EFFECTS OF THE CONTINENTALITY AND THE AGE OF PRICKLY PEAR (*OPUNTIA FICUS-INDICA* (L.) MILL.) PLANTATIONS ON SOIL PROPERTIES ALONG A COASTAL AND CONTINENTAL TRANSECT IN A PRE-SAHARAN REGION OF SOUTH-CENTRAL MOROCCO (AIT BAAMRANE)

YOUS, F. Z.[1*] – FERRADOUS, A.[2] – ELGADI, S.[1] – MOSTAKIM, L.[3] – HAFIDI, M.[1] – OUHAMMOU, A.[1] – ALIFRIQUI, M.[1]

[1]*Laboratory of Microbial Biotechnology, Agrosciences and Environment, Faculty of Sciences Semlalia, Cadi Ayyad University, BP 2390, Marrakesh 40000, Morocco*
(e-mail: sara.elgadi@ced.uca.ma, Hafidi@uca.ac.ma, ouhammou@uca.ac.ma, alifriqui@gmail.com)

[2]*Forestry Research Center, BP 12360, Marrakesh 40000, Morocco*
(e-mail: ferabder@yahoo.fr)

[3]*Laboratory of Water, Biodiversity and Climate Change, Faculty of Sciences Semlalia, Cadi Ayyad University, BP 2390, Marrakesh 40000, Morocco*
(e-mail: mostakim.lahcen@gmail.com)

[*]*Corresponding author*
e-mail: yousfatimazahra@gmail.com; phone: +212-691-083-141

(Received 23rd Sep 2022; accepted 7th Dec 2022)

Abstract. Prickly pear (*Opuntia ficus-indica* (L.) Mill.) is a plant that was spontaneous in South-Central Morocco. Our study focuses on the evaluation of the effects of prickly pear plantations through their ages: young (<10 years), middle (10-25 years) and old (> 25 years) on edaphic characteristics (grain size, pH, organic matter, total Nitrogen, available phosphorus, C/N ratio, exchangeable cations, cation exchange capacity and base saturation rate). These plantations are located along a coastal-continental transect in a Pre-Saharan region of South-Central Morocco: Ait Baamrane region (Sidi Ifni Province). In each zone, prickly pear orchards were classified in four classes with three repetitions each: unplanted plots (control) and three age groups (young, middle and old plantations). Three soil samples were collected, respectively, at 20, 50 and 100 cm from the plant of *Opuntia ficus-indica* (L.) Mill., in the direction of surface flow. Each time the first 5 cm of surface soil was removed. The results showed that the continentality and plantation age of *Opuntia ficus-indica* (L.) Mill. factors had statistically significant effects on some soil parameters, while the distance from the plant of cactus has no significant effect. This study suggested that prickly pear plantations can significantly improve soil proprieties and contribute to the rehabilitation of arid ecosystems and marginal areas.
Keywords: *Opuntia ficus-indica (L.) Mill., desertification, edaphic characteristics, rehabilitation, arid environments*

Introduction

Desertification is classically considered as a major oncoming threat which the Earth will have to deal with (Xu et al., 2014). It is defined by the United Nations Convention to Combat Desertification (UNCCD) as 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). Africa is the most affected continent by this phenomenon where about 43% of the continent’s surface area is classified under the threat of desertification, which affects the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

economy of most African countries (Ouma and Ogallo, 2007). 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 Houerou, 1995). Desertification indicators affecting vital ecosystem attributes are the deterioration of soil properties, including the reduction of water reserves and fertility, often up to critical regression of vegetation production (Aidoud et al., 2006). The reconstitution of the vegetation cover in degraded rangelands can no longer be ensured by natural regeneration mechanisms, and therefore requires the use of specific development and management techniques with a rigorous choice of plant species adapted to these areas (Mihi et al., 2019). Indeed, for over 40 years, these fragile ecosystems have been targeted by rehabilitation efforts and sustainable development programs (Le Houerou, 2000).

The prickly pear (*Opuntia ficus-indica* (L.) Mill.) and *Atriplex s*sp.; monospecific plantations were among the established rehabilitation programs for North African rangelands (Le Houerou, 2000). They were launched in these degraded habitats since 1990 (Le Houerou, 2000).

Thus, prickly pear is a shrub with low ecological requirements (Snyman, 2006), its cultivation is currently experiencing a revival of interest in several countries because of its contribution to the development of marginal lands and arid and semi-arid areas, as well as its adaptation to various climates and soils (Mulas and Mulas, 2004). It is a better alternative for the fight against the effects of drought. Indeed, the prickly pear plantations contributes to the protection against erosion and enhance characteristics of marginal and infertile lands where crop species are difficultly cultivated (Stintzing and Carle, 2004). In addition, it has a food value as a fruit (Pimienta-Barrios, 1993) and as alternative forage sources especially during drought periods (Bensalem et al., 2002). Most studies on the prickly pear have focused on its spatial distribution in the Mediterranean region (Erre et al., 2009), its biology (Reyes-Aguero et al., 2006) and on the production and quality of its fruit (Parish and Felker, 1997). Related works to the impact of plantations on the natural resources of degraded environments, particularly in North Africa, are rather rare and mainly in Morocco.

Prickly pear cultivation in Morocco occupies more than 150 000 ha, of which more than 40% is localized in the south Center of Morocco (Genin et al., 2017), particularly the Ait Baamrane region under study. Traditionally, products from prickly pear are fruits and cladodes for human and livestock feeding (Russell and Felker, 1987). Nowadays in Morocco, prickly pear seeds oil is also used in the cosmetic industry, and the fruits are sold in a dynamic national market, providing an additional income to local populations while allowing them to delineate plots and maintain land ownership (Genin et al., 2017). The prickly pear is the main plant cultivated in the study area, due to its ease of implementation, the production of diverse products (fruits, forage, oil) and for some with high added value.

This work aimed at studying the act as a facilitator in degraded rangelands. We tested how prickly pear plantations, through their ages: young (<10 years), middle (10-25 years) and old (> 25 years) affected soil properties. These plantations were located along a coastal-continental transect in a Pre-Saharan region of South-Central Morocco: Ait Baamrane region (Sidi Ifni Province). The study evaluated the effects of continentality and prickly pear plantations compared to unplanted plots (control) on the variation of edaphic parameters: grain size, pH, organic matter, total nitrogen, available phosphorus, C/N ratio, exchangeable cations, cation exchange capacity and base saturation rate.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

The results of this work would contribute to the understanding changes in soil properties along coastal to continental transects following the establishment of prickly pear plantations of arid area located in South-Central Morocco.

Material and methods

Study area

The territory of Ait Baâmrane (29°09' N, 10°12' W) is located in the north-west of the Guelmim-Oued Noun region; it covers 1310 km². Its location, in the proximity of the Atlantic Ocean, the Canary Islands, and the pre-Sahara, makes it a well-defined geographical entity where a large natural area is distinguished, corresponding to the western chain of the Anti-Atlas Mountains composed of the granite massif of Sidi Ifni (Tayi, 2011).

The three sampling zones in the study are listed below (*Figs. 1* and *2*).

