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Particular effects of steppic plants in the rehabilitation of degraded soils, ability to control wind erosion

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Abstract

In arid zones, plowing and overgrazing, accentuate steppe degradation risk, silting and wind erosion are the consequences, plants disappear and others persist and adapt. We aimed in this study, to identify steppic plants that can grow in a silted environment and find their effects on dune soil. Under three perennial plants (*Retama raetam*, *Aristida pungens*, and *Astragalus armatus*); the texture, physical and microbiological soil characteristics, were analyzed and compared to those of dune soil without vegetation. The results of the fixed and unfixed dune, soil characteristics were different; the micro dune under *A. pungens* did not contain silt and clay (0%). The micro dune fixed by *A. armatus* contained more silt and clay with respectively (9%, 10%). The micro-dune of the soil fixed by *R. raetam* showed the highest contents in N, C and bacterial richness with respectively (0,08%, 0,82%, 1,21x10^5 ufc/g). The micro dune fixed by *A. pungens* showed a high content of, $CaCO_3$, electrical conductivity and fungal richness with respectively (2.37%, 0.92ms/cm, and 0.63x10^5 germ/g). We noted at the end of this study, particular effects of each plant in the rehabilitation of degraded soils. The association of these plants had a complementary effect, which could be used to control wind erosion.

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Introduction

Steppic vegetation represents the most widespread rangeland in the North African countries. In Algeria, they occupy 9% of the country total surface in the semi-arid and arid areas, between the sub-humid northern coastal areas (5%) and the Sahara desert in the south (86%). In Algeria, Morocco, and Tunisia, the total of national territories affected by desertification was estimated at about 80% in the early 1980s (Dregne, 1983). The map of sensitivity toward desertification established by the Algerian National Centre of Space Techniques reveals that of the entire area of the Algerian steppe, 53% was classified as very sensitive to desertification (Oussedik *et al.*, 2003).

The sandstorms problems have become very acute in arid and semi-arid countries, especially in Northern Africa. In Algeria outside the Saharan area, the most affected parts are the high plains extending in the north, with 500,000 ha of wind formations (Franchis and Ibanez, 2003). Wind erosion is an important physical factor causing exhaustion of agricultural land (Bielders *et al.*, 2002), due to severe environmental degradation and particularly soil impoverishment (Ikazaki *et al.*, 2012).

The barren inter-plant spaces generate soil erosion by wind and nutrient losses from the landscape (Langford, 2000; Parsons *et al.*, 2003). In an open environment where vegetation has a lower cover of around 30%, the wind operates by carrying fine particles such as sand and clay and leaves behind a skeletal and stony soil (Reg or Hamada). Such erosion causes a loss of soil of around 150-300 tons per ha per year in cleared steppes (Le Houérou, 1995). Nearly 600,000 hectares of land are totally desertified steppes losing possible biological recovery, and nearly 6 million hectares are at risk because of wind erosion (Ghazi and Lahouati, 1997).

The extension of plowing and mechanization introduction is as important degrading factors such as overgrazing. Plowing techniques used by agro-pastoralists have erosive action, destroying the surface horizon and sterilizing the soil, often irreversibly (Nedjraoui and Badrani, 2008). Psammophile steppes are ecologically related to the sandy texture of surface horizons generated by wind. They follow the corridors of sand encroachment and are evenly distributed along the depressions formed by the Chotts. They are more common in arid and pre-Saharan areas. These formations are usually psammophile steppes of *Aristida pungens* and *Thymelaea microphylla* or shrubby steppes of *Retama raetam* (Le Houérou, 1995).

In arid and semiarid ecosystems, where variations in the spatial and temporal availability of water and nutrients are extreme, vegetated mounds, hummocks, or nebkhas cause local changes in microclimate and soil properties (Bendali *et al.*, 1990). Many studies have focused on the geomorphologic or pedological significance of nebkhas in arid and coastal areas (Hesp and McLachlan, 2000; Langford, 2000).

Bishop *et al.* (2002) modeled desert dune fields based on discrete dynamics. Wanga *et al.* (2006) carried out research on Nebkha development and its significance to wind erosion and land degradation in semi-arid areas. Burri *et al.* (2011) studied efficiency plants to trap sediments, in relation with species for wind erosion, also Erktan *et al.* (2013) for hydric erosion. Barchyn and Hugenholtz (2012) examined dunes stability and evolution in relation with climate and vegetation. Ola *et al.* (2015) explored the plants' roots effect on soil erosion and hydrological processes.

