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# *Rehabilitation of Degraded Rangeland in Drylands by Prickly Pear (Opuntia ficus-indica L.) Plantations: Effect on Soil and Spontaneous Vegetation*

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**Abstract.** In arid and semi-arid lands, the spiny prickly pear (*Opuntia ficus-indica*) is an outstanding plant for soil conservation and restoration. To determine the role of *Opuntia ficus-indica* on vegetation recovery process in desertified areas of Southern Tebessa (Northeast Algeria), we investigated the effect of prickly pear plantation age and some soil properties (grain size, pH, electrical conductivity, organic matter, total nitrogen, available phosphorus, and $CaCO_3$ equivalents) on native plant community. Vegetation cover and plant diversity were assessed by calculating the number of individual plants ($N$), species richness ($S$), their ratio ($N/S$), Shannon index, and Evenness in prickly pear plantation plots of different ages (control, 5 and 20 years). Even if surveyed soil parameters did not differ significantly among *O. ficus-indica* plantations, results of ANOVA testing the effect of *Opuntia* plantations on native vegetation traits revealed significant variation for plant abundance ($P < 0.0001$), $N/S$ ratio ($P = 0.003$) and vegetation cover ($P < 0.0001$). Vegetation cover differed significantly with both prickly-pear plantation age ($P = 0.031$) and seasons ($P = 0.019$). Tukey's tests revealed that all vegetation traits were significantly higher on prickly pear plantations than in control plots. Multiple comparisons also showed that plant abundance, $N/S$ ratio and vegetation cover were significantly different between both young and old plantations and the controls. Prickly pear cultures facilitated the colonization and development of herbaceous species by ameliorating the severe environmental conditions. In conclusion, the facilitative effect of *O. ficus-indica* has been clearly demonstrated for both abundance and cover of native vegetation.

**Key words:** rangeland, land rehabilitation, *Opuntia ficus-indica*, soil restoration, plant diversity, Algeria, drylands.

## Introduction

Desertification is defined by the United Nations Convention to Combat Desertification (UNCCD) as being degradation or loss of productive capacity of land in arid, semi-arid and dry-sub-humid areas resulting from the combination of several factors including climate variations and anthropogenic activities (SIVAKUMAR, 2007). Desertified lands have an area of 3.6 billion worldwide, arid and semi-arid ecosystems represent over 25% of the earth (SMITH *et al.*, 2000). Arid rangelands occupy an area of over 600,000 km² in North Africa covering, approximately 34% of Algeria, 31% of Libya, 19% of Morocco, 11% of Tunisia and 5% of Egypt (LE HOUÉROU, 1995).

Desertification indicators affecting vital ecosystem attributes are the deterioration of soil properties, including the reduction of


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water reserves and fertility, often up to critical regression of vegetation production (NEDJRAOUI, 2004; AIDOUD *et al.*, 2006). These characteristics are a sign of huge vulnerability toward natural and/or man-induced changes (SIVAKUMAR, 2007; NEDJRAOUI & BEDRANI, 2008), which explains the complexity or impossibility to remediate damage occurring in these environments (BENABDERRAHMANE & CHENCHOUNI, 2010).

Rehabilitation of degraded rangeland habitats necessarily involves strategies; as the restoration of native shrubs to restore biodiversity and prevent both erosion and desertification processes (CARAVACA *et al.*, 2003), or through manmade improvement, using even non-native plant species (NEFFAR *et al.*, 2011). The use of drought-resistant plants in the rehabilitation of degraded semi-arid rangelands is very common, such as the cases of Acacias or Aloe (KING 2008). These plants can increase dynamics of biological resources and restore degraded vegetation, thus improving the severe conditions that limit the establishment of plant species (LE HOUÉROU, 1995). The fact that the presence of a plant species improves environmental conditions and provides favorable sites where less tolerant species can establish, is called facilitation (CALLAWAY, 1995). Through such positive interactions, plants facilitators can greatly influence composition, dynamics and diversity of the ecological community (WEZEL *et al.*, 2000).

Besides its arid climate, characterized by erratic and insufficient rainfall with large seasonal and interannual variations, Algerian rangelands, extending over 20 million hectares (DJEBAILI, 1984), are intensively used for livestock activities. They feed 2/3 of Algerian populations of sheep and goat (DJEBAILI *et al.*, 1989). Although these natural steppes play a key role in agricultural economy of the country they have been subject to rapid and severe degradation over the last three decades (SLIMANI *et al*. 2010), due to recurrent droughts and increasing human pressure mainly by clearing, overgrazing and inappropriate exploitation of unsuitable lands for crops (NEDJRAOUI & BEDRANI, 2008). This land degradation and desertification, when at its most advanced stage, reduces biological potential and breaks ecological and socio-economic balances (NEDJRAOUI & BEDRANI, 2008). Moreover, about 75% of the area of Algerian rangelands are being desertified or are at the desertification threshold (BENSLIMANE *et al.*, 2008, BENABDERRAHMANE & CHENCHOUNI, 2010).

A shrub with low ecological requirements (SNYMAN, 2006) the prickly pear (*Opuntia ficus-indica*) is among the fodder plantations as well as *Atriplex* plantations, which are commonly used to combat desertification in Algeria (NEFFAR, 2012). The question that arises, can it act as a facilitator in degraded rangelands? Because arid-rangeland rehabilitation by plantations is known to have facilitative effects for (i) increasing and improving soil features (CARAVACA *et al.*, 2003) and (ii) accelerating ecological succession processes (WEZEL *et al.*, 2000), also since the identification of changes in soil properties is needed to understand the effectiveness of ecological reclamation and changes in soil nutrients in relation to plantation age (SHAO *et al*. 1996); we tested how prickly pear plantations, through their age, affect *in situ* edaphic factors of superficial horizons and traits of spontaneously "natural" vegetation. This study is an investigation that aims to assess changes in soil and native vegetation properties following the establishment of prickly pear plantations (*Opuntia ficus-indica* var. *amyclaea*) in an arid area located in Northeastern Algeria.

