rhizomes (Fig. 1*b*), making *L. spartum* efficient in soil stabilisation. Each short internode bears a leaf and a root. The rhizome is totally protected and covered with very hard short scales over the whole length of the internodes. This is one of the main differences from the rooting system of *S. tenacissima* (on limestone) and *A. pungens* (on mobile sand), which are papery, twisted and convoluted, with little rootlets and long internodes (Aidoud 1989).

Although *L. spartum* propagates by rhizome growth, it also spreads via seeds (Fig. 1*c*, *d*; Nedjimi 2013), a single plant generally producing flowers from May to July. If the autumnal rains are sufficient, early flowering can be detected in April (Aidoud 1989). Under field conditions, Djabeur *et al*. (2008) observed that the diploid cytotype generally produces more numerous seeds that grow more rapidly than the polyploid cytotype. The slower seed germination of the polyploid cytotype was attributed to the presence of the lemmas' caryopsis (Djabeur *et al*. 2010). However, Nedjimi (2013) reported that seed hair removal strongly increased the germination percentage of *L. spartum*.

Stress tolerance

Tolerance to extreme temperatures

L. spartum, a species adapted to the Mediterranean climate, possesses a C3 carboxylation pathway (Smith and Brown 1973). The maximum photosynthetic rate (*A*) is found in late autumn (10.7°C), reaching 0.14 $\mu mol\ m^{-2}\ s^{-1}$ (Pugnaire and Haase 1996). In the western Algerian steppe (Rogassa region, El Bayadh), *L. spartum* is a cold-tolerant plant, with average minimum temperatures in the coldest months of around –12°C, yet it is able to tolerate hot summers (+40°C; Aidoud 1989).

Tolerance of salinity stress

In North Africa, *L. spartum* is predominantly a gypsophyt ('gypsum-loving') plant, with most *L. spartum* populations occurring on gypsum terraces. However, Nedjimi *et al*. (2010) classified this grass as a moderately salt-tolerant plant, able to tolerate soil salinity levels equivalent to electrical conductivity (EC) values of 4–5 $dS\ m^{-1}$. At the germination stage, *L. spartum* appears to tolerate salinity at 10–20°C (Nedjimi 2013). Moderate concentrations of sodium chloride (<60 mM) enhance the growth of *L. spartum*, whereas higher levels have been shown to be inhibitory (Nedjimi 2009, 2011). This adaptation to salt stress was attributed to improvements in net CO_2 assimilation and stomatal conductance (g_s; Nedjimi 2009).

Similar to other salt-tolerant plants, *L. spartum* accumulates the main ions of salinity (i.e. Na^+ and Cl^-) and other anions in its tissues (Nedjimi 2014), sequestering them in vacuoles. This active intracellular ionic accumulation, or osmotic adjustment or osmoregulation, produces low water potential (Ψ_w), decreases osmotic potential (Ψ_p; e.g. –0.21 MPa) and maintains tissue turgor (Ψ_t; Nedjimi *et al*. 2013). Simultaneously with the accumulation of ions in the vacuoles, there is cytoplasmic accumulation of organic osmolytes (primarily glycine betaine and valine) that do not interfere with normal metabolic activities (Nedjimi 2011). These maintain the osmotic balance and structural membrane integrity. In addition, significant accumulation of soluble sugars, probably associated with osmotic adjustment and protection of membrane stability, occurs in roots of salinised plants (Nedjimi 2011). However, at high external salinity (>100 mM NaCl), dry matter (DM), root hydraulic conductivity (L_0), g_s, chlorophyll content and mineral nutrients, such as Ca^{2+}, Mg^{2+} and PO_4^{3-}, decrease significantly with increasing salinity (Nedjimi 2009).

Tolerance of drought stress

Xerophytic C3 species such as *L. spartum* have some morphological and physiological adaptions to moisture stress, are water use efficient and are therefore adapted to dry climates. After rain, the dense and shallow root system rapidly absorbs soil moisture (Mattia *et al*. 2005). *L. spartum* can respond rapidly to small variations in soil water content, such as that from summer precipitation (Pugnaire and Haase 1996). When exposed to drought, water-stressed *L. spartum* plants can enhance both Ψ_p and Ψ_w. Pugnaire and Haase (1996) concluded that the enhanced water use efficiency contributed to better growth in several arid regions.