Size, shape, and architecture of the host species canopy are an important key affecting sand accumulation size in several arid and semi-arid regions (Bochet *et al.*, 2000; Hesp and McLachlan, 2000; Dougill and Thomas, 2002; El-Bana *et al.*, 2007). The soil roughness and the slope gradient have a significant influence on mound height index (Bendali *et al.*, 1990; Danin, 1991). Zarnetske *et al.* (2012) observed that plant species differ in their ability to capture sand, the native species have higher sand capture than non-native species. Durán *et al.* (2008), observed real parabolic dunes that commonly show preferential growth of vegetation in regions of sand deposition.

If vegetation grew on the slip face, it would encroach the dune crest, subsequently resulting in their stabilization (Barchyn and Hugenholtz, 2012). Burylo *et al.* (2012) showed the abilities of species in reinforcing the soil and reducing erosion rates, this ability was positively correlated to leaf area, canopy density, and fine roots to trap sediment.

Houyou *et al.* (2014) reported that sandstorms, cause 75.32 t.ha^{-1}.year^{-1} land soil losses within the area of Mokrane in the Algerian steppe because of land clearing and plowing.

Therefore, in the same zone (Mokrane), we conducted an inventory of steppic vegetation that colonizes sandy accumulations (Mallem *et al.*, 2017). However, in order to study the effect of this vegetation, in degraded soil; we asked the following question: What are soil characteristics under plants canopy that can grow on sandy accumulations. This is our aims in the following study. Our results can be used for control of wind erosion.

Material and methods

The study area

The study area (33°48′1·56" N, 2°48′21·95" E) is located on the alluvial plain of Mokrane, 4 km West of Laghouat city in Algeria (Fig. 1). Climatic data of Laghouat between 1996 and 2015 (National Meteorological Office -Laghouat Station), show that monthly average temperatures were the highest in July (32.43°C).

The lowest monthly average temperatures were registered in December (8.93°C) and the monthly average relative humidity was lowest between July and August, around 27 and 30%. Humidity tended to rise rapidly in September–October, reaching 46-54% between December and March. September was the wettest month with 26mm of rainfall, whereas July was the driest month with 6.32mm. The average total annual rainfall was 163.3mm. Houyou *et al.* (2014) observed an average wind velocity of 6m.s^{-1} during the study period.

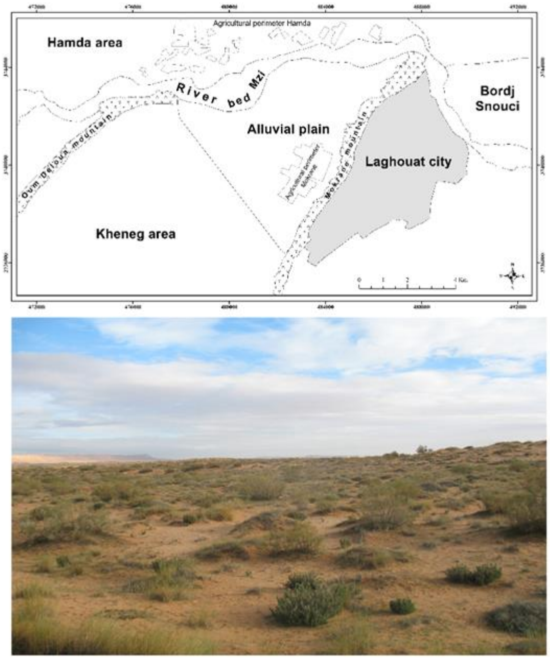

Fig. 1. Location and view of the study area (Mokrane zone).

Soil characteristics measurements

Three host species (accumulated sediment occupier) have been selected for this study, *Retama raetam*, *Aristida pungens*, and *Astragalus armatus,* because of their continuous predominance in the study area (Mallem *et al.* 2017). we covered an area of 200 to 400m² for each plant community. In eight randomly selected accumulated sediment points associated with each host species (fixed soil) and eight sediment accumulation points not colonized by vegetation (unfixed soil), measurement of the following factors were done, Moisture soil content, particle size distribution, total nitrogen content, limestone content, electrical conductivity (EC), pH and organic matter content.