**Materials and methods**

*Study Area.* The study was conducted in Mzara (Tebessa, Northeastern Algeria) located at 780 m above sea level (34°51'08.4"N and 08°15'05.3"E; Fig. 1). Soils are skeletal and of sandy texture, poor in organic matter and are susceptible to degradation. Long-term climatic data (1990–2005) revealed that the Mediterranean climate of this region is arid-type with cold dry winters and severe hot dry summers. The region receives an average of 163 mm of rain per year. Average annual temperature is about 14.1 °C with a minimum of 5.8 °C in January and a maximum of 23.5 °C in July. According the GAUSSEN and BAGNOULS' diagram (1954), the drought period extends over the entire year. During the study year 2008, the area had irregular monthly precipitation with several peaks of rainfall throughout the year except during summer "June-August" (Fig. 2). In addition, the index of De MARTONNE (1926) applied for the region revealed an arid climate (DE MARTONNE's index value = 6.76). According to NEFFAR (2012), overall the sparse-type vegetation of Tebessa steppes is represented by several native plant species such as *Stipa tenacissima* (L.), *Lygeum spartum* (L.), *Arthtrophytum scoparium* (Pomel.), *Artemisia herba alba* (Asso.), and *Astragalus armatus* (Willd.).

*Sampling Design.* The study was conducted in three types of *Opuntia ficus-indica* plantations: (i) plantations aged less than 5 years, (ii) more than 20 years and (iii) unplanted plots, taken as control. Three plots, of 2 – 4 ha in size and similar topographic properties, were selected for each plantation type as replicates located in separate plantations. The sampled plots, including control, were chosen close to each other to reduce site-variations of soil and climate. *Opuntia* plantation age was determined based on field investigations and confirmed by the High Commission for the Development of the Steppe (HCDS) in Tebessa.

*Soil Analysis.* In each surveyed plot, eight soil samples were collected using an auger on an average depth of 15–20 cm. All soil samples of the same plot type of plantation age "treatment" were pooled before processing. In the laboratory, physical and chemical analyzes were carried out on the fine earth (Ø < 2mm). The following edaphic parameters were measured repetitively six times on the pooled soils of each treatment:

— Grain size was determined by wet sieving method (AFNOR, 1990) once for each treatment. Then soil texture was derived by projecting fraction values of clay, silt and sand on the textural triangle according to USDA classification (DUCHAUFFOUR, 1977).

— The pH and electrical conductivity (EC) were measured at 1:5 soil-water suspension ratio.

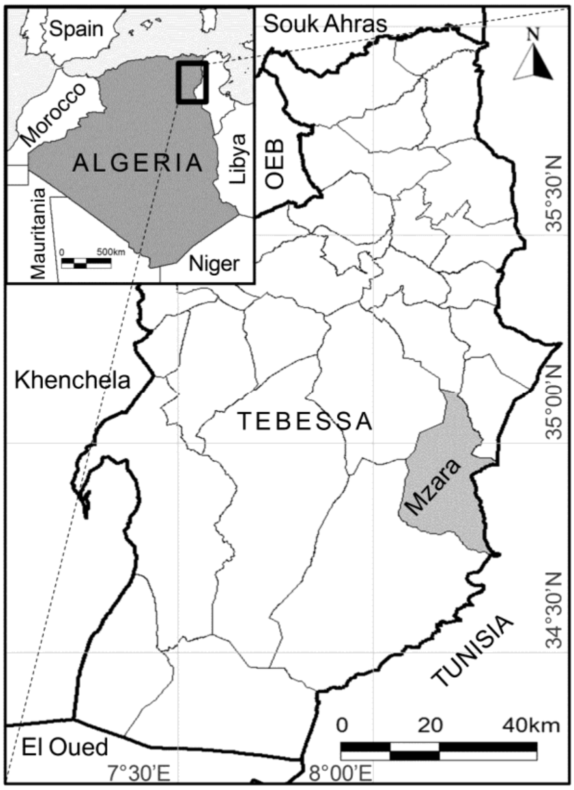


**Fig. 1.** Geographical localization of study area "Mzara" in Tebessa (Northeastern Algeria, North Africa).

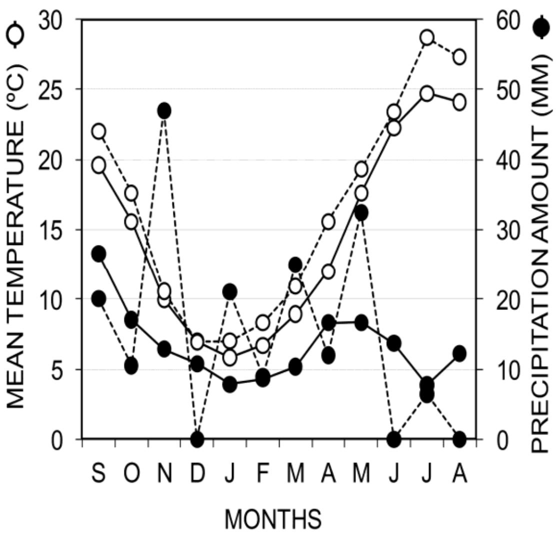


**Fig. 2.** Diagram of Gaussen and Bagnouls applied for Mzara (Tebessa, Northeast Algeria). Continuous lines represent data of 16–years period (1990–2005) and dashed lines symbolize climate data of 2008.

— The levels of calcium carbonate equivalent (CCE) were determined by volumetric calcimetry (DERMECH *et al.*, 1982), which is based on decomposition of calcium carbonates by a strong acid (HCl) (V: 1/3) and measuring the volume of $CO_2$ released.

— DROUINEAU's method was used to determine the amount of active calcium carbonate equivalent (ACCE) (MATHIEU & PIELTAIN, 2003), which is based on calcium's property of combining with oxalate to give insoluble calcium oxalate.

— Organic carbon was determined by Anne method (BONNEAU & SOUCHIER, 1994) by oxidation of carbon with excess potassium dichromate ($K_2Cr_2O_7$) in sulfuric acid medium (heat source). The amount of non-consumed dichromate was measured back by Mohr's salt.

— The rate of organic matter (OM) was estimated by multiplying the percentage of carbon by 1.72 (MATHIEU & PIELTAIN, 2003).

— The total nitrogen was determined by the KJELDAHL method described by BONNEAU & SOUCHIER (1994). It consists of a mineralization of the nitrogenous organic matter by concentrated sulfuric acid in hot conditions. The transformed nitrogen into ammonia was determined by the amount of sulfuric acid in the form of ammonium sulfate.

— Available phosphorus (AP) was determined by Olsen method (MATHIEU & PIELTAIN, 2003) after extraction with a solution of sodium bicarbonate at 0.5 M.

*Vegetation Sampling.* Vegetation traits (vegetation cover, number of individuals and diversity) were estimated using linear transect or "line intercept" method (COOK & STUBBENDIECK, 1986) which consists in measuring the length covered by various species projected along a line graduated of 10 by 10 cm, and stretched through the vegetation, either at ground or on top of the dominant stratum for bushy and/or shrubby species. In total we have carried out three replications per season in each plot sampled. In every replication four line intercept measures were randomly carried out at the interline spacing between prickly pear plants and then these measures were averaged to have only one value per replication.