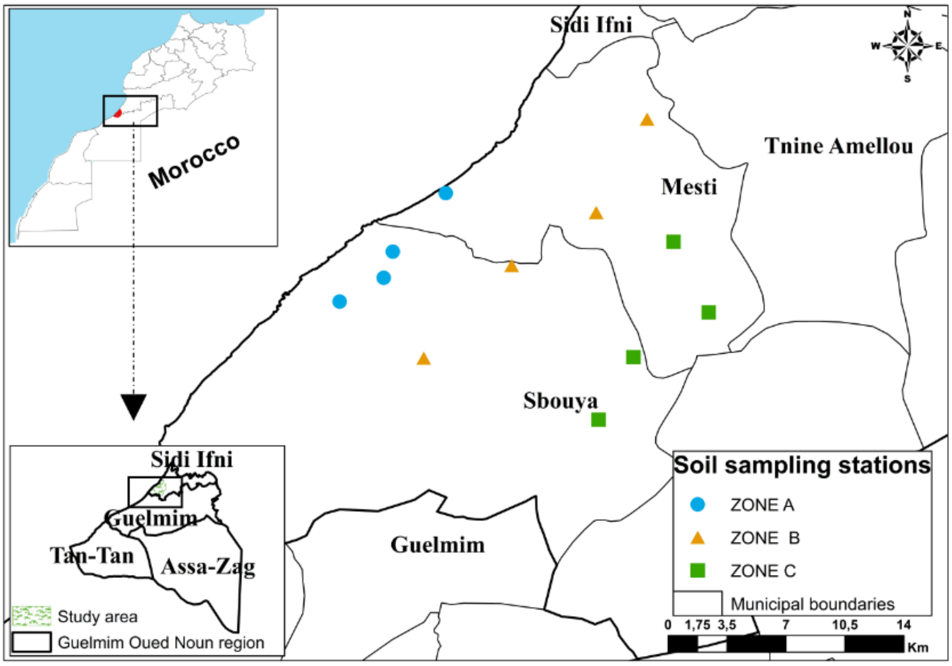


***Figure 1.** Geographic location of the studied area (Ait Baâmrane) and soil sampling stations (A, B and C). [Zone A: dunes and seaside cliffs, Zone B: coastal plains, hills and plateau, Zone C: mountains inside Argan forest]. Map constructed with ArcGIS*

***Figure 2.** Pictures of the sampled areas. [Zone A: dunes and seaside cliff; Zone B: hills and plateau; Zone C: mountains inside Argan forest.]*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

Zone A: (29°14'42.0"N 10°16'40.3"W) the coastal zone (dunes and seaside cliffs) is characterized by a flat relief, in relation to a geomorphological dynamic linked to the proximity of the Atlantic Ocean. The altitude is between 0 and 100 m a.s.l. The vegetation is a steppe dominated by a few representatives of the Amaranthaceae family (*Atriplex* genus) and Euphorbiacae (such as *Euphorbia balsamifera* Aiton). The rest are mostly annual species.

Zone B: (29°14'15.3"N 10°12'51.9"W) the plateaus and hills constitute the second unit. It has a levelled surface and a low to medium slope. The altitude is between 100 and 400 m a.s.l. The oceanic influences allow an abundance of humidity on the coastal zone where fogs are very frequent. The climatic vegetation has been greatly altered by intense plantations of prickly pear, which is an introduced species locally. The dominant physiognomy of the current stands is a woody steppe with Argan trees (*Argania spinosa* (L.) Skeels) and a bushy stratum with *Lycium intricatum* Boiss. and *Euphorbia* spp. We were currently witnessed an interesting plant dynamic and a return of natural vegetation, with in particular numerous regenerations of the argan tree and other woody plants as *Genista ferox* (Poir.) Dum. Cours. and *Kleinia anteuphorbium* (L.) Haw.

Zone C: (29°09'18.8"N 10°10'04.7"W) the continental mountainous area, constitutes the third zone. The land is rugged, with great relief protecting the area from Saharan influences. The altitude is between 400 and 900 m.a.s.l. The vegetation is made up of a shrubland forest with climax argan trees, mainly with euphorbia species (*Euphorbia officinarum* subsp. *echinus* (Hook. f. & Coss.) Vindt and *Euphorbia regis-jubae* J. Gay) and various bushes.

Concerning pedological characteristics, the Aït Baâmrane area is dominated by poorly evolved soils, followed by calcimagnesic soils. The fersialitic and iso-humic soils are less represented in the zone. However, this distribution of soil classes should be considered as a rough estimate in the absence of more in-depth pedological studies (Tayi, 2011).

The climate in general is Mediterranean, with a strong Saharan and Atlantic effects, with dry hot summers and wet cool winters. The region receives an average of 203 mm of rain per year. Average annual temperature is about 18.1°C with a minimum of 14.4°C in January and a maximum of 22.8°C in August (*Fig. 3*) (https://fr.climate-data.org). According the Gaussen and Bagnouls' diagram (1953), the drought period extends over the entire year (*Fig. 3*). In addition, the continentality index (M-m) were M, mean maximum temperature of the warmest month (°C); and m, mean minimum temperature of the coldest month (°C) (Debrach, 1953) is equal to 15.8°C, so the thermal climate is Coastal (15 > M-m < 25°C) (*Table 1*).

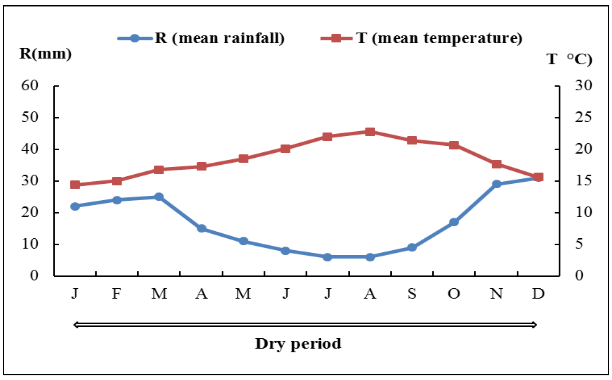


***Figure 3.** Diagram of Gaussen and Bagnouls applied for Sidi Ifni region (https://fr.climate-data.org)*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

Table 1. *Climatic characteristics of Sidi Ifni region (https://fr.climate-data.org)*

	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Average monthly relative humidity (%)	65	65	63	70	73	76	71	72	77	72	68	65
Average temperature of the coldest month (m) (°C)	**10.7**	11.5	13.2	14.3	15.7	17.3	18.9	19.8	18.7	17.6	14.4	12
Average temperature of the warmest month (M) ((°C)	18.4	18.9	20.8	20.7	21.8	23.4	25.7	**26.5**	24.8	24.3	21.4	19.6
Continentality index (M-m): 15.8 (°C)												

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

The region is characterized by significant summer cloudiness accompanied by relative coolness and very high relative humidity which frequently exceeds 60% throughout the year, with a minimum of 60% in March and a maximum of 77% in September (*Table 1*) (https://fr.climate-data.org).

Sampling of soil

In each zone, prickly pear orchards were classified in four classes (three repetitions each): unplanted plots (control) and three age groups (Young plots aged 0-10 years old, Middle aged 10-25 years old, and Old plots over 25 years old) (*Fig. 4*), on the basis of owners' information and of two used factors: presence of lignified cladodes (cactus around 20 years old) and number of cladodes's floors on the cactus (one floor per year), as reported by Boujghagh and Chajia (2001). Three soil samples (500 g for each soil) were collected, respectively, at 20, 50 and 100 cm from the plant of Opuntia (*Fig. 5*), in the direction of surface flow. Each time the first 5 cm of surface soil was removed. Samples were put in bags and brought to the laboratory for processing. The sampling was carried out during April and May 2016.