In March 2014, using a hand auger, soil samples were collected from the top 30cm of each accumulated sediment, at a distance of 10-15cm from the center of the host plant (El-Bana *et al.*, 2007). They were taken at the end of the rainy season when soil decomposer activity is peaking. Soil moisture content was calculated from the mass difference before and after drying at 105°C for 24h. The soil particle size distribution was determined with sieving and sedimentation methods, providing percentages sand

and fine fractions (silt and clay) (Cost and Sanglerat, 1981). Organic matter was estimated by drying and subsequent ignition at 600°C for 5h. Soil pH and EC were determined in an aqueous solution (10g soil dissolved in 50 ml distilled water, shaken for ½ h, using a digital conductivity meter (YSI Inc., OH, US.). Total soil nitrogen (N) was determined using the Kjeldahl method. $CaCO_3$ content was determined following the procedures of the United States Salinity Laboratory (Jackson, 1962). For microbial enumeration, two mediums were used, PDA (Potato dextrose agar) medium for fungi and LPGA (Yeast Peptone Glucose Agar) medium for bacteria (Klement *et al.*, 1990).

Data statistical analysis

Soil factor measurements were analyzed by one-way ANOVA (Statistical software Minitab 17.1.0), and significant differences for all statistical tests were evaluated at the level of $P \leq 0.05$ (Tukey 95%), tests grouping were done by Fisher's method. PCA (Principal component analysis) was adopted in XLSTAT software 2016.02.28451 for evoking soil relationship species**.**

Results

Particle size distribution

Sediment accumulation under and out of the canopy was highly rich in fine sand with a rate up to 50% (Fig. 2), the highest rate, 64%, was registered for *A. pungens*. The U. soil (unfixed soil) was the richest in coarse sand, 46% was observed; under *A. armatus* the lowest content of coarse sand 30% was observed. The soil under *Aristida pungens* does not contain silt and clay. However, the soil fixed by *Astragalus armatus* contained more silt and clay representing respectively 9%, and 10%.

Fig. 2. Particle content of accumulated sediments under and out of the canopy.

Chemical characteristics

The soil under *R. raetam* was the wettest at an average content of water (2.39%), unlike the U. soil which presented the lowest moisture rate (1.06%) (Table 1). Statistical analysis revealed a significant difference between the soil moisture under the canopy and that out of the canopy ($P = 0.01$), the soil moisture rate under the three plant species does not show a difference, forming a single statistical group. The soil out of the canopy with the soil under the canopy of both plant species *A. pungens* and *A. armatus* were more alkaline with a mean pH value of 8.72, while under *R. raetam* the soil showed the lowest mean of pH value with 8.30 ($P < 0.05$). The soil under the canopy of *A. pungens* showed the highest value of EC with a mean value of 0.92 ms/cm. The lowest mean was measured for *A. armatus* close to that of the soil under *R. raetam*. Between the extremes values, the soil out of the canopy (U.soil) presented a mean of electrical conductivity equal to 0.50 ms/cm. Statistically, ANOVA revealed a highly significant difference ($P < 0.001$). The soil under the canopy of *R. raetam* and *A. armatus* presented contents of nitrogen up to 0.06% registering the highest values. The lowest value of N content was observed for the soil out of the canopy with a mean rate of 0.02%. Under the canopy of *A. pungens,* the nitrogen soil mean rate was between the values above, showing a rate mean of 0.04% ($P = 0.005$).

The soil under the canopy of the three plant species presented a mean rate of organic carbon (C) up to 0.68%. In contrast, the soil out of the canopy showed the lowest mean rate of carbon with a value of 0.25% ($P = 0.01$). The greatest value of the limestone was registered for the soil under the canopy of *A. pungens* with an average rate of 2.37%. In addition, the lowest average rate of limestone was registered in the soil under the canopy of *A. armatus* with an average rate of 1.55% ($P = 0.70$). The C/N ratio indicates the decomposition speed of organic matter in the soil. The most elevated value was registered under the canopy of *A. pungens* with an average of 14.54, while the lowest value of C/N ratio was observed in the soil under the canopy of *R. raetam* with a mean of 8.57 ($P = 0.66$).

Table 1. Means ± standard deviation of chemicals soil properties sampled under and out of the canopy.

Soil parameters	Under the canopy of			Out of the canopy	*P*-value
	R.raetam	*A.armatus*	*A.pungens*	Unfixed soil	
Moisture (%)	2.39^a±0.48	1.89^a±0.86	2.24^a±0.48	1.06^b±0.64	0.01
pH	8.30^b±0.46	8.87^a± 0.07	8.76^a±0.07	8.72^a±0.12	0.009
EC(ms/cm)	0.40^b±0.07	0.39^b± 0.08	0.92^a±0.06	0.50^b±0.06	< 0.001
C (%)	0.82^a±0.27	0.70^a±0.26	0.68^a±0.29	0.25^b±0.18	0.01
N (%)	0.08^a±0.01	0.06^{ab}±0.01	0.04^{bc}±0.01	0.02^c±0.01	0.005
$CaCO_3$ (%)	1.75±0.89	1.55±1.11	2.37±0.89	1.96±0.47	0.70
O.M (%)	1.42^a±0.48	1.21^a±0.45	1.16^a±0.51	0.43^b±0.32	0.001
C/N	8.57±2.06	11.25±4.17	14.54±1.04	13.97±4.93	0.66

The values with similar letters do not differ significantly by the studied characteristics, given 5% probability.