The tape length depended on the width of the interline spacing of *Opuntia* plantations, which varied between 2 and 13 meters. Along the stretched tape, the monitoring of vegetation parameters "number of individuals" was performed at one point every 10 cm where every individual touching a point of the line was noted. Points of the tape touched by the plant were counted, and then their percentage relative to the total number of points of the tape was calculated. The vegetation cover was evaluated by estimating continuously the percentage of ground covered by vegetation as the ratio of the length occupied by vegetation to the total length of the line. Although this method is not very precise, if the sampled transect was not representative, but at least has the advantage in rapid assessment (COOK & STUBBENDIECK, 1986).

While vegetation cover was measured seasonally (three months per season), the census of plant species and their abundance "number of individuals" were carried out during period of maximum growth of vegetation, which coincides with the month of April (mid spring: March–May). Species diversity was assessed by Shannon index (*H'*) (FAURIE *et al.*, 2003).

$$H' = -\sum_{i=1}^{S}[(\frac{ni}{N}) \times Log_2 (\frac{ni}{N})]$$

where: $n_i/N$ is the relative abundance, $n_i$ is the number of individuals of each species, $N$ is the total number of individuals of all species, and $S$ the total number of species (species richness).

The evenness ($E$) is the ratio of Shannon index ($H'$) and the maximum diversity value that is assessed for $S$ species with equal population distribution. Evenness varies between zero and one (FAURIE *et al.*, 2003).

$$E = H' / log_2 S$$

*Statistical analysis.* One–way analysis of variance (ANOVA) was carried out to test the effect of plantation age of prickly pear on soil parameters. The effects of prickly pear plantation age on the traits of spontaneously vegetation "including the total number of individual plants ($N$), species richness ($S$), the ratio $N/S$, Shannon index, Evenness and vegetation cover" were analyzed using one–way ANOVA. Before computations, the normal distribution and homogeneity of data was verified by the SHAPIRO-WILK normality test, then all vegetation traits were log-transformed to normalize their distributions, and after that, we tested if the data meets the basic assumption of equal variance (homoscedasticity). We used a modified version of LEVENE's test, as described by GLANTZ & SLINKER (2000). The vegetation data were transformed by obtaining the absolute difference between each value and the corresponding group median (not the mean as in the original method), and then the test performed an analysis of variance on the transformed data (GLANTZ & SLINKER, 2000). Since the ANOVA makes a general statement about whether or not there are significant differences between the data groups, once the result is positive ($P < 0.05$) post-hoc tests were performed to find out which of the multiple comparisons that are possible for plantation age data set were significant. The post-hoc method performed multiple comparisons using TUKEY test, which requires computation of the so-called studentized range "$q$" (Rafter *et al*. 2002). The studentized range is the difference between the largest and smallest data in a sample measured in units of sample standard deviations.

In addition, two–way ANOVA was applied for testing the effect of plantation age, seasons and the interaction "age*season" on spontaneously vegetation cover. ANOVA-tests were considered statistically significant (*), highly significant (**) or very highly significant (***) for probability-value $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

**Results**

*Physicochemical properties of soils.* Overall, the factor "plantation age" statistically had no significant effect on all studied soil parameters (Table 1). According to values of clay, sand and silt fractions, projected onto a texture triangle, studied soils belong to sandy class. The pH showed values exceeding 8, indicating an alkaline soils. The values of electrical conductivity (EC) were below 1000 µS cm$^{-1}$ in all surveyed plots. Although EC variations were noticeable between unplanted and planted plots, there are no statistically significant differences for both variables (pH: $F = 2.40$, $P = 0.121$; EC: $F = 2.97$, $P = 0.082$).

The $CaCO_3$ equivalent showed average values, ranging between 12 and 15% in all samples with no significant difference among them. It is the same for the rate of ACCE that marked values between 4.81 and 6.69% in the planted plots and 7% in control plots. Planted plots showed an average rate of total nitrogen (0.06 to 0.12%) and that was similar to controls (0.12%). No significant difference was registered for available phosphorus concentrations that were slight and organic matter (OM) between planted plots (OM = 0.36 to 0.57%) and control plots (OM = 0.46%). The C/N ratio recorded mean values ranging from 2.72 and 1.75 in planted plots and 2.86 in control plots (Table 1).

*Effect on vegetation characteristics.* The highest value of spontaneously vegetation cover was observed in winter, followed by cover of spring and summer. Nevertheless, whatever the season, the planted plots (young and old plantations) showed a higher vegetation cover than controls (Fig. 3), which was statistically reported as significant ($P = 0.031$) considering plot-to-plot cover variation within treatment (Table 2). While the seasons had also a significant effect on vegetation cover variations ($P < 0.019$), the interaction "Plantation age*Season" was not significant ($P = 0.798$).

Indeed the lowest vegetation cover was observed during summer with 9% in controls and between 21% and 27% in planted plots, compared to winter in which the control plots recorded a value of 33% and in planted plots between 37 and 52%. In spring, vegetation cover varied between 39 and 45% among planted samples, and was 25% in unplanted plots (Fig. 3).

Shannon index ($H'$) and evenness ($E$) were low in both young plantations ($H' = 1.49$ bits, $E = 0.57$) and control plots ($H' = 1.26$ bits, $E = 0.54$), and experienced a slight rise in old plantations ($H' = 1.99$ bits, $E = 0.58$). Regarding plant life forms, the area had 66% of therophytes in young planted plots, followed by 16% of geophytes and hemicryptophytes. In old plantations, the chamaephytes represented 42% followed by geophytes with 28%. While in control-plots, geophytes and chamaephytes occurred equally with 33%, followed by hemicryptophytes and therophytes with 16% for each (Table 3).

Regarding the effect of *O. ficus-indica* plantation age on natural plant species abundance and species richness (Fig. 4), both *Opuntia*-planted plots recorded an average plant abundances ranging between 19 and 21 individuals, slightly higher compared to controls (15 individuals), and the statistical analysis revealed a highly significantly deference ($P < 0.0001$). However even there was a high trend for species richness to be greater in *Opuntia*-planted plots compared to controls, its variation was not significant ($P = 0.052$). In addition, the ANOVA testing the effect of *Opuntia* plantations on native vegetation features revealed that N/S ratio and vegetation cover differed highly significantly, $P = 0.003$ and $P < 0.0001$, respectively (Table 4). The test was non-significant for plant diversity parameters including either Shannon's index ($P = 0.247$) and evenness ($P = 0.415$).