L. spartum leaves are arranged such that self-shading decreases transpiration and g_s at high diurnal temperatures (Lemée 1954). *L. spartum* tussocks can form knolls of organic debris and fine soil particles that retain more humidity and nutrients than the soil between tussocks (Aidoud 1989).

Tolerance of heavy metals stress

L. spartum spontaneously colonises contaminated soils and mining sites. In southern Spain, its field tolerance mechanisms to heavy metals have been investigated by Conesa *et al*. (2007). Studies of *L. spartum* grown in pots containing contaminated soil demonstrated that it is tolerant of high of Cd, Cu, Pb, As and Zn concentrations (Conesa *et al*. 2009*a*). In addition, Conesa *et al*. (2009*a*) indicated that heavy metals are retained in roots rather than being transported to the shoots, which may decrease the risk of metals entering the animal food chain.

Arbuscular mycorrhizal fungi

In Mediterranean soils, the presence of *L. spartum* increases the density of root arbuscular mycorrhizal fungi, organic carbon and mineral uptake from superficial soil layers (depth to <20 cm; Caravaca *et al*. 2005). The resistance of *L. spartum* to heavy metal stress is related to the amelioration of Zn nutrition by mycorrhizal fungi (Díaz and Honrubia 1995). Díaz *et al*. (1996) studied the effect of two different mycorrhizal fungi, namely *Glomus macrocarpum* and *G. mosseae*, on plant growth and Pb uptake by *L. spartum* and found that arbuscular mycorrhizae can play a significant role in the restoration of polluted soils by protecting the plants from high concentrations of heavy metals, and that this effect is due, in part, to an improvement in a plant's phosphorus status. For *L. spartum* plants grown in the Cartagena–La Unión mining district in south-east Spain, Carrasco *et al*. (2010) reported that the *L. spartum* rhizosphere was dominated by fungal and bacterial phospholipid fatty acid (PLFA) communities; however, Caravaca *et al*. (2005) suggested that soil properties, such as aggregate stability, are enhanced by rhizosphere microbial activity.

Potential applications of *L. spartum*

Basketry

L. spartum was used in the mid-1920s in Europe and the UK in the manufacture of boaters, light straw hats with a stiff flat crown and brim. The boater is still a common part of the school uniform in many boys' schools in Britain and some Commonwealth countries. *L. spartum* is an important economic product in North African countries, used largely for basket handicraft. The most traditional uses of its leaves are for making cordage, sandals, ropes, matting, mattress stuffing, bags and carpets (Keith 1965). The leaves of *L. spartum* are collected from July to November (Aidoud 1989). In Algeria, the local population uses a traditional harvesting method, whereby the green leaves are turned around a short baton and vigorously pulled to detach them from the tussocks (the same traditional method is used to harvest *S. tenacissima* leaves).

L. spartum can produce cellulosic fibres appropriate for paper manufacture (Harche *et al*. 1990, 1991; Zeriahene *et al*. 1998; Berzosa 2012; Belouadah *et al*. 2015). However, in the North African steppes and in Spain, two principal constraints prevent the use of *L. spartum* for paper making: (1) the low biomass production (300–500 kg DM ha^{-1}) from very limited areas; and (2) harvesting *L. spartum* stands enhances the potential for soil degradation, particularly given that this species grows mostly on gypsum crusts where few other species can grow.

Livestock fodder

L. spartum produces 0.3–0.4 feed units (FU) kg^{-1} DM (Bechet *et al*. 1982). In terms of pastoral use, *L. spartum* steppes provide a valuable source of forage during dearth periods because of the high total productivity, floristic diversity and forage value of the plant associations where *Lygeum* is dominant (Aidoud-Lounis 1984). In Algerian steppes, Djebaili *et al*. (1989) reported that plant associations of *L. spartum* (relative productivity 300–500 kg DM ha^{-1} $year^{-1}$ and pastoral production of 150 FU ha^{-1} $year^{-1}$) provide an average stocking rate of 3.5 ha^{-1} sheep, compared with 2.5 ha^{-1} sheep for plant associations of *S. tenacissima*. However, this production is much less under standard, open-grazing conditions (130–180 kg DM ha^{-1} $year^{-1}$; Rodin *et al*. 1970; Aidoud *et al*. 2006).