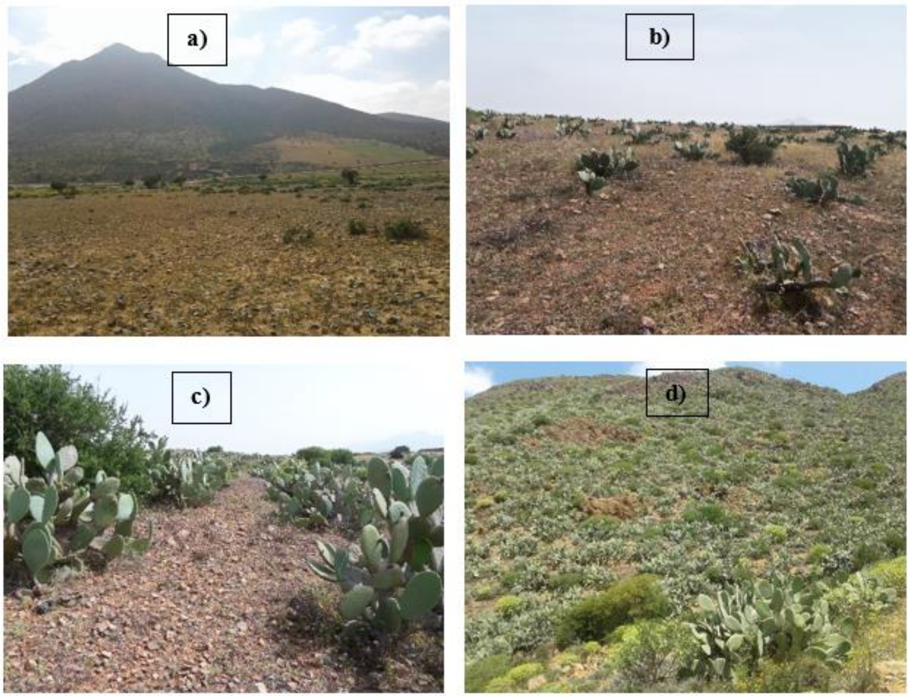


Figure 4. *Plantation age of prickly pear (Opuntia ficus-indica (L.) Mill. [a) control (Unplanted); b) young (< 10 years old); c) middle (10-25 years old); d) old (> 25 years)]*

Soil analysis

In the laboratory, the fine fraction (Ø < 2mm) of soil samples was retained for physical and chemical analysis according to standard methods and protocols:

- pH (hydrogen potential): was assessed using a pH meter (pH 1970i WTW GmbH, Weilheim, Germany).
- Total organic carbon was determined by Anne method described by Aubert (1978).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

- The rate of organic matter was estimated by multiplying the percentage of carbon by 1.72 (Dabin, 1967).
- Total nitrogen was determined using the Kjeldahl procedure (Wilke, 2005).
- Available phosphorus was determined by the Olsen method (Olsen et al., 1954).
- Cation exchange capacity (CEC) and exchangeable cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+): Widely used throughout the world, the ammonium acetate method was proposed by Metson (1956) described in the standard AFNOR NFX 31-130.
- Base saturation rate (V): Base saturation is calculated as the percentage of CEC occupied by base cations (Base Saturation (%) = Sum of the exchangeable bases /CEC) x 100) (Culman et al., 2019).
- Grain size was determined by the Robinson pipette method, following the standardized method AFNOR NF X31-107 (Buol et al., 2011). Then soil texture was derived by projecting fraction values of clay, silt and sand on the textural triangle according to USDA classification (Duchauffour, 1977).

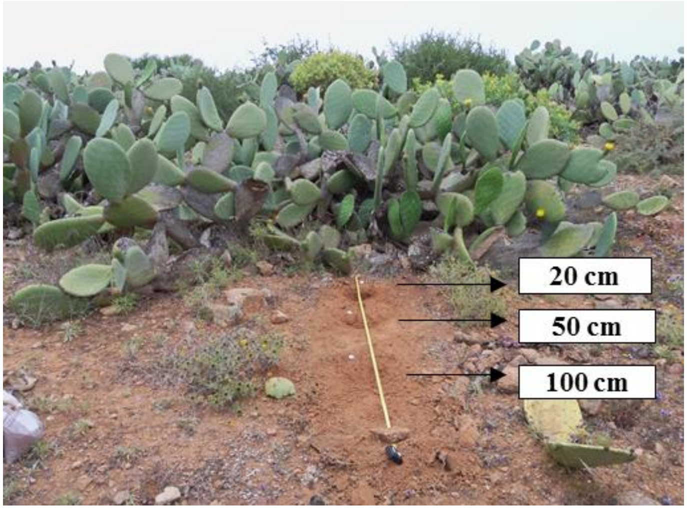


Figure 5. *Sampling of soil method*

Statistical analysis

All data were reported as the mean ± standard deviation (SD). One-way analysis of variance (ANOVA) combined with the Tukey test was applied to determine the differences between sampling sites. ANOVA was performed using SPSS Statistics version 21 (IBM Corp, Armonk, NY, USA), with p values ≤ 0.05 considered statistically significant. A principal component analysis (PCA) was performed using R software version 3.6.2 (R Foundation for Statistical Computing, Vienna, AT) to identify correlations between different zones and plantations age of prickly pear on the soil properties. Heatmap and hierarchical clustering were realised using Euclidean distance analysis to determine the interaction between zone and plantation age in one hand and plantation age and distance from the prickly pear plant in the other hand using R software version 4.2.1 (R Foundation for Statistical Computing, Vienna, Austria).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

Results

Overall, the factors “zone”, “plantation age” and “interaction (zone x plantation age)” statistically had significant effects ($p < 0.05$) on all studied soil parameters (*Tables 2* and *3*). while the factors “distance from the prickly pear plot” and the “interaction (plantation age x sampling distance from the prickly pear plant)” had no significant effects ($p > 0.05$) on most studied soil parameters (*Table 4*).

Table 2. *Effect of the age of prickly pear plantation on the physico-chemical soil properties*

Soil traits		Plantation age of *Opuntia ficus-indica* (L.) Mill			
		Control (Unplanted)	**Young (< 10 years)**	**Middle (10-25 years)**	**Old (> 25 years)**
pH		7.88 ± 0.58bc	7.69 ± 1.05b	8.06 ± 0.57c	7.16 ± 1.11a
Organic carbon (%)		1.61 ± 1.16b	1.11 ± 0.51a	1.12 ± 0.65a	1.25 ± 0.48a
Organic matter (%)		2.78 ± 2.00b	1.91 ± 0.88a	1.94 ± 1.12a	2.15 ±0.83a
Total nitrogen (%)		0.05 ± 0.01a	0.05 ± 0.02a	0.06 ± 0.03b	0.06 ± 0.02b
C/N		35.01± 15.70d	20.62± 6.15a	21.11± 2.73b	24.06± 9.89c
Available phosphorus (mg/g soil)		0.24 ± 0.06c	0.15 ± 0.06a	0.14 ± 0.07a	0.19 ± 0.12b
Exchangeable cations (mEq/100g)	$Ca^{2}+$	3.22 ± 0.40a	3.46 ± 2.23b	3.69 ± 2.24d	3.68 ± 1.11c
	$Mg^{2}+$	3.34 ± 0.26a	3.43 ± 2.11b	4.10 ± 2.59a	4.45 ± 1.42d
	Na+	12.35 ± 1.07a	17.44 ± 6.53d	16.97 ± 6.61c	13.70 ± 5.04b
	K+	2.71 ± 0.11b	2.66 ± 0.93a	2.83 ± 0.74c	2.87 ± 0.65d
CEC (mEq/100g)		37.18 ± 1.91a	38.42 ± 5.99b	43.89 ± 6.46c	44.32 ± 7.37d
Base saturation rate (%)		58. 42 ± 6.29a	58.98 ± 16.47b	61.64 ± 17.95c	63.80 ± 12.75a
Clay (%)		22.80 ± 13.51c	11.54 ± 7.48a	17.66 ± 10.83b	21.98 ± 11.66c
Silt (%)		36.35 ± 13.69a	45.87 ± 11.59b	45.35 ± 14.59b	44.91 ± 10.44b
Sand (%)		40.85 ± 17.08bc	42.59 ± 12.82c	37.00 ±7.43ab	33.11 ± 11.24a
Texture		Silt	Silt	Silt	Silt