Multiple comparisons (TUKEY's test) revealed that all vegetation traits (plant abundance, N/S ratio and vegetation cover) were significantly higher on *Opuntia* plantations than in control plots. Multiple comparisons also revealed that plant abundance was significantly different between both young and old *Opuntia* plantations and the controls. While the $N/S$ ratio was only significantly different between old plantations and controls, the test indicated also that vegetation cover was highly significantly different ($P < 0.0001$) between either young and old *Opuntia* plantations and the controls (but not between young and old plots). The $q$-values calculated for young and old plantations comparisons were the lowest (except for N/S ratio), indicating a slight range difference between these two treatments (Table 5).

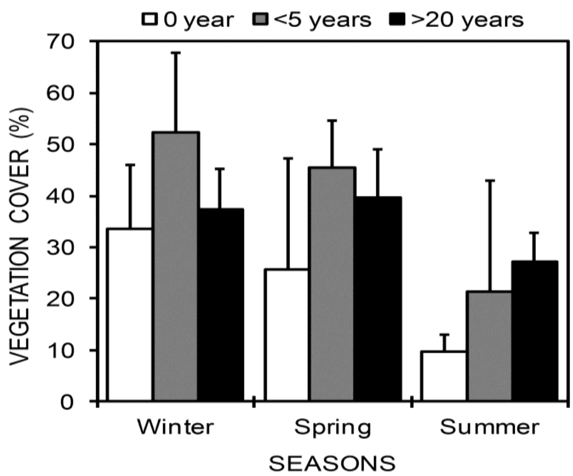


**Fig. 3**. Seasonal variation of vegetation cover according to ages of spiny prickly pear plantations.

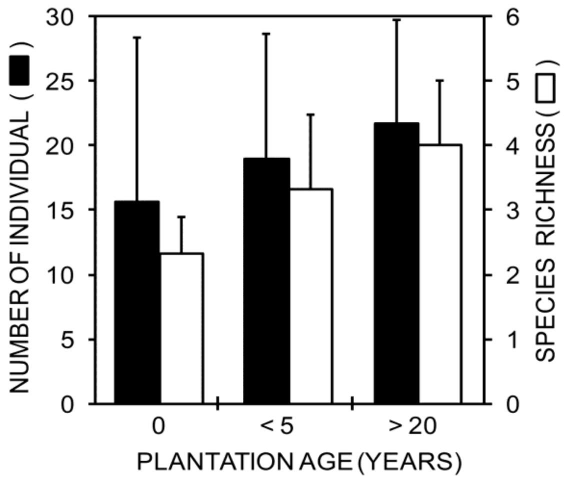


**Fig. 4**. Variation of the total number of plant individuals ($N$) and species richness ($S$) according to plantation ages of *Opuntia ficus-indica*.

**Table 1**. Mean values (± SD) of physicochemical soil parameters based on six measurements, followed by effect of the prickly pear plantation age on soil traits based on One–way ANOVA outputs. (EC: Electrical conductivity, CCE: calcium carbonate equivalent, ACCE: active calcium carbonate equivalent, AP: Available phosphorus).

| Soil traits | Plantation age of *Opuntia ficus-indica* | | | ANOVA | |
|---|---|---|---|---|---|
| | Control (unplanted) | < 5 years | > 20 years | *F* | *P* |
| Sand (%) | 85.40 | 79.71 | 87.78 | | |
| Silt (%) | 4.29 | 6.76 | 4.07 | | |
| Clay (%) | 10.30 | 13.52 | 8.14 | | |
| pH | 8.07 ± 0.08 | 8.14 ± 0.03 | 8.09 ± 0.03 | 2.40 | 0.121 |
| EC (µS $cm^{-1}$) | 753.66 ± 29.39 | 767.5 ± 27.13 | 826.16 ± 85.97 | 2.97 | 0.082 |
| CCE (%) | 15.30 ± 4.24 | 12.04 ± 3.90 | 13.98 ± 1.83 | 1.32 | 0.296 |
| ACCE (%) | 7.23 ± 2.39 | 4.81 ± 2.48 | 6.69 ± 1.32 | 2.11 | 0.155 |
| Carbon (%) | 0.27 ± 0.20 | 0.34 ± 0.26 | 0.21 ± 0.12 | 0.67 | 0.528 |
| Total Nitrogen (%) | 0.12 ± 0.05 | 0.06 ± 0.01 | 0.12 ± 0.07 | 2.60 | 0.108 |
| Organic matter (%) | 0.46 ± 0.35 | 0.59 ± 0.45 | 0.36 ± 0.21 | 0.66 | 0.530 |
| C/N | 2.86 ± 2.57 | 2.75 ± 1.93 | 1.72 ± 1.55 | 0.92 | 0.418 |
| AP (ppm) | 1.23 ± 0.46 | 1.80 ± 0.43 | 1.43 ± 0.66 | 1.42 | 0.271 |

**Table 2.** Results of two–way ANOVA testing for effects of prickly pear plantation age and season on for native vegetation cover.

| Source | *Df* | *SS* | *MS* | *F* | *P* | |
|---|---|---|---|---|---|---|
| Age | 2 | 1340.1 | 670.0 | 6.55 | 0.031 | * |
| Plot | 6 | 613.8 | 102.3 | | | |
| Season | 2 | 2408.6 | 1204.3 | 5.60 | 0.019 | * |
| Age*Season | 4 | 352.8 | 88.2 | 0.41 | 0.798 | |
| Res. error | 12 | 2578.6 | 214.9 | | | |
| Total | 26 | 7293.9 | 280.5 | | | |

**Table 3.** List and abundances of native plant species recorded in different plantation plots of prickly pear (*Opuntia ficus-indica*), with vegetation traits and diversity indices. (Ch: Chamaephyte, Geo: Geophyte, Hem: Hemicryptophyte, Th: Therophyte).