Compared with *S. tenacissima* (another important grass of arid rangelands), *L. spartum* tussocks had a much higher growth rate throughout the seasons (Pugnaire and Haase 1996). In addition, Pugnaire and Haase (1996) demonstrated that the DM yield and rain use efficiency of *S. tenacissima* are lower than those of *L. spartum* because of their different environmental situations, with *S. tenacissima* growing on calcareous shallow soils, whereas *L. spartum* occurs in deeper soils with higher field capacity and better water content. Andueza *et al*. (1999) reported that the crude protein content and digestibility of *L. spartum* are similar to those of other forage species, such as *Stipa* sp. and *Brachypodium retusum*. However, El-Shesheny *et al*. (2014) demonstrated recently that the nutritive value of *L. spartum* is lower than that of other perennial native plants grown in coastal western Egypt.

Phytoremediation

The tolerance of *L. spartum* to heavy metals provides a possible phytoremediation option for contaminated soils in the Spanish mining industry (Conesa *et al*. 2009*a*), with numerous studies into the use of *L. spartum* in phytoremediation under field conditions (Conesa *et al*. 2007). In addition, Conesa *et al*. (2007) confirmed the ability of *L. spartum* to phytostabilise Cd and Pb in the roots, and to restrict accumulation in the shoots.

L. spartum plants grown in polluted mine tailing soils exhibited rapid growth and accumulated high concentrations of heavy metals without visible symptoms of toxicity (chlorosis) compared with *Piptatherum miliaceum* grass (Conesa *et al*. 2009*b*). Ottenhof *et al*. (2007) reported a significant contribution of *L. spartum* to accumulated organic matter (OM) in mining areas, a key pedologic factor for restoration of degraded soils. Díaz *et al*. (1996) showed that *L. spartum* encourages rhizospheric mycorrhizae in polluted soils, which increases the availability of water and nutrients to the plants (especially PO_4^{3-}) and that it may also be able to restrict heavy metal uptake.

Soil rehabilitation

In North Africa, *Lygeum* plant associations colonise the encrusted glacis (terraces) covered with a thin sand layer (up to 15–20 cm) on the top soil. *L. spartum* rhizomes play an important role in reducing soil loss and land degradation processes. On sloping terrain, *L. spartum* plants significantly contribute to soil stabilisation and cohesion because of the morphological characteristics of their root systems (Mattia *et al*. 2005). In addition, Mattia *et al*. (2005) found that *L. spartum* roots provided higher soil reinforcement than *P. lentiscus* and *A. halimus* (two woody shrubs) in the superficial soil layers. However, De Baets *et al*. (2007, 2008) demonstrated that *L. spartum* plant associations have a very high erosion-reducing potential with low soil detachment rates by concentrating water flow in the top 0–0.1 m of the soil profile because of their very high root density (19.77 kg m^{-3}), substantial root cohesion (100 kPa) and root tensile strength (210 MPa). In Cartagena (Spain), Ottenhof *et al*. (2007) reported that *L. spartum* stands increased soil OM levels in the saline mined areas compared with no-saline soils. Caravaca *et al*. (2005) also reported that *L. spartum*, together with *Halimione portulacoides*, increased soil porosity, reduced erosion through run-off and improved soil aggregation.

According to García-Fuentes *et al*. (2001), *Lygeum* roots are very effective in fixing soil on steep slopes. Consequently, Hooke and Sandercock (2012) proposed that *L. spartum* is a suitable species in Mediterranean environments for revegetation planting against gully erosion on flat terraces by intercepting rainfall (splash effect) and increasing water infiltration and soil stabilisation.

Grazing management of *L. spartum* rangelands

The principal activity in the Algerian steppe region is livestock production. Pastoralism is the traditional occupation of the local population, but in recent decades the nomadic system has been subject to profound changes through the privatisation of rangelands, overgrazing, clearing of the natural vegetation for cereal cropping and sedentariness of the nomadic population. Currently, these rangelands contribute approximately 40% of total livestock feed requirements, compared with 70–80% in the 1970s (Nedjimi and Guit 2012).

