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Rehabilitation of Algerian rangelands: effects of *Atriplex canescens* plantation on biodiversity, soil physico-chemical parameters and soil surface elements

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Abstract. The 20 million hectares that covered the Algerian rangelands were the preferred area for breeding a livestock estimated at 24 million head of which 80% were sheep. Examination of desertification sensitivity and biomass maps showed that more than 55% of rangelands were classified as desertification-sensitive and the average animal load was 5.6 ha/head. To combat desertification and support livestock needs, the HCDS had launched a rehabilitation program through the introduction of a forage plant *Atriplex canescens*. This study was conducted in the department of Djelfa, on a 947 ha plantation, dealing with 4 age groups (2, 5, 10 and 15 years old). For each age group, 3 parcels were selected. In each parcel, 20 plants were pre-selected. For each foot we measured the height and the 4 cardinal rays. Three individuals per parcel were selected on the basis of their membership of the mean ± SE range over the five measured parameters. Three control shrubs, 9 shrubs per age class, 2,340 soil tests and 2,080 contact points were treated under R 3.5.2. It appeared that in 2 years we saw an improvement in the state of the soil surface, in 10 years we noticed an improvement in the carbon level in the soil as well as the diversity indices tested. For the 15-year-old class, an increase in the total nitrogen rate was underlined with a decrease in diversity indices.

Keywords. Desertification – Algeria – Rangelands – *Atriplex canescens* – Biodiversity.

La réhabilitation des parcours algeriens : efects de la plantation de* Atriplex canescens *sur la biodiversité, sur les parametres physico-chimiques du soil et sur les elements de la superficie du sol

Résumé. *Les 20 millions d'hectares que couvrent les parcours Algérien sont l'espace de prédilection de l'élevage d'un cheptel estimé à 24 millions de têtes dont 80 % d'ovins. L'examen des cartes de sensibilité à la désertification et de biomasse, montre que plus de 55 % des parcours sont classés sensibles à la désertification et que la charge animale moyenne est de 5,6 ha/tête. Pour lutter contre la désertification et subvenir aux besoins du cheptel, le HCDS a lancé un programme de réhabilitation par l'introduction d'une plante fourragère* Atriplex canescens. *La présente étude est menée dans la wilaya de Djelfa sur une plantation de 947 ha, renfermant 4 classes d'âges (2, 5, 10 et 15 ans). Pour chaque classe d'âge, 3 parcelles ont été retenues. Dans chacune des parcelles, 20 pieds ont été présélectionnés. Pour chaque pied nous avons mesuré la hauteur et les 4 rayons cardinaux. Trois individus par parcelle sont sélectionnés sur leur appartenance à la moyenne ± l'écart type sur les cinq grandeurs mesurées. 3 pieds témoins, 9 pieds par classe d'âge, 2340 analyses de sol et 28080 points-contact ont été traités sous R 3.5.2. Il ressort qu'à 2 ans on assiste à une amélioration des états de la surface du sol, à 10 ans à une amélioration du taux de carbone dans le sol ainsi que des indices de diversité testés. Pour la classe des 15 ans, une augmentation du taux d'azote total est soulignée avec une diminution des indices de diversité.*

Mots-clés. *Désertification – Algérie – Parcours –* Atriplex canescens *– Biodiversité.*

I – Introduction

Algerian rangelands cover 32 million hectares, 20 million being considered as steppic and 12 as presaharian. The predominant use of this vast swathe of land was livestock breeding, with an estimated number of 20 million heads, of which 80% were sheeps. Examination of desertification sensitivity and standing biomass maps, produced respectively by the General Forest Office (DGF) and the High Commission for Steppe Development (HCDS) showed that more than 55% of rangeland were classified as sensitive to highly sensitive to desertification, and that mean animal load was of 5.6 ha/ind. The carrying capacity of the Algerian steppe was thus of only 3.6 million heads.

To face this degradation, the Algerian state had planned and launched, since 1994 and by the means of the HCDS (Haut Commissariat au Développement des Steppes, High Commission for the Development of the Steppe), a vast program of restoration *sensu lato* named great steppic projects. Important means were attributed to the HCDS in order to control the desertification process, which had driven to an overall biological potential loss, and a breakage of previous ecological and socioeconomical equilibria (Hoppe *et al*., 2016; Kouba *et al*., 2018; Baranova *et al*., 2019).

Several restoration techniques had been selected among which fodder plantation, and several plant species had been introduced aiming at degraded rangeland restoration and fodder provision for a growing livestock. The choice of the restoration technique depended on the level of degradation of the area under consideration. Fencing was considered appropriate when the ecosystem was yet resilient and degradation minor. When a more degraded state was reached, fodder plantation was the chosen strategy. The criterion chosen by HCDS technicians was the Overall Vegetation Cover (OVC) with a threshold at 20%. When this parameter was below this level, fodder plantation was the chosen restoration technique. Among the fodder shrubs introduced in Algeria were *Atriplex nummularia*, *Atriplex glauca*, *Medicago arborea* and *Opuntia ficus-indica* but the species chosen for a massive plantation was *Atriplex canescens* (Pursh) Nutt. This species was chosen due to (i) its low production cost (3 Algerian Dinar per seedling), (ii) its resistance to cold and sand, (iii) its overall 1-year resumption rate of 130% (Amghar, 2012). We focused this study on (i) the facilitative effect of Atriplex canescens of contrasted ages on plant recruitment and its impact on (ii) soil chemical parameters and (iii) soil surface properties.