| FAMILLY<br>Species | Morphologic forms | Life forms | Opuntia Plantation age<br>Control | <br>< 5 years | <br>> 20 years |
|---|---|---|---|---|---|
| POACEAE | | | | | |
| *Cynodon dactylon* L. | Perennial | Th/Geo | 35 | 35 | 23 |
| *Hordeum murinum* L. | Annual | Th | 0 | 16 | 0 |
| BRASSICACEAE | | | | | |
| *Sinapis arvensis* L. | Annual | Th | 0 | 2 | 0 |
| *Raphanus raphanistrum* L. | Annual | Th | 0 | 1 | 0 |
| PLANTAGINACEAE | | | | | |
| *Plantago albicans* L. | Perennial | Hem | 3 | 2 | 26 |
| LILIACEAE | | | | | |
| *Asparagus stipularis* | Perennial | Geo | 0 | 1 | 1 |
| FABACEAE | | | | | |
| *Astragalus armatus* Willd | Perennial | Ch | 6 | 0 | 5 |
| CHENOPODIACEAE | | | | | |
| *Haloxylon scoparius* Forsk | Perennial | Ch | 1 | 0 | 1 |
| ASTERACEAE | | | | | |
| *Artemisia campestris* L. | Perennial | Ch | 0 | 0 | 3 |
| ZYGOPHYLLACEAE | | | | | |
| *Peganum harmala* L. | Perennial | Hem | 0 | 0 | 26 |
| ASTERACEAE | | | | | |
| *Echinops spinosus* L. | Perennial | Geo | 2 | 0 | 1 |
| Abundance "*N*" | | | 47 | 57 | 86 |
| Species richness "*S*" | | | 5 | 6 | 8 |
| Ratio *N/S* | | | 9.4 | 9.5 | 10.8 |
| Vegetation cover (%) | | | 25.6 ± 1.6 | 45.6 ± 8.9 | 39.8 ± 9.3 |
| Shannon index "*H'*" (in bits) | | | 1.26 | 1.49 | 1.99 |
| Evenness "*E*" | | | 0.54 | 0.57 | 0.58 |

**Table 4.** Results of ANOVAs testing for effect of plantation age of *Opuntia ficus-indica* on natural vegetation traits. Test for equal variance (*F*, *df* (numerator, denominator) and *P* values) was given for each vegetation variable.

| Dependent variable<br>(Test for equal variance) | Source | *Df* | *SS* | *F* | *P* | |
|---|---|---|---|---|---|---|
| Plant abundance "N"<br>($F_{2,6}$ = 0.82, $P$ = 0.485) | Between groups<br>Within groups | 2<br>6 | 0.0160<br>0.0006 | 79.92 | <0.0001 | *** |
| Species richness "S"<br>($F_{2,6}$ = 0.45, $P$ = 0.656) | Between groups<br>Within groups | 2<br>6 | 0.0016<br>0.0010 | 5.06 | 0.052 | |
| N/S ratio<br>($F_{2,6}$ = 0.46, $P$ = 0.651) | Between groups<br>Within groups | 2<br>6 | 0.0402<br>0.0070 | 17.13 | 0.003 | ** |
| Shannon index<br>($F_{2,6}$ = 1.32, $P$ = 0.334) | Between groups<br>Within groups | 2<br>6 | 0.0176<br>0.0297 | 1.78 | 0.247 | |
| Evenness<br>($F_{2,6}$ = 1.02, $P$ = 0.414) | Between groups<br>Within groups | 2<br>6 | 0.0000<br>0.0000 | 1.02 | 0.415 | |
| Vegetation cover<br>($F_{2,6}$ = 3.58, $P$ = 0.095) | Between groups<br>Within groups | 2<br>6 | 0.0436<br>0.0002 | 750.20 | <0.0001 | *** |

**Table 5**. Summary of multiple comparisons (Tukey's range test) examining the effect of plantation age of *Opuntia ficus-indica* on natural vegetation traits (Parameters which differed significantly in ANOVA: $P < 0.05$). (Age of *Opuntia* plantation plots: C: control, 5y: < 5 years, 20y: > 20 years)

| Dependent variable | Comparison | Sorted treatment | Delta means | *SE* | *q* | *P* | |
|---|---|---|---|---|---|---|---|
| Plant abundance | 5y * C | 20y > 5y > C | 0.103 | 0.006 | 17.87 | <0.0001 | *** |
| | 20y * C | | 0.054 | 0.006 | 9.38 | 0.001 | ** |
| | 5y * 20y | | 0.049 | 0.006 | 8.49 | 0.002 | ** |
| N/S ratio | 5y * C | 20y > 5y > C | 0.032 | 0.020 | 1.60 | 0.533 | |
| | 20y * C | | 0.155 | 0.020 | 7.83 | 0.004 | ** |
| | 5y * 20y | | 0.123 | 0.020 | 6.24 | 0.011 | * |
| Vegetation cover | 5y * C | 5y > 20y > C | 0.148 | 0.003 | 47.45 | <0.0001 | *** |
| | 20y * C | | 0.148 | 0.003 | 47.43 | <0.0001 | *** |
| | 5y * 20y | | 0.0001 | 0.003 | 0.02 | 0.999 | |

**Discussion**

Results of this study revealed that plantations of prickly pear had no effect on soil parameters, but a variable effect is reported on spontaneously vegetation parameters.

*Effects on soil characteristics.* In general, the effect of prickly pear plantations on soil properties is not significant; the causes as well the result values can be explained as follows:

All plots showed an alkaline pH, included in the range of base (7.5 and 8.5) following the classification of BAIZE & JABIOL (1995). Soil pH is mainly affected by the parental material (REZAEI & GILKES, 2005) as well the organic matter transformed. Indeed, the soil of the station is classified as moderately calcareous (BAIZE & JABIOL, 1995), attributed to the calcareous origin of the steppe region (DJEBAILI, 1984) and the Mediterranean basin (NOUAIM & CHAUSSOD, 1995). The active fraction varies between 5 and 6%, which probably explains this alkalinity. According ROMANYA and ROVIRA (2007), this reduces the availability of phosphorus for plants and microorganisms, hence explains the low values observed for this element, reflecting a poor soil according to Olsen's method (MATHIEU & PIELTAIN, 2003).

Our results showed there was a trend for phosphorus content to be higher in planted treatments compared to control. This is probably because livestock (cattle, sheep, goats) graze in untreated plots, but avoid plots of the spiny prickly pear plants, which kept out livestock, in particular when *Opuntia* plantation was grown into dense shrubby bush. Knowing that livestock feces somehow contribute in extent nitrogen content (PEI *et al*., 2007), the latter factor has a strong trend to be lower in treated plots compared to unplanted areas (URIOSTE *et al*., 2006), which is attributed to plant uptake, so by the prickly pear in our case. LI *et al*. (2004), attribute this decline to drought. Indeed, the climate of study area is arid-type, where the index of De MARTONNE is 6.76 and rainfall is around 163 mm, making the mobility of nutrients such as phosphorus, very difficult.