Transhumance (nomadic pastoralism) is the seasonal displacement of nomads (pastoral people) with their livestock between northern rangelands in summer and southern rangelands in winter (Trautmann 1989; Kanoun 2016). Currently, transhumance, which was previously used by the nomadic population as a means of adapting to the spatial variation in rainfall, is declining due to the sedentariness of pastoral farmers, the scarcity of rangeland forage and the provision of additional feedstuffs (barley supplementation and other concentrates; Nedjimi 2012).

In North African countries, three livestock production systems predominate: the pastoral, the agro-pastoral and the intensive. The effectiveness of these production systems depends on rainfall and the availability of a water source (Kanoun *et al*. 2013).

Several techniques have been established to deal with these limitations to livestock production, and many practices are used to increase rangeland productivity, including deferring grazing, determination of the exact period of grazing, rangeland rotation and stocking rate variations. Some of these techniques have provided positive results under favourable conditions.

Rangeland protection has induced substantial regeneration of *L. spartum* stands (Benaradj *et al*. 2013). The duration of deferred grazing depends on the degree of rangeland degradation and the amount of precipitation following protection. In rainy periods, deferring grazing for 2–3 years provides best results. However, this technique is not efficient when rangelands are extremely degraded. Generally, a few grazing periods alternating with rest periods are better than total deferral, because this grazing system can stimulate plant leaf growth (Le Houérou 2000).

Maintaining the current state of the rangeland via an adequate grazing rate, through increasing grazing rangeland areas and/or reducing livestock numbers (average stocking rate of 3.5 sheep ha^{-1}; Djebaili *et al*. 1989) can contribute to the protection of *L. spartum* rangelands against degradation.

Restoration of *L. spartum* rangelands

In North Africa, *L. spartum* is an essential plant mechanism to protect soil against erosion and an economic source for traditional craftsmen. However, the combined actions of overgrazing, a prolonged cycle of aridity, uprooting of tussocks for basket manufacture and the limited and often incorrect knowledge regarding this plant have resulted in degradation of *L. spartum* steppes.

Protection and the rational exploitation of the *L. spartum* stands with other Poaceae, such as *S. tenacissima* and *A. pungens* stands, are necessary for the development of arid steppe areas. Research into the physiology, biology and field ecology of these species is paramount to achieve these objectives. Numerous studies on this topic have been conducted (Nedjimi 2009; Nedjimi *et al*. 2010; Nedjimi and Beladel 2015), but their impact is dependent on a national plan for the rehabilitation of the *Lygeum* rangelands. Several management techniques have been used to increase *L. spartum* steppe productivity and plant association with *Lygeum* (e.g. annual species and small chamaephytes), including deferral and protection from grazing. These techniques demonstrated significant positive effects under favourable conditions, with a positive effect on vegetation recovery, floristic richness and phytomass production (Benaradj *et al*. 2013).

For arid zones, grazing deferral for 2–3 years synchronised with the rainy seasons provided good regeneration of *L. spartum* steppes if there was sufficient seed in the soil (Ferchichi and Abdelkebir 2003; Slimani *et al*. 2010). Sowing *L. spartum* seeds can be considered an alternative method. Under field conditions, germination of *L. spartum* seeds occurs during the rainy seasons (late autumn and winter) when the temperature and soil salinity are usually lower. However, seeds are unable to germinate under hypersaline conditions (Nedjimi 2013).

Concluding remarks

Its ecological, biological and physiological adaptations to harsh environmental conditions (salinity, drought, low temperatures and high concentrations of certain heavy metals) enable *L. spartum* to grow throughout the arid and semi-arid zones of the West Mediterranean basin.

L. spartum plants have a high potential to reduce soil erosion and enhance soil stabilisation by their dense rooting system and short internodes (rhizomes), and may accumulate a thin sand layer (up to 15–20 cm) on the topsoil.

L. spartum rangelands are valuable sources for pastoral use because of their overall productivity, floristic diversity and forage value of plant associations. The green leaves of this species are very useful in basket making. *L. spartum* can also be used in the phytoremediation of contaminated sites (phytostabilisation).

However, overgrazing, the uprooting of tussocks for basket manufacture and clearing of natural vegetation for cereal cropping have largely exposed *L. spartum* stands to intense degradation and regressive evolution. Intervention practices, such as protection and deferred grazing, are urgently needed to regenerate and rehabilitate these degraded rangelands.

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