Values are expressed as mean ± SD. Different letters in the same line designate significant differences ($p < 0.05$)

Table 3. *Effect of the of distance to the Atlantic Ocean on the physico-chemical soil properties*

Soil traits		Sampled units		
		Zone A	**Zone B**	**Zone C**
pH		8.25 ± 0.46c	7.68 ± 0.92b	7.16 ± 0.96a
Organic carbon (%)		0.84 ± 0.39a	1.27 ± 0.53b	1.71 ± 0.99c
Organic matter (%)		1.44 ± 0.67a	2.19 ± 0.91b	2.95 ± 1.71c
Total Nitrogen (%)		0.04 ± 0.01a	0.05 ± 0.01a	0.07 ± 0.02b
C/N		20.19 ± 6.84a	21.22 ± 10.76b	33.54 ± 10.32c
Available phosphorus (mg/g soil)		0.11 ± 0.05a	0.20 ± 0.07b	0.22 ± 0.09b
Exchangeable cations (mEq/100g)	$Ca^{2}+$	2.32 ± 0.68a	2.78 ± 0.82b	5.43 ± 1.28c
	$Mg^{2}+$	2.57 ± 0.74a	3.29 ± 1.01b	5.62 ± 1.93c
	Na+	18.50 ± 6.30c	17.16 ± 3.29b	9.68 ± 1.12a
	K+	2.54 ± 0.68a	2.79 ± 0.59b	2.97 ± 0.70c
CEC (mEq/100g)		35.81 ± 2.36a	42.00 ± 7.34b	45.04 ± 5.21c
Base saturation rate (%)		47.70 ± 3.10a	58.12 ± 8.03b	76.30 ± 10.02c
Clay (%)		15.47 ± 8.63a	23.67 ± 10.74b	16.35 ± 13.98a
Silt (%)		35.38 ± 10.07a	44.24 ± 11.13b	49.74 ± 13.87c
Sand (%)		49.15 ± 10.26b	32.09 ± 12.37a	33.92 ± 8.72a
Texture		Silt sand	Silt	Silt

Values are expressed as mean ± SD. Different letters in the same line designate significant differences ($p < 0.05$)

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

Table 4. *Effect of the of distance from the prickly pear plant on the physico-chemical soil properties*

Soil traits		**Sampled units**		
		20 cm	**50 cm**	**100 cm**
pH		7.72 ± 0.86a	7.70 ± 0.99a	7.66 ± 0.93a
Organic carbon (%)		1.24 ± 0.62a	1.40 ± 1.11a	1.18 ± 0.40a
Organic matter (%)		2.13 ± 1.06a	2.41 ± 1.92a	2.04 ± 0.70a
Total Nitrogen (%)		0.05 ± 0.01a	0.05 ± 0.02a	0.06 ± 0.02a
C/N		23.47 ± 3.79a	31.18 ± 17.05a	20.94 ± 3.72a
Available phosphorus (mg/g soil)		0.18 ± 0.09a	0.18 ± 0.08a	0.18 ± 0.09a
Exchangeable cations (mEq/100g)	Ca²+	3.59 ± 1.61c	3.46 ± 1.71a	3.48 ± 1.75b
	Mg²+	4.06 ± 1.93c	3.90 ± 2.01b	3.53 ± 1.61a
	Na+	13.96 ± 4.53a	15.66 ± 6.24b	15.71 ± 6.06c
	K+	2.65 ± 0.78a	2.78 ± 0.70b	2.86 ± 0.52c
CEC (mEq/100g)		40.36 ± 6.31a	40.80 ± 6.47b	41.70 ± 7.03c
Base saturation rate (%)		59.34 ± 13.18a	62.39 ± 15.74c	60.41 ± 13.38b
Clay (%)		17.09 ± 11.04a	19.79 ± 13.74a	18.60 ± 10.60a
Silt (%)		43.50 ± 12.56a	41.84 ± 15.03a	44.01 ± 11.80a
Sand (%)		39.40 ± 13.75a	38.37 ± 11.15a	37.39 ± 14.11a
Texture		Silt sand	Silt	Silt

Values are expressed as mean ± SD. Different letters in the same line designate significant differences ($p < 0.05$)

The pH values were alkaline for zone A, slightly alkaline for zone B, while the zone C has slightly neutral value. The control, young and middle plots have alkaline values, while the old plot has slightly neutral value.

The percentages of organic matter in soil varied from 1.44 to 2.95% in all samples and showed a significant difference between the three zones (continental or coastal), with more organic matter in the continental and plateau zones than in the coastal, also the percentages of organic matter varied from 1.91 to 2.15% in the planted plots and 2.78% in control plots with significant difference between different plots.

The total nitrogen content was low with significant difference between the three zones and between the plantation age of prickly pear.

The available phosphorus concentrations showed a significant difference between the three zones and the plantation age of prickly pear. The highest values were registered in zone C and zone B, with 0.22 and 0.20 mg/g soil, respectively. While the zone A showed the minimal value (0.11 mg/g soil). Also, the available phosphorus concentrations marked values between 0.15 and 0.19 mg/g soil in the planted plots and 0.24 mg/g soil in control plots.

Values of C/N ratio ranged between 20.19 and 33.54 in the three zones with significant difference among them. It is the same for the plantation age of prickly pear that marked values between 20.62 and 24.06 in the planted plots and 35.01 in control plots.

A significant difference was registered for exchangeable cations concentrations between the three zones and between the plantation age of prickly pear. Sodium (Na+) is the most dominant element of exchangeable cations in all soils, it recorded values ranging from 9.68 and 18.50 mEq/100 g in the three zones. The highest values were registered in coastal and plateau zones. While, the continental zone showed the minimal value. It ranged from 13.70 to 17.44 mEq/100 g in planted plots and 12.35 mEq/100 g in control plots; followed by magnesium (Mg^{2+}), the calcium (Ca^{2+}), and the potassium (K^{+}) is in the fourth rank.

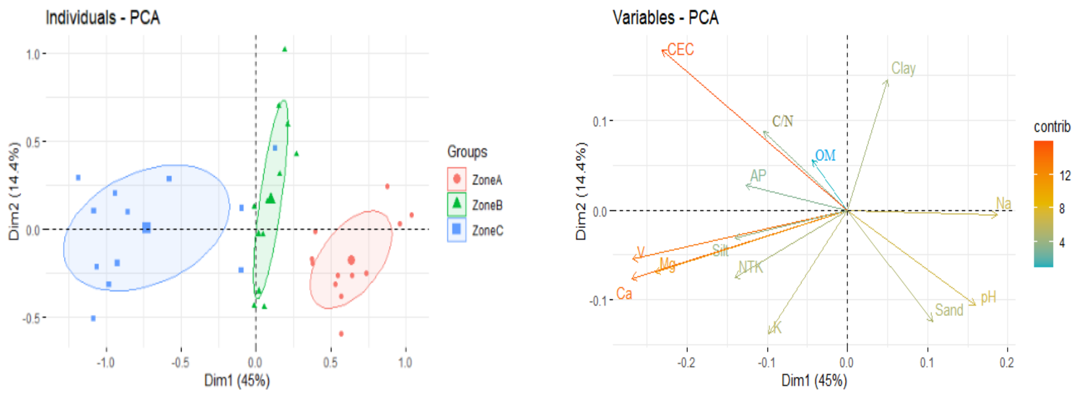
http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

The CEC showed average values, ranging between 35.81 and 45.04 mEq/100g in the three zones with significant difference among them. It is the same for the plantation age of prickly pear that marked values between 38.42 and 44.32 mEq/100 g in the planted plots and 37.18 mEq/100 g in control plots.