Regarding the electrical conductivity, due to its average value less than 1000 µS $cm^{-1}$, it reveals slightly salty soil (MATHIEU & PIELTAIN, 2003). These values do not automatically imply an increase in salinity but probably reflect an increased concentration of mineral nutrients that is released during decomposition of organic matter (SU & ZHAO, 2003), which is fast under hot arid conditions.

The ratio C/N of a given soil in balance with its environment is about 10~12 and its variation is indicative of nitrogen variation in organic matter (ABULE *et al*., 2007). In the present essay, values of C/N were low in all surveyed plots, probably indicating a rapid mineralization of herbal plant litter (WEZEL *et al.*, 2000) or a loss of nitrogen than carbon, which means a high rate of nitrogen mineralization in relation to carbon (MARTÍNEZ-GARCÍA *et al.*, 2011). It is clear that the ratio C/N was low because of the low rate of OM recorded in the study station. The latter may have originated from the litter of ephemeral vegetation developed after rain, or from the slight yield of biodegradation of Prickly Pear rackets, since their main composition are based of resistant mucilage (BRIGGS *et al.*, 2007). Finally, this ratio fully depends on the nature of organic debris and maturation of humus (BENABADJI *et al.*, 1996).

*Effect on vegetation traits.* Vegetation cover is considered as a key-indicator revealing the degree of restoration success because it clearly reflects changes in the rehabilitation process (YANG *et al.*, 2006). With that in mind, this study reveals that vegetation cover and number of individual plants are greater in planted plots compared to the control, where vegetation cover is average (around 45%) and mainly composed of Poaceae (*Cynodon dactylon* and *Hordeum murinum*) and Zygophyllaceae (*Peganum harmala*). These plant species are ubiquitous and explain the homogenization of steppe flora. Indeed, *Cynodon dactylon* characterizes a crop-disturbed soil surface (LE HOUÉROU, 1996), while *Peganum harmala* is known as a degradation-indicator that replaces climax species such as *Stipa tenacissima* and *Artemisia herba alba* of Algerian rangeland ecosystems (LE HOUÉROU, 1995; NEDJRAOUI, 2004).

The decrease in vegetation cover and change in floristic composition are the elements that characterize regressive evolution of rangelands (NEDJRAOUI, 2004 ; SLIMANI *et al.*, 2010). This is also seen through the Shannon index and evenness that showed low values, which did not differ significantly. This expresses low species richness with dominance of one or two plant species over others, which characterizes a pioneer community that still young and unstable within its environment. Considering the situation within rehabilitation context, biological recovery in a degraded land requires long time periods while taking into account the limiting factor "water", on which revegetation significantly depends (CAO *et al.*, 2007 but see YANG *et al.*, 2006). Although this is not always true, because it was reported a high degree of vegetation cover and a large recovery, while soil water was limited (YANG *et al.*, 2006). It is recognized that the perennial species are the focus of restoration projects in arid environments because of their stability and effective soil protection capacity (OTT *et al,* 2011). However, OFTEDAL (2002) noted that annual plants are also important in term of plant biodiversity and ecological succession.

The biological spectrum is typical for the semi-arid Mediterranean bioclimate, with a well-marked presence of therophytes and chamaephytes. These life forms characterize plant adaptation strategy in drylands (HASHEMI, 2001). Indeed, the hyperarid climate and the instable soil structure promote the development of short-lived plants (therophytes, mainly annuals). The domination of therophytes and chamaephytes in the vegetation life forms of M'zara agrees closely with proportions of life forms recorded near a lake at the Algerian Sahara Desert (CHENCHOUNI, 2012) and in desert and sub-desert habitats of Saudi Arabia (El GHANIM *et al.*, 2010). As for hemicryptophytes, if they are not abundant, it is because of the low amount of organic matter (GHEZLAOUI *et al.* 2011). PINK *et al.* (2010) and WEZEL *et al.* (2000) indicate the importance of soil texture, salinity and organic carbon for the composition and species richness of plant communities. According to ZHANG *et al.* (2010), organic matter is a pivotal soil fertility factor that can affect phytodiversity.

Following results of this study, in concordance to plantations of spineless prickly pear cactus (*inermis*) in another station of North Tebessa (NEFFAR *et al.*, 2011), the facilitator effect of *Opuntia ficus-indica* was clearly highlighted for (i) native vegetation cover, (ii) number of plant individuals, and (iii) the ratio of the latter and species richness. The most important factor facilitating the establishment of several species, in particular herbaceous plants, inside *Opuntia* plots may be that the spiny prickly pear plants keep out domestic herbivores, except at very young stage of the plantation or when the distance between prickly pear plants is large. According to NOY-MEIR *et al*. (1989) and MILCHUNAS and NOY-MEIR (2002) grazing by herbivores occurs selectively and thus causes differences among plant species. It alters notably species abundance by introducing the competition for light, water and nutrients.

The presence of perennial species such as *Stipa tenacissima* and *Artemisia herba alba* and ephemeral species may be a source of litter for agroecosystems like based-prickly plantations (AIDOUD *et al*., 2006). This shrub, as well as other species such as *Acacia* or *Aloe* (KING, 2008), may create under its canopy a microclimate for the installation of less tolerant species of barren environment conditions. By increasing its stock of plant seeds, it could create an island of fertility that represents a starting point for improving soil conditions and therefore a gradual increase of vegetation cover. Herbaceous litter is the main source of organic matter especially in these harsh environments. Not only it decomposes more easily than shrubs (LI *et al*. 2006), but could greatly improve soil structure and fertility without neglecting the great annual production of seeds (HUANG *et al*., 2007), whose rapid life cycle (growth and death) provides an important carbon pool for the soil and the nutrients (SU & ZHAO, 2003).

*Opuntia ficus-indica* in this case, even if not directly involved in the supply of soil organic matter in our study site due to the severity of climatic conditions, could have an indirect effect on this variable by improving harsh environmental conditions that will favorite the installation of grasses then the colonization and development of other less tolerant plant species.

Upon completion of this study, it is possible to argue that restoration of soil fertility induced by revegetation is a complex ecological process that is subject to simultaneous effect of biotic and abiotic factors (SU & ZHAO, 2003). However, the advantage of prickly pear plantations is its drought resistance (TEGEGNE *et al*., 2007), and its shoots can trap nutrient-rich dusts (WEZEL *et al*., 2000). Its roots have showing very high rates of mycorrhization (work in progress), reinforcing its environmental benefits.