Microbiological characteristics

Higher numbers of total bacterial colony-forming units (cfu) were observed in soil associated to host species than in unfixed sediment (Fig. 3). The soil under the canopy of the two Fabaceae species (*R. raetam* and *A. armatus)* was richer in bacteria with respectively (1.21×10⁵ cfu/g, 1.08×10⁵ cfu/g) than under the grass specie (*A. pungens*) which allowed a mean value of 0.35×10⁵ cfu/g. The soil out of the canopy was the less rich in bacteria with a mean value of 0.11×10⁵ cfu/g. ANOVA test revealed a significant difference (P < 0.001). Otherwise, the highest occurrence of fungi was observed in the soil under the canopy of *A. pungens* with a mean value of 0.63×10⁵ cfu/g followed by soil under the canopy of *R. raetam* with a mean value of 0.46×10⁵ cfu/g. The soil under *A. armatus* showed a low value close to that of the U. soil.

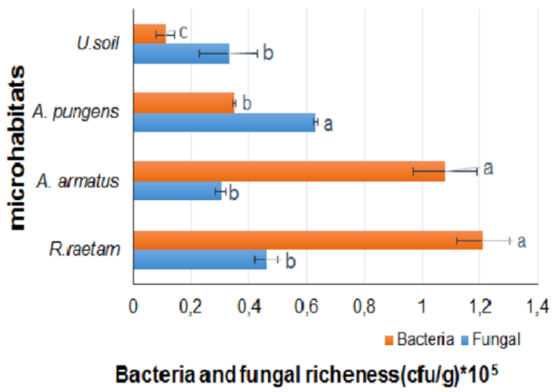

Fig. 3. Accumulated sediment microbial richness under and out of the canopy.

Discussion

Our results showed that soil under the canopy has high levels of moisture, organic matter, carbon, nitrogen and microbial richness than the content of the soil out of the canopy. This may be due to the higher moisture content, which stimulates the growth and activity of soil microorganisms (Hesp and McLachlan, 2000). The high content of soil moisture measured under the canopy in Laghouat could be influenced by the decrease of temperature, which stimulates also organic matter decomposition. In fact, Lopez-Pintor *et al.* (2006) found that woody vegetation provides a less environmentally stressful microclimate below the canopy, reducing the direct effects of high radiation and temperature, providing greater availability of water and causing an accumulation of nutrients and organic matter. Pyke and Archer (1991) indicated that soil under the canopy of trees could maintain a higher population of bacteria presumably through a conservation and accumulation of carbon and nitrogen. This is in agreement with our measurements, under perennial plant species. The high rate of nitrogen in soil under the canopy of the perennial plant species can be explained by the presence of N_2-fixer shrubs (*R. raetam* and *A. armatus*, Table 1) which was in agreement with the results of Muñoz-Vallés *et al.* (2011) in Spain who registered high content of carbon and nitrogen under the canopy of *Retama monosperma*. Similarly, Halvorson *et al.* (1994) observed a high content of N soil under a desert shrub in the USA.

Vegetation also contributes to a reduction of subsurface water flow (Yair *et al.*, 1997) and nutrient increase, by accumulating nutrients under the canopy (Danin, 1991; Alpert and Mooney, 1996; El-Bana *et al.*, 2003). So we observed the formation of microbiotic crust on the soil surface of sediment accumulation in the study site.

This is an important factor for conserving soil moisture, several studies reported that the existence of microbiotic crust is necessary for plant community development (Danin *et al.*, 1989), it affects water regime by altering water runoff (Yair *et al.*, 1997; Kidron, 1999) and decreasing evaporation (Verrecchia *et al.*, 1995).

Rhizosphere microbial communities can be stimulated or inhibited by components of root exudates (Hartmann *et al.*, 2009). Our results registered that the three perennial species reacted differently for the microbial richness. We found that the soil under *A. pungens* contains more fungi than bacteria than the soil under *R. raetam* and *A. armatus,* this may be explained by the N_2-fixing process of both Fabaceae plants involving a varying number of bacterial nitrogen-fixing on the roots.