A significant difference was registered for the base saturation rate (V) between the three zones (V = 47.70 to 76.30%) and between planted plots (V = 58.98 to 63.80%) and control plots (V = 58.42%).

According to values of clay, sand and silt fractions, projected onto a texture triangle, studied soils belong to silt class for the plots planted by the prickly pear and the control plots, which concerns the zones; zone A has a sandy silt texture while zone B and C have a silt texture.

Principal component analysis (PCA) showed the score plot of PCA for three geographic zones; the littoral zone (zone A), the plateau's zone (zone B) and the continental zone (zone C) according to the physicochemical characteristic of soil (*Fig. 6*). The first two principal components explain approximately 59.4% of the total variance. PC1 (Dim1) presents 45% of the total inertia, whereas PC2 (Dim2) presents 14.4%. Most of the points for zone C were pointed to the left of PC1, for zone A were pointed to the right of PC1. On the other hand, most points for zone B are pointed to the right of PC1 and between zones A and C. According to parameters contribution (*Fig. 6(a)* and *6(b)*) the group of zone C showed the highest correlation to base saturation rate (V), CEC, Mg^{2+} (Mg) and Ca^{2+} (Ca). However, the group of zone B has the highest correlation to clay. A third group of zone A has the highest association to available pH, Na^{+} (Na) and sand.



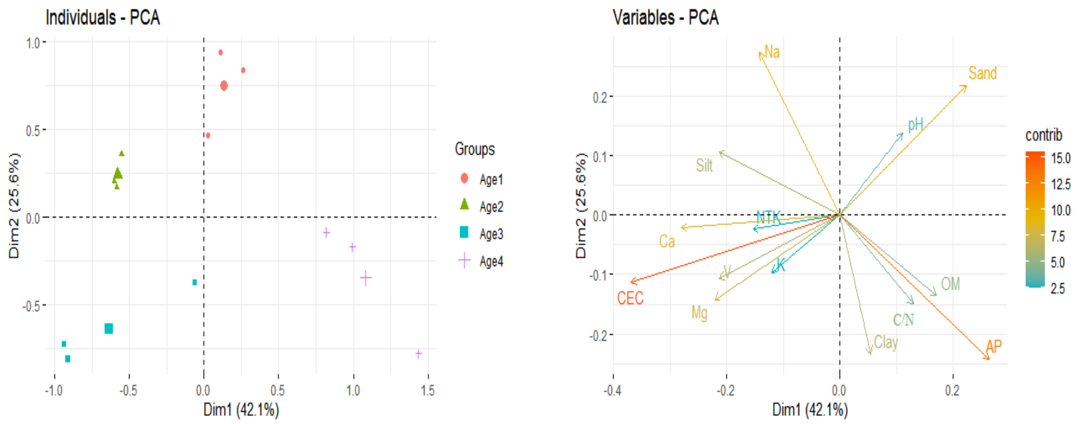
(a) (b)

Figure 6. *(a) Scores and (b) loading plots with principal component analysis (PCA) for sampled units (A, B and C) according to the physicochemical characteristic of soil. [CEC: cation exchange capacity; OM: organic matter; AP: available phosphorus; V: base saturation rate; NTK: total nitrogen]*

Figure 7 shows the score plot of PCA for planted (young, middle and old) and control plots according to the physicochemical characteristic of soil. The first two principal components explain 67.7% of the total inertia. PC1 (Dim1) presents 42.1% of the total inertia. However, PC2 (Dim2) presents 25.6%. Most of the points for young plots (Age 1) and control plots (Age 4) were pointed to the right of PC1. On the other hand, points for middle plots (Age 2) and old plots (Age 3) are presented on the left of PC1. Parameters contribution (*Fig. 7(a)* and *7(b)*) revealed that group of young plots showed the highest

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

correlation to sand. However, the group of middle plots has the highest correlation to Na^+ (Na). A third group of old plots has the highest association to CEC. the last group of control plots has the highest correlation to available phosphorus (AP).



(a) (b)

Figure 7. *(a) Scores and (b) loading plots with principal component analysis (PCA) for plantation age of prickly pear according to the physicochemical characteristic of soil. [CEC: cation exchange capacity; OM: organic matter; AP: available phosphorus; V: base saturation rate; NTK: total nitrogen; Age 1: young (< 10 years old); Age 2: middle (10-25 years old); Age 3: old (> 25 years); Age 4: control (Unplanted)]*

The interaction between zone and plantation age of prickly pear was revealed in a heatmap combined with hierarchical clustering (*Fig. 8*). Horizontal ordinate presented the interaction between zone and plantation age. However, the vertical ordinate showed the interaction between soils physicochemical properties. Highest and minimal interactions were highlighted by red and blue color respectively. The majority of soil parameters are related to the age of the plots; they increase with the age of the prickly pear plantations in all the studied zones. We found that control plots of zone A (Age4ZA) show some similarities with the young plots of zone A (Age1ZA) and middle plots of zone B (Age2ZB), young plots of zone B (Age1ZB) were close to middle plots of zone A (Age2ZA) and old plots of zone A (Age3ZA), control plots of zone C (Age4ZC) were close to control plots of zone B (Age4ZB), and middle plots of zone C (Age2ZC) were near to young plots of zone C (Age1ZC), old plots of zone C (Age3ZC) and old plots of zone B (Age3ZB). In contrast, the interactions; control plots of zone A, young plots of zone A and middle plots of zone B were far away from the interactions; middle plots of zone C, young plots of zone C, old plots of zone C and old plots of zone B.

The soil parameters distance-heatmap showed that pH was closer to Na^+ and sand, CEC was closer to total nitrogen, base saturation rate, Ca^{2+} and Mg^{2+}, and K^+ was closer to silt, organic matter, available phosphorus and clay.

Figure 9 shows the heatmap combined with hierarchical clustering for interactions between plantation age and sampling distance from the prickly pear plant according to the physicochemical characteristics of soil. Horizontal ordinate showed the interactions between plantation age and distance from the prickly pear plant. However, the vertical ordinate presented the interactions between soil physicochemical properties. Highest and minimal interactions were highlighted by red and blue color respectively. The majority of soil parameters vary according to the age of the prickly pear. However, they vary

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

slightly according to sampling distance from the plants. The interaction; 50 cm from the plants of middle plots (D2Age2) was close to 20 cm from the plants of young plots (D1Age1), 100 cm from the plants of young plots (D3Age1) and 50 cm from the plants of young plots (D2Age1), the interaction; 100 cm from the plants of middle plots (D3Age2) was near to 20 cm from the plants of middle plots (D1Age2), and 100 cm from the plants of old plots (D3Age3) show some similarities to 50 cm from the plants of young plots (D2Age3) and 20 cm from the plants of old plots (D1Age3). In contrast, 50 cm from the plants of middle plots, 20 cm from the plants of young plots and 100 cm from the plants of young plots were far away from the 50 cm from the plants of young plots and 20 cm from the plants of old plots.