**Conclusions**

This study reveals that after the establishment of *Opuntia ficus-indica* in arid rangelands of Tebessa (Northeast Algeria), the intended effect on the microenvironment was not statistically noticeable in soil properties, but by the concentration of plant species around the base of the planted shrub, which can only express an improvement in micro-environmental conditions. The results also show that the rehabilitation of degraded steppes can be achieved by developing a revegetation with herbaceous layer. Plantations can maintain vegetation cover in arid and semi-arid areas and over time contribute to the improvement of soil quality.

The use of prickly pear plantations in the Mediterranean basin should be encouraged not only for the restoration of biodiversity, but also to stop erosion and desertification processes in arid and semi-arid lands. The choice of this shrub as a modulator of rehabilitation returns to its power to stimulate the growth of vegetation points around it "fertility islands". On this basis, the expansion of prickly pear plantations is emerging as a promising strategy to raise the dynamic of resources and restore vegetation in arid and semi-arid rangelands.

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**Reference**

ABULE E., H. SNYMAN, G. SMITH. 2007. Rangeland evaluation in the middle awash valley of Ethiopia: III. Relationships among soils and vegetation variables. - *Journal of Arid Environments,* 70: 293–303.

AFNOR. 1990. *Granulats, analyse granulo-métrique par tamisage.* Norme P18–560.

AIDOUD A., E. LE FLOCH', H. LE HOUÉROU. 2006. Les steppes arides du Nord de L'Afrique. - *Sécheresse,* 17: 19–30.

BAIZE D., B. JABIOL. 1995. *Guide pour la description des sols: techniques et pratiques*. INRA, Paris.

BENABADJ N., M. BOUAZZA, G. METZE, R. LOISEL. 1996. Description et aspect des sols en région semi-aride et aride au sud de Sebdou (Oranie–Algérie). - *Bulletin de l'Institut des Sciences,* 20: 77–86.

BENABDERRAHMANE M., H. CHENCHOUNI. 2010. Assessing Environmental Sensitivity Areas to Desertification in Eastern Algeria using Mediterranean Desertification and Land Use "MEDALUS" Model. - *Int. J. Sust. Water Environ. Systems,* 1: 5–10.

BENSLIMANE M., A. HAMIMED, W. EL ZEREY, A. KHALDI, K. MEDERBAL. 2008. Analyse et suivi du phénomène de la désertification en Algérie du nord. - *VertigO,* 8(3). URL: [http://vertigo.revues.org/6782].

BONNEAU M., B. SOUCHIER. 1994. *Constituants et propriétés du sol*. Ed. Masson, Paris.

BRIGGS J., H. SCHAAFSMA, D. TRENKOV. 2007. Woody vegetation expansion in a desert grassland: Prehistoric human impact. - *Journal of Arid Environments,* 69: 458–472.

CALLAWAY R. 1995. Positive interactions among plants. - *Botanical Review,* 61: 306–349.

CAO S., L. CHEN, C. XU, Z. LIU. 2007. Impact of three soil types on afforestation in China's Loess Plateau: Growth and survival of six tree species and their effects on soil properties. - *Landscape Urban Planning*, 83: 208–217.

CARAVACA F., M. ALGUACIL, D. FIGUEROA, J. BAREA, A. ROLDAN. 2003. Re-establishment of *Retama sphaerocarpa* as a target species for reclamation of soil physical and biological properties in a semi arid Mediterranean area. - *Forest Ecology Management*, 182: 49–58.

CHENCHOUNI H. 2012. Diversité floristique d'un lac du Bas-Sahara Algérien. - *Acta Botanica Malacitana,* 37: 33–44.

COOK CW., J. STUBBENDIEK. 1986. *Range Research: Basic problems and techniques*. Society of Range management, Denver, Colorado, pp. 51–71.

DERMECH K., M. KAROUANI, M. EL BELKHI. 1982. *The essential in Soil Science*. Ed. Direction of Academic Publications, Aleppo, Syria. (In Arabic).

DJEBAILI S., Y. DJELLOULI, P. DAGET. 1989. Les steppes pâturées des Hauts Plateaux algériens. - *Fourrages,* 120: 393–400.

DJEBAILI S. 1984. *Steppes algériennes: phytosociologie et écologie*. Ed. OPU, Algiers.

DUCHAUFFOUR P. 1977. *Pédogénèse et classification*. Ed. Masson, Paris.

EL GHANIM W., L. HASSAN, T. GALEL, A. BADR. 2010. Floristic composition and vegetation analysis in Hail region north of central Saudi Arabia. - *Saudi Journal of Biology Sciences,* 17: 119–128.

FAURIE C., C. FERRA, P. MEDORI. J. DEVAUX, J. HEMPTINNE. 2003. *Ecologie: approche scientifique et pratique.* Tec & Doc, Paris.

GHEZLAOUI B., N. BENABADJI, D. BENMANSOUR, A. MERZOUK. 2011. Analyse des peuplements végétaux halophytes dans le Chott El-Gharbi (Oranie-Algérie). - *Acta Botanica Malacitana*, 36: 113–124.

GLANTZ S., B. SLINKER. 2000. *Primer of Applied Regression & Analysis of Variance.* 2nd Ed. McGraw-Hill, 949 p.

HASHEMI A. 2001. *Variation diachronique saisonnière de la dynamique de végétation dans une zone présaharienne (Cas de la région de Mesaad W. Djelfa)*. Engineer Dissertation, Univ. Djelfa, Algeria.

HUANG D., K.Wang, W. Wu. 2007. Dynamics of soil physical and chemical properties and vegetation successions characteristics during grassland desertification under sheep grazing in an agropastoral transition zone in Northern China. - *Journal of Arid Environments,* 70: 120–136.

KING E. 2008. Facilitative effects of *Aloe secundiflora* shrubs in degraded semi-arid ranglands in Kenya. - *Journal of Arid Environments,* 72: 358–369.

LE HOUÉROU H. 1995. Bioclimatologie et biogéographie des steppes arides du Nord de l'Afrique. Diversité biologique, développement durable et désertisation. *CIHEAM, Options Mediterranéennes*, Series B, 10, 396 p.

LE HOUÉROU H. 1996. The role of cacti (*Opuntia* sp.) in erosion control, land reclamation, rehabilitation and agricultural development in the Mediterranean Basin. - *Journal of Arid Environments,* 33: 135–159.

LI FM., Q. SONG, P. JJEMBA. Y. SHI. 2004. Dynamic of soil biomass microbial C and soil fertility in Cropland mulched with plastic film in a semi arid agro-ecosystem. - *Soil Biology and Biochemistry,* 36: 1893–1902.