Our results showed that soil texture was different under the canopy compared to Unfixed soil, the soil under the canopy exhibited higher rates of fine particles (silt and clay). El-Bana *et al.* (2003) reported that there were significant differences in soil texture content related to grazing and microhabitat, the proportion of finest soil particles was higher under the canopy than the adjacent inter-nebkha.

The PCA (Fig. 4) allowed better visualization of soil variability behavior in presence of vegetation and investigated the relationship between the edaphic variables. Each plant reacts differently, *R. raetam* gives more information on the rate of nitrogen, carbon and bacterial richness. Several studies reported the role of *R. raetam* in dune fixation (Guerrache *et al.*, 2014). According to El-Bana *et al.* (2002), *R. raetam* nebka's can be considered as "vegetation islands" in areas where the soil is subject to severe deflation. The cladodes of *R. raetam* shrub are effective in capturing and retaining soil (El-Bana *et al.*, 2003). Danin (1996) reported that *R. raetam* shrub could survive under cycles of deflation of sand. Our results were similar to Sarig *et al.* (1999) who explained that woody, N_2-fixing Fabaceae such as *R. raetam* might enhance soil nutrient content, improve soil structure by adding nitrogen, rich organic matter to the soil through litterfall and root shape, owing to their symbiotic associations with both rhizobial bacteria and mycorrhizal fungi. Through this study, we can add the effect of *A. armatus*, which has characteristics close to those of *R. raetam*.

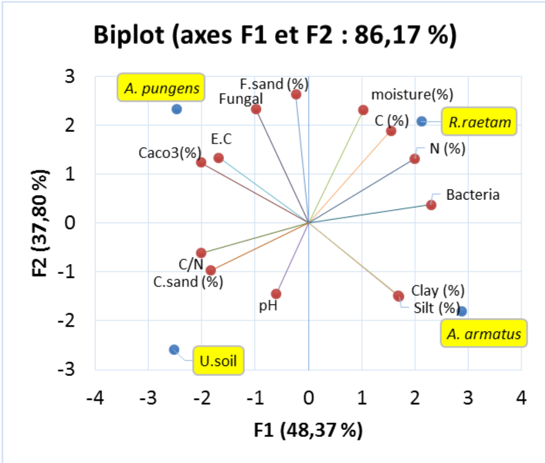

Fig. 4. First two axes of PCA showing the relation between soil characteristics and plant species.

The first axis F1 has been positively correlated with contents of bacteria, N and C, this variability has been linked to presence of R. raetam (r = 0.40), A.armatus (r=0.61) has been correlated with clay and silt contents. F1 axis was negatively correlated with coarse sand (C.sand) content , C/N, CaCO3 and EC this variability has been linked to the presence of A. pungens (r = 0.46). The second axis (F2), has been positively correlated with contents of fine sand (r= 0.99), fungal (r =0.78) and moisture (r=0.76), it was related to presence of A. pungens (r=0.46). The negative side of the F2 axis has been linked to the lack of vegetation on U. soil (r = 0.47).

In this work, only three species *Retama raetam, Aristida pungens* and *Astragalus armatus* were considered hosts plants. If the first two are known as true psammophiles, the last one is less known as psammophile in the Maghreb. Le Houérou (1995) indicated that *A. armatus* was even an indicator of clay, marl or even gypsum. It is true that A. *armatus* is also known as an indicator of degradation (Le Floc'h, 2001) and therefore can be in terms of silting but not an "initiator" of Nebkha. It seems normal that the values of silt and clays under the canopy of *A. armatus* at Laghouat were higher; this may well be an environmental legacy on the alluvial and colluvial deposits sediments of Mokrane area. *Aristida pungens* can be considered as "facilitator" (sensu Connell and Slatyer, 1977) rather than the initiator of nebkha. This role had already been described in Tunisia (Bendali *et al*., 1990) for *A. pungens* which regresses and disappears once the degradation silting-phase completed. Our results showed that *A. pungens* seems to act mainly in trapping fine sand, soil EC, and fungal rate.

Conclusion

The three steppic plant species (*R. raetam*, *A. pungens*, and *A. armatus*), have shown selectivity in relation to particles size for sediment trapping. Accumulated sediments relating to diversity of species have presented an improvement of water reserve, microbial richness, organic matter and nitrogen content. Both of N_2-fixer shrubs (*R. raetam* and *A. armatus*) and the grass perennial specie (*A. pungens*) must be used together in a reforestation program to prevent soil erosion because of the characteristics provided by each plant. Our results can be useful to ecologists and bio geomorphologists, as well as to practitioners working on wind erosion control.

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