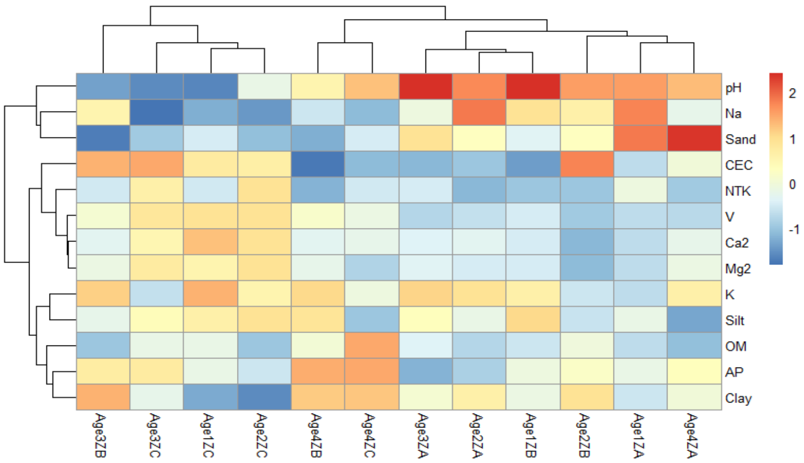


Figure 8. *Heatmap and hierarchical clustering for interaction between zone and plantation age of prickly pear according to the physicochemical characteristic of soil. [CEC: cation exchange capacity; OM: organic matter; AP: available phosphorus; V: base saturation rate; NTK: total nitrogen; ZA: Zone A; ZB: Zone B; ZC: Zone C; Age 1: young (< 10 years old); Age 2: middle (10-25 years old); Age 3: old (> 25 years); Age 4: control (Unplanted)]*

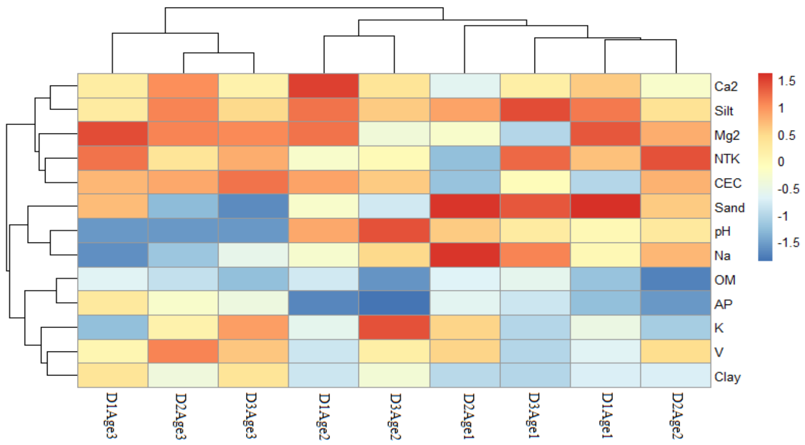


Figure 9. *Heatmap and hierarchical clustering for interaction between plantation age and sampling distance from the prickly pear plant according to the physicochemical characteristic of soil. [CEC: cation exchange capacity; OM: organic matter; AP: available phosphorus; V: base saturation rate; NTK: total nitrogen; D1: 20cm from the plant; D2: 50cm from the plant; D3: 100cm from the plant; Age 1: young (< 10 years old); Age 2: middle (10-25 years old); Age 3: old (> 25 years); Age 4: control (Unplanted)]*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

Discussion

Results of this study revealed that soil parameters evolve according to the continentality and the plantation age of prickly pear.

In general, the factors “zone”, “plantation age” and “interaction (zone x plantation age)” statistically had significant effects ($p < 0.05$) on all studied soil parameters. while the factors “distance from the prickly pear plants” and the “interaction (plantation age x distance from the prickly pear plants)” had no significant effects ($p > 0.05$) on most studied soil parameters.

The pH is a parameter considered as one of the most important soil indicators (Li et al., 2006). It is a key in agronomy because its degree of acidity or basicity plays a very important role on the assimilation of nutrients by the plant, it has an influence on three important components of the fertility of a soil: the bioavailability of nutrients, biological activity and structural stability, The variation of pH depends on seasonal variations and the buffering capacity of soil (the number of ions in reserve on the clay-humus complex) ,the water status of the soil, its temperature and the presence or not of a crop in active growth period (Baize, 2000; Dinon et al., 2008). Indeed, the pH values were alkaline for zone A, slightly alkaline for zone B, while the zone C has slightly neutral value. The control, young and middle plots have alkaline values, while the old plot has slightly neutral value. The neutral pH of zone C can be explained by the leaching caused by runoff, while the alkalinity of zones A and B may be due to the oceanic influence which causes a variation of the soil pH. Indeed, Smith et al. (2000) showed that pH can be influenced by climate and vegetation. Thus, the high pH mainly affected by calcareous parental material and low leaching (low rainfall) (Wezel et al., 2000; Sierra et al., 2009).

Concerning the organic matter, clearly in the continental and plateau zones, the levels of this element are higher than those of the coastal zone, this difference is more pronounced in the old plots compared to young and middle plots. The amount of soil organic matter is a sensitive indicator of soil quality, rangeland health and sustainability because of its contribution to soil stability, increased water holding capacity of the soil, fixation of mineral elements, and substrate for soil microorganisms (Fernandez et al., 2008; Drouet, 2010; Dai et al., 2011), it represents nutrient storage, especially in poorly soils (Zhou et al., 2008), such as mediterranean soils (Aranda and Oyonarte, 2005). The observed values in this research are probably related either to soil texture (Silt sand in zone A and silt in zone B and C). According to Singh et al. (2007), the sandy soil contains less organic matter and nitrogen. However, the organic matter content can be positively correlated with the presence of fine particles (clay and silt) and is an important agent in the stabilization of soil aggregates (Li et al., 2006; Zhao et al., 2006; Huang et al., 2007). The age effect was well reported in this study, the levels of the organic matter are higher in the old plots than the middle and young plots. Similar results reported by Mandouri (2000); Neffar et al. (2011, 2022); Genin et al. (2017) showed that the old prickly pear plantation improves greatly soil organic fertility by increasing the organic matter content.

Phosphorus is one of the essential elements for the growth and development of plants. In particular, it plays an essential role in the establishment of the root system, photosynthesis and plant reproduction. Their variation depends on the physicochemical properties of the soil (Elalaoui, 2007). In our case, the available phosphorus concentrations showed a significant difference between the three zones and the plantation age of prickly pear. The highest values were registered in zone C and zone B than the zone A, this difference is more pronounced in the old plots compared to young and middle plots. This is probably related to the organic matter content of zone C and old plots that

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

have experienced the same trend. The same observation was made by Li et al. (2004) where a linear increase is reported between phosphorus and organic matter levels. Indeed, The PCA analysis results confirmed that organic matter was positively correlated with other soil parameters (*Figs. 6 and 7*).

The C/N ratio, which expresses the state of microbial activity (Rezaei and Gilkes, 2005), the difference between the three zones and between the plantation age of prickly pear can be attributed to the effect of organic matter that tends to accumulate (Su and Zhao, 2003). The high C/N ratio noted in zone C and in old plots is linked to the high organic matter (Boyer, 1982), thus expressing a mineralization slower of carbon than of nitrogen (Urioste et al., 2006).

Results concerning the soil exchangeable cations content showed that sodium (Na^+) is the most dominant element in all soils; followed by the magnesium (Mg^{2+}), the calcium (Ca^{2+}), and the potassium (K^+) is in the fourth rank. The highest values of sodium observed in zones A and B are probably related either to the alkalinity of this zones. According to Dabin (1970), In alkaline soils, sodium is the most important. The cation exchange capacity (CEC) of a soil is the maximum amount of cations that a soil can adsorb, in other words, this measure represents the total negative soil charges available for fixing H^+ and Al^{3+} ions and exchangeable bases. This parameter depends on colloids and soil pH (El Mderssa, 2019). The highest values were registered in zone C and zone B than the zone A, this difference is more pronounced in the old plots compared to young and middle plots. This is probably related to the organic matter content of zone C and old plots that have experienced the same trend. Effectively, according to Brady (1974); Benhassine (2006), clay and organic matter are the two soil colloids upon which the phenomena of cation exchange processes rest. Thus, Mandouri (2000), declared that an old prickly pear plantation (~60 years) improves greatly soil organic fertility by increasing the organic matter content and the mineral richness of the adsorbent complex. According to this author, this plant produces a humus-bearing horizon relatively quickly, which creates a mineral complex thick enough to give rise to a dynamic soil. This dynamism is translated by an intense microbial activity, a fast melanization of the organic matter released especially by the roots which bring into play the action of humic and fulvic acids which are sufficiently aggressive towards the bedrock, a chemical alteration and a deepening of the soil from 15 to 30 cm. By consequently, this plant can be considered as a pioneer in the formation of soils particularly in arid zone.