II – Materials and methods

The study took place on the Ain Chouhada plantation, 1225 m a.s.l., situated in the Southwestern part of the Djelfa department, at 80 km from the city. Its 947 ha had been planted in a few sequences from 1996 up to 2011, with the first aim to protect the village from sandstorms and thus to fix the sand. This aim had led to forbid any livestock to enter in the plantation since its beginning, whereas other plantation were usually rented after 5 years. This feature was an opportunity to study the long-term effects of plantation on soil and vegetation properties. The plantation was situated between 34°14’39’’ and 34°17’46’’N, 2°31’41’’ and 2°21’35’’E. Ain Chouhada is under a mean semi-arid bioclimate, with rainfall concentrated in fall and springtime. The minimum of rainfall and thermal maximum was in summer, typical feature of the Mediterranean climate (Daget, 1977). Mean annual rainfall (1971-2011) was 342 mm, and mean temperature for the hottest month and the same period is 33°C whereas it was of -0.1 °C for the coldest. The dry period lasted 5 months. Soils were xeric calcimagnesic with lime accumulation (Djebaili, 1978). Typical vegetation groups were dominated by *Stipa tenacissima*, *Artemisia herba-alba* and their degraded facies (Le Houérou, 1992).

Our aim being to characterize the effects of individual *A. canescens* on soil and vegetation properties, we selected in the plantation 4 age classes: 2, 5, 10 and 15 years since plantation. For each age class we sampled 3 plots, with a minimal distance between plots of 900 m, to control auto-replication. In each plot we chose 20 *A. canescens* individuals, the first randomly and the other on a systematic distance of 20 m between plants on a square grid. The plantation was designed at an initial density of 1000 seedlings/ha, in rows separated by 2.5 m, with 4 m between each plant in a row. We measured on these 20 individuals the plant height and its 4 rays in the cardinal directions. We then chose in each age class 3 individuals for which the 5 biometrical parameters were within the mean+/-SD range, thus sampling on the most representative *Atriplex* in each age class.

For these 36 individual shrubs (4 age classes*3 plots*3 shrubs), we drew 4 transects from the shrub center toward each cardinal direction. For each transect we doubled the radius length observed and divided the total length in 60 equal intervals. These 60 points were divided in three subsets of 20 points, i.e. from the center on the shrubs 20 In points, then 20 Border points, and 20 Out points. On each of these 60 points we described (i) the vegetation using a vertical rod and noted each plant species contacts by the rod, *Atriplex* excluded; and (ii) the soil surface state. Plant species covers were calculated from these transects (240 points per *A. canescens*) and expressed as coverage percentage (Godron, 1968). For each of the 36 shrubs we calculated plant Species Richness (R) and Shannon diversity index (H'). Soil surface state had been quantified using the linear sampling technique (Daget *et al*., 1971). Three control areas were delimited in a plot neighbouring the plantation, where de degradation state was high, and similar to the state of pre-plantation. Three ghost *Atriplexs* were delimited and sampled, based on the 5- year old class dimensions, and sampled using the same protocol.

Soils were sampled in the superficial horizon H1. Ten cm diameter cores were sampled in the middle of each of the 3 compartments delimited in the transect (In, Border, Out). These 468 soil samples were 2-mm sieved and air-dried. Parameters measured on soils samples were organic matter determined following the Anne method (organic C measured by sulfo-chromic oxidation, ISO 14235) and total nitrogen obtained using Kjeldahl method (Bremner, 1996). We also calculated C:N ratio to inform soil mineralization status.

Data were, due to lack of normality, compared using non parametrical Kruskal-Wallis test (Zar, 1984) for diversity indices, soil chemical parameters and surface elements. All tests were performed using R 3.5.2 software (R Core Team, 2013).

III – Results and discussion

Floristic richness varies with Atriplex age: with respective values of 0 and 14 at 0 and 5 years, it culminated at 10 years with a value of 22, before decreasing at 16 at 15 years (Table 1).

Atriplex canescens introduction in Algerian rangelands, aiming at desertification control and fodder provision in order to cover growing livestock needs, was considered as a major mean of rangelands improvement (Amghar *et al*., 2008, Amghar *et al*, 2012). In their study in Tunisia, Jeddi *et al*. (2009) had shown that this species acts as a nurse plant, increasing soil nutrients and thus enhancing plant recruitment under and around them.