LI X., X. JIA, J. DONG. 2006. Influence of desertification on vegetation pattern variation in the cold semi arid grasslands of Qinghai-Tibet Plateau, North-west China. - *Journal of Arid Environments*, 64: 505–522.

MARTINEZ-GARCIA L., C. ARMAS, J. DE DIOS MIRANDA, F. PADILLA, F. PUGNAIRE. 2011. Shrubs influence arbuscular mycorrhizal fungi communities in a semi-arid environment. - *Soil Biology and Biochemistry,* 43: 682–689.

MATHIEU C., F. PIELTAIN. 2003. *Analyse chimique de sol: méthodes choisies*. Tec & Doc, Paris.

MILCHUNAS D., I. NOY-MEIR. 2002. Grazing refuges, external avoidance of herbivory and plant diversity. - *Oikos,* 99: 113–130.

NEDJRAOUI D., S. BEDRANI. 2008. La désertification dans les steppes algériennes: causes, impacts et actions de lutte. - *VertigO,* 8. [http://vertigo.revues.org/index5375.html].

NEDJRAOUI D. 2004. Évaluation des ressources pastorales des régions steppiques algériennes et définition des indicateurs de dégradation. - *CIHEAM, Cahiers Options méditerranéennes,* 62: 239–244.

NEFFAR S., A. BEDDIAR, N. REDJEL, J. BOULKHELOUA. 2011. Effets de l'âge des plantations de figuier de Barbarie (*Opuntia ficus-indica* f. *inermis*) sur les propriétés du sol et la végétation à Tébessa (zone semi-aride de l'est algérien). - *Ecologia Mediterranea,* 37: 5–15.

NEFFAR S. 2012. *Etude de l'effet de l'âge des plantations de figuier de Barbarie (Opuntia ficus indica L. Miller) sur la variation des ressources naturelles (sol et végétation) des steppes algériennes de l'Est. Cas de Souk Ahras et Tébessa*. PhD Thesis, Univ. Annaba, Algeria. 132 p.

NOUAIM R., R. CHAUSSOD. 1995. Rôle des mycorhizes dans l'alimentation hydrique et minérale des plantes, notamment des ligneux de zones arides. - *CIHEAM, Cahiers Options méditerranéennes,* 20: 9–26.

NOY-MEIR I., M. GUTMAN, Y. KAPLAN. 1989. Responses of Mediterranean Grass-land Plants to Grazing and Protection. - *Journal of Ecology,* 77: 290–310.

OFTEDAL O. 2002. The nutritional ecology of the desert tortoise in the Mohave and Sonoran desert. - *In*: Van Devender T. (Ed.), *The Sonoran Desert Tortoise: Natural History, Biology and Conservation*. University of Arizona Press, Tucson, AZ, pp. 194–241.

OTT J., E. MC ARTHUR, C. SANDERSON. 2011. Vegetation dynamics at a Mojave Desert restoration site, 1992 to 2007. - *Natural Resources and Environmental Issues*. Issue 1 Shrublands: Wildlands and Wildlife Habitats, Volume 16.

PEI S., H. FU, C. WAN. 2007. Changes in soil properties and vegetation following exclosure and grazing in degraded Alxa desert steppe of Inner Mongolia, China. - *Agriculture, Ecosystems and Environment*, 124: 33–39.

PINKE G., R. PAL, Z. BOTTA-DUKAT. 2010. Effects of environmental factors on weed species composition of cereal and stubble fields in western Hungary. - *Central European Journal of Biology,* 5: 283–292.

RAFTER J., M. ABELL, J. BRASELTON. 2002. Multiple Comparison Methods for Means. - *SIAM Review,* 44: 259–278.

REZAEI S., R. GILKES. 2005. The effect of landscape attributes and plant community on soil chemical properties in rangelands. - *Geoderma,* 125: 167–176.

ROMANYA J., P. ROVIRA. 2007. Labile phosphorus forms in irrigated and rained semi arid Mediterranean grassy crops with long-term organic or conventional farming practices. - *European Journal of Agronomy,* 27: 62–71.

SHAO G., G. ZHAO, S. ZHAO, H. SHUGART, S. WANG, J. SCHALLER. 1996. Forest cover types from landsat TM imagery for Changbai Mountain area of China. - *Canadian Journal of Forest Research,* 26: 206–216.

SIVAKUMAR M. 2007. Interactions between climate and desertification. - *Agricultural and Forest Meteorology,* 142: 143–155.

SLIMANI H., A. AIDOUD, F. ROZÉ. 2010. 30 years of protection and monitoring of a steppic rangland undergoing desertification. - *Journal of Arid Environments,* 74: 685–691.

SMITH O., G. PETERSON, B. NEEDDMAN. 2000. Environmental indicators of agro-ecosystems. - *Advances in Agronomy*, 69: 75–97.

SNYMAN H. 2006. A greenhouse study of root dynamics of cactus pears, *Opuntia ficus indica* and *O. robusta*. - *Journal of Arid Environments,* 65: 529–542.

SU Y., H. ZHAO. 2003. Soil properties and plant species in an age sequence of *Caragana microphylla* plantations in the Horqin Sandy land, North China. - *Ecological Engineering,* 20: 223–235.

TEGEGNE F., C. KIJORA, K. PETERS. 2007. Study of the optimal level of cactus pear (*Opuntia ficus indica*) supplementation to sheep and its contribution as source as water. - *Small Ruminant Research,* 72: 157–164.

URIOSTE A., G. HEVIA, E. HEPPER, L. ANTON, A. BONO, D. BUSCHIAZZO. 2006. Cultivation effects of the distribution of organic carbon, total nitrogen and phosphorus in soils of the semiarid region of Argentinian Pampas. - *Geoderma,* 136: 621–630.

WEZEL A., J. RAJOT, C. HERBRIG. 2000. Influence of shrubs on soil characteristics and their functions in Sahelian agroecosystems in semi arid Niger. - *Journal of Arid Environments,* 44: 383–398.

YANG H., Q. LU, B. WU, H. YANG, J. ZHANG, Y. LIN. 2006. Vegetation diversity and its application in sandy desert revegetation on Tibetan Plateau. - *Journal of Arid Environments,* 65: 619–631.

ZHANG K., H. DANG, S. TAN, Z. WANG, Q. ZHANG. 2010. Vegetation community and soil characteristics of abandoned agricultural land and pine plantation in the Qinling Mountains, China. - *Forest Ecology and Management*, 259: 2036–2047.

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