Finally, for the base saturation rate, the highest values were registered in zone C and zone B than the zone A, this difference is more pronounced in the old plots compared to young and middle plots. These increases can be attributed to the increases in the base elements content of the soils as the prickly pear age plantation. Moreover, because of low leaching intensities in semi-arid regions, base elements in soils are not usually intensively leached out, and hence the bases tend to occupy a very high percentage of the base exchange sites in the soils (Abubakar, 1996). According to Brady (1974), under such conditions the base elements tend to occupy 90 per cent or more of such exchange complexes.

The high value of soil parameters observed in zone C, could only be explained by the topography of zone C (continental) located in the mountains, which allowed the plots to absorb runoff water and fogs making the soil moister and enriching with nutrients. Thus, the mountains provide a very favorable climate, and consequently a very important vegetation cover. Indeed, Pei et al. (2008) declared that the high value of organic matter may be attributed to the vegetation cover, following the reduction of wind erosion (Zhang

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

et al., 2005). In fact, the heatmap and hierarchical clustering shows that the ages of zone C were closer to each other and were far away from the ages of zone A and B. Thus, the PCA analysis results confirmed that most soil parameters were positively correlated with zone C excluding pH, Na^+ and sand which correlated with zone A. Effectively these three parameters were closer to each other and were far away from the other soil parameters in the heatmap and hierarchical clustering (*Fig. 8*). In zone A, the effect of factors related to the proximity of the sea, materialize above all by the very high atmospheric humidity, the sea breezes, transporting sand and salt spray to a depth of a few hundred meters from the littoral. Similar results reported by Su and Zhao (2003) showed that the recovery of a degraded habitat is under the influence of climatic conditions. Moreover, the results of this recherche showed that the old prickly pear plantations improve greatly soil organic fertility by increasing the organic matter content on surface layers of soils. The heatmap and hierarchical clustering results confirmed that the highest levels of the organic matter and other soil parameters were represented by the old prickly pear plantations (*Fig. 9*). The origin of the latter could be multiple: either directly from biodegradation and photodegradation of prickly pear plantations cladodes, which are very high in the lignin-rich litter, due to its high photo-absorption capacity thus ensuring its decomposition (Gallo et al., 2009); or indirectly by creating a microclimate facilitating the installation of other plant species those were unable to settle in bare environments. In fact, the prickly pear would have served to some extent of barrier trapping the seeds dispersed by the wind of the steppe species. Therefore, he facilitates installation of herbaceous plants and facilitating colonization and development of other species which would contribute to increase the organic matter content in soils by its contribution from litter (Singh et al., 2001). This would result in increased nutrient deposition and reduction of runoff during showers, as well as better mechanical protection and biological improvement of soil surface (Li et al., 2007).

Consequently, *Opuntia ficus-indica* (L.) Mill. seems to be a suitable ‘nurse’ plant in these drylands because of its effect on the composition and structure of degraded soils, as reported for other Mediterranean dryland plants (Soliveres et al., 2012). Thus, Michalet (2010) declared that it fully participates to the multiple and complex interactions observed for facilitation in arid environments.

The high values of soil parameters observed in the controls (not planted) can be explained by the fact that the plots are under fallow.

Conclusion

This study highlighted the significant positive effects of continentality and prickly pear plantations on soil parameters in the South-Central Morocco (Ait Baamrane region). Indeed, in the continental zone, the levels of the most soil parameters are higher than those of the plateau and coastal zones. Thus, these soils parameters differ within each zone according to the age of the plots, they increase with the age of the prickly pear plantations due to interconnected changes in traditional land uses and the activation of facilitation factors such as the improvement of the soil organic matter and other nutrients.

Opuntia ficus-indica (L.) Mill., an arid-resistant shrub, could protect the soil against erosion with its extensive roots system, trap with its aerial part nutrient-rich dusts, thus playing the role of a resource plant allowing the sequestration of seeds that cannot be established elsewhere, and creating a favorable microclimate that reduces the rigidity of

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

open spaces. Prickly pear plantations could be a promising strategy for the conservation of Moroccan ecosystems and marginal areas that have lost all agropastoral disposition.

Acknowledgements. Authors would like to extend their sincere thanks to the population of the Ait Baâmrane region for their kindness, understanding and help.

REFERENCES

[1] Abubakar, S. M. (1996): Rehabilitation of degraded lands by means of fallowing in a semi-arid area of northern Nigeria. – Land Degradation & Development 7(2): 133-144.
[2] Aidoud, A., Le Floch, E., Le Houerou, H. (2006): Les steppes arides du Nord de L'Afrique. – Sécheresse 17: 19-30.
[3] Aranda, V., Oyonarte, C. (2005): Effect of vegetation with different evolution degree on soil organic matter in a semi-arid environment (Cabo de Gata-Nijar Natural Park, SE Spain). – Journal of Arid Environments 62: 631-647. https://doi.org/10.1016/j.jaridenv.2005.01.019.
[4] Aubert, G. (1978): Méthodes d'analyse des sols. 2ème édition. – Centre national de documentation pédagogique, Marseille, 191p.
[5] Bagnouls, F., Gaussen, H. (1953): Saison sèche et indice xérothermique. – Bulletin de la Société d'Histoire Naturelle de Toulouse 88: 193-239.
[6] Baize, D. (2000): Guide des analyses en pédologie: choix, expression, présentation, interprétation. – 2e éd., INRA-Paris 255p.
[7] Benhassine, H. (2006): Nature minéralogique et rôle nutritionnel des argiles de sols céréaliers en région subhumide à semi-aride (Tunisie). – C.R. Géosciences 338: 329-340.
[8] Bensalem, H., Nefzaoui, A., Bensalem, L. (2002): Supplementation of Acacia cyanophylla Lindl foliage-based diets with barley or shrubs from arid areas (*Opuntia ficus-indica* f. inermis and *Atriplex nummularia* L.) on growth and digestibility in lambs. – Anim. Feed. Sci. Tech. 96: 15-30. https://doi.org/10.1016/S0377-8401 (01)00338-8.
[9] Boujghagh, M., Chajia, L. (2001): Le cactus: outil de gestion de la sécheresse dans le Sud Marocain. – Terre et vie 52: 1-7.
[10] Boyer, P. (1982): Quelques aspects de l'action des termites du sol sur les argiles. – Clay Minerals 17: 453-462.
[11] Brady, N. C. (1974): The Nature and Properties of Soils. – In: Abubakar, S. M. (1996) (ed.) Rehabilitation of degraded lands by means of fallowing in a semi-arid area of northern Nigeria. Land Degradation & Development 7(2): 133-144.
[12] Buol, S. W., Southard, R. J., Graham, R. C., McDaniel, P. A. (2011): Soil genesis and classification. – John Wiley and Sons 13: 978-0-8138-0769-0.
[13] Climat Sidi Ifni-climate-Data.org. https://fr.climate-data.org/afrique/maroc/sidi-ifni/sidi-ifni-26355/ (accessed 22.03.2022).
[14] Culman, S., Mann, M., Brown, C. (2019): Calculating cation exchange capacity, base saturation, and calcium saturation. – Ohio State University.
[15] Dabin, B. (1967): Application des dosages automatiques à l'analyse des sols: part 3. – Cahiers ORSTOM, Série Pédologie 5(3): 257-263.
[16] Dabin, B. (1970): Les facteurs chimiques de la fertilité des sols (bases échangeables, sels, utilisation des échelles de fertilité). – In: Ségalen, P., Dabin, B., Maignien, R., Combeau, A., Bachelier, G., Schmid, M., Bosser, J., Guinard, M., Verdier, P. (eds.) Pédologie et développement. Paris: ORSTOM; BDPA 10: 221-237.
[17] Dai, F., Su, Z., Liu, S., Liu, G. (2011): Temporal variation of soil organic matter content and potential determinants in Tibet, China. – Catena 85: 288-294. https://doi.org/10.1016/j.catena.2011.01.015.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