Shannon index follows a patterns similar to species richness (Table 1): at its lower in the control area (0.4) it reached its maximum in the 10-year age class (2.18). Plantations were more diverse and present a highest cover than in control areas ($p<0.05$). Both indices culminated in the 10-year age class. This can be acknowledged as an example of nurse effect: the shrub mitigated the harshness of the surrounding environment, either physical (moisture, nutrients) or biological (protection from livestock) and thus created a favourable environment (Orth et Girard, 1996), especially in our case for therophytes. This plant type benefited from the presence of the shrubs, and this effect, in the time span included in our sampling design, decreased after 10 years.

Table 1. Effect of Atriplex canescens age on floristic parameters. Values were Means +/- SE. Differences between age classes were tested by non-parametric Kruskal Wallis rank sum test, with a significance level as follows: * = p < 0.05, *** = p < 0.001. Different letters indicated significant differences between age classes

	Age class (years)					χ^2	P-Value
	0	2	5	10	15		
Diversity indices							
Floristic richness (R)	0.00 ± 0.00^{c}	14.11 ± 5.65^{b}	12.78 ± 2.73^{b}	22.56 ± 7.00^{a}	16.00 ± 5.72^{b}	16.31	<0.01
Shannon index (H')	0.40 ± 0.08^{c}	1.86 ± 0.30^{b}	1.97 ± 0.23^{ab}	2.18 ± 0.45^{a}	1.87 ± 0.39^{ab}	12.36	<0.05
Soil chemical parameters							
% Carbon	0.41 ± 0.29^{b}	0.51 ± 0.38^{b}	0.54 ± 0.40^{ab}	0.96 ± 0.56^{a}	1.10 ± 0.69^{a}	103.27	<0.0001
% total Nitrogen	0.01 ± 0.07^{c}	0.01 ± 0.01^{c}	0.01 ± 0.01^{c}	0.02 ± 0.01^{b}	0.04 ± 0.05^{a}	236.3	<0.0001
C:N	29.73^{c}	47.06^{ab}	51.83^{a}	41.09^{b}	26.18^{c}	25.21	<0.0001
Soil surface elements (%)							
Coarse elements (CE)	14.17 ± 3.97^{a}	1.22 ± 1.72^{ab}	0.05 ± 0.15^{b}	0.52 ± 0.78^{ab}	0.71 ± 0.98^{ab}	15.14	<0.01
Litter (Lit)	0.00 ± 0.00^{b}	56.00 ± 29.64^{ab}	65.10 ± 27.89^{ab}	72.26 ± 23.80^{a}	65.02 ± 31.41^{ab}	9.24	<0.05
Glazing crust (GC)	85.83 ± 3.97^{a}	31.99 ± 27.74^{ab}	24.58 ± 19.42^{ab}	19.78 ± 18.32^{b}	25.08 ± 24.95^{ab}	9.18	<0.05
Sand (S)	0.00 ± 0.00	10.79 ± 8.56	10.27 ± 9.16	7.44 ± 6.77	9.20 ± 6.97	6.73	NS

Soil chemical analyses exhibited a highly significant difference in both parameters (C and N), and their ratio (Table 1). C and N reached their maximum in the 10 and 15-year age class, but C:N ratio was minimum at both ends of our time span, being maximum at ages 2 and 5-year. The increase in both C and N was expected after plantation, as a result of a litter input (and also rhizodeposition) from *Atriplex*. This improvement in soil chemistry enhanced soil macroscopical properties (structure, aggregation, infiltration) thus limiting the highly negative water runoffs.

The bell-shape pattern of the C:N ratio was less expected, especially the low ratio at 15-year. Soil C being quickly mineralized in these soils (Pouget, 1980), this feature can be linked to the N dynamics during *Atriplex* growth: the shrub could have an acquisitive strategy towards N during its first 10 years, beginning to restitute it at 15 years, thus enhancing C:N and promoting mineralization.

Soil surface elements exhibited a pattern consistent with vegetation parameters: elements unfavourable to seedling recruitment (CE and GC) were dominant in early age classes (from 100% in the control stage to 33.2% in the 2-year age class. The litter showed a significant increase during the first 10 years, and a slight decrease at 15-year, proportional with the shrub phytomass. The sand, even if the only non-significant soil surface state, presented an increase consistent with the role of sand-trap played architecturally by the shrubs. The fact that some proportion of CE and GC remained at the older age classes may be linked to residual runoff, thus questioning the opportunity of planting in a linear fashion.

IV – Conclusion

Our aim was to evaluate the impact of plantation age of an exotic American species (*Atriplex canescens*) on floristic diversity and some aspects of soil chemistry and surface. The plantation age had a significant impact on almost all the parameters measured. However, these differences were not univalent and some (litter, SR, Shannon) would lead us to recommend an opening of the plantation to grazing after 10 years, whereas other parameters (N, C, C:N) would increase this number to 15 years and maybe below. The somewhat conflicting objectives between fodder provision (reached early during *Atriplex* growth) and soil and diversity restoration (reached later) could lead to an "ageing island" management of plantations, with very long term exclosures.

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