[18] Debrach, J. (1953): Notes sur les climats du Maroc occidental. – Maroc Oriental 32(242): 1122-1134.
[19] Dinon, E., Gerstmans, A. (2008): L'influence du pH sur l'assimilation des elements nutritifs du sol par les plantes et sur la variété des plantes. – Universitede Liège, Printemps Des Sciences.
[20] Drouet, Th. (2010): Pédologie. – BING-F-302, 137.
[21] Duchauffour, P. (1977): Pédogénèse et classification. – Ed. Masson, Paris.
[22] El Mderssa, M., Benjelloun, H., Zennouhi, O., Nassiri, L., Ibijbijen, J. (2019): Pedogenetic characterization and classification of forest soils in the Central Middle Atlas (Morocco). – Eurasian Journal of Soil Science 8(2): 152-158.
[23] Elalaoui, A. (2007): Fertilisation Minérale des Cultures Les éléments fertilisants majeurs (Azote, Potassium, Phosphore). – Bulletin mensuel d'information et de liaison du PNTA.
[24] Erre, P., Chessa, I., Nieddu, G., Jones, P. G. (2009): Diversity and spatial distribution of *Opuntia* spp. in the Mediterranean Basin. – Journal of Arid Environments. DOI: 10. 1016/j. jaridenv.2009. 05.010.
[25] Fernandez, D. P., Neff, J. C., Reynolds, R. L. (2008): Biogeochemical and ecological impacts of livestock grazing in semi-arid southeastern Utah, USA. – Journal of Arid Environments 72: 777-791. https://doi.org/10.1016/j.jaridenv.2007.10.009.
[26] Gallo, M., Porras-Alfaro, A., Odenbach, K., Sinsabaugh, R. (2009): Photoacceleration of plant litter decomposition in an arid environment. – Soil Biol Biochem 41: 1433-1441. http://doi.org/10.1016/j.soilbio.2009.03.025.
[27] Genin, M., Alifriqui, M., Fakhech, A., Hafidi, M., Ouahmane, L., Genin, D. (2017): Back to forests in pre-Saharan Morocco? When prickly pear cultivation and traditional agropastoralism reduc-tion promote argan tree regeneration. – Silva Fennica 51 (1B). https:// doi.org/10.14214/sf.1618.
[28] Huang, D., Wang, K., Wu, W. L. (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. http://doi.org/10.1016/j.jaridenv.2006.12.009.
[29] Le Houerou, H. N. (1995): Bioclimatologie et biogeographie des steppes arides du Nord de l'Afrique: Diversite biologique, developpement durable et desertisation. – CIHEAM, Options Mediterraneennes. Series B: 10, 396p.
[30] Le Houerou, H. N. (2000): Restoration and rehabilitation of arid and semiarid Mediterranean ecosystems in North Africa and West Asia: a review. – Arid Soil Res. Rehab. 14: 3-14.
[31] Li, F. M., Song, Q. H., Jjemba, P. K., Shi, Y. C. (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.
[32] Li, X. R., Jia, X. H., Dong, G. R. (2006): Influence of desertification on vegetation pattern variation in the cold semi-arid grasslands of Qinghai-Tibet Plateau, North-West China. – J. Arid Environ. 64: 505-522. http://doi.org/10.1016/j.jaridenv.2005.06.011.
[33] Li, J., Zhao, C., Zhu, H., Li, Y., Wang, F. (2007): Effect of plant species on shrub fertile island at an oasis-desert ecotone in the South Junggar Basin China. – J Arid Environ 71: 350-361. http://doi.org/10.1016/j.jaridenv.2007.03.015.
[34] Mandouri, T. (2000): Hydromasse et biomasse des Opuntia. Cactus: (*Opuntia* à fruits comestibles). – Actes de la journée nationale sur la culture du cactus. El Kelaa des Sraghna. Morocco.
[35] Metson, A. J. (1956): Methods of chemical analysis for soil survey samples. – N Z Soil Bur Bull 12.
[36] Michalet, R. (2010): Is facilitation in arid environments the result of direct or complex interactions? – New Phytologist 169(1): 3-6. http://dx.doi.org/10.1111:j.1468-8137.2006.01617.x.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

[37] Mihi, A., Tarai, N., Chenchouni, H. (2019): Can palm date plantations and oasification be used as a proxy to fight sustainably against desertification and sand encroachment in hot drylands? – Ecological Indicators 105: 365-375. http://doi.org/10.1016/j.ecolind.2017.11.027.

[38] Mulas, M., Mulas, G. (2004): The strategic use of *Atriplex* and *Opuntia* to combat desertification. – Desertification Research Group, University of Sassari, Italia.

[39] Neffar, S., Beddiar, A., Redjel, N., Boulkheloua. J. (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.

[40] Neffar, S., Beddiar, A., Menasria, T., Chenchouni, H. (2022): Planting prickly pears as a sustainable alternative and restoration tool for rehabilitating degraded soils in dry steppe rangelands. – Arab J Geosci 15: 287. https://doi.org/10.1007/s12517-022-09579-1.

[41] Olsen, S. R., Cole, C. V., Watanabe, F. S., Dean, L. A. (1954): Estimation of available phosphorus in soils by extraction with sodium bicarbonate. – US Dep. Agric. Circ 939: 18-19.

[42] Ouma, G. O., Ogallo, L. A. (2007): Desertification in Africa. Department of metrology, University of Nairobi. – IGAD Climate prediction and Application Center.

[43] Parish, J., Felker, P. (1997): Fruit quality and production of cactus pear (*Opuntia* spp.) fruit clones selected for increased frost hardiness. – Journal of Arid Environments 37: 123-143.

[44] Pei, S., Fu, H., Wan, C. (2008): Changes in soil properties and vegetation following exclosure and grazing in degraded Alxa desert steppe of Inner Mongolia, China. – Agric. Ecosyst. Environ. 124: 33-39. http://doi.org/10.1016/j.agee.2007.08.008.

[45] Pimienta-Barrios, E. (1993): El nopal (*Opuntia* spp.) una alternative ecologica productive para les zonas aridas y semiaridas. – In: Kabas, O., Ozmerzi, A., Akinci, I. (2006) (eds.) Physical properties of cactus pear grown wild in Turkey. Journal of Food Engineering 73(2): 198-202.

[46] Reyes-Aguero, J. A., Aguirre, J. R., Valiente-Banuet, A. (2006): Reproductive biology of *Opuntia*: A review. – Journal of Arid Environments 64: 549-585.

[47] Rezaei, S., Gilkes, R. (2005): The effect of landscape attributes and plant community on soil chemical properties in rangelands. – Geoderma 125: 167-176. http://doi.org/10.1016/j.geoderma.2004.07.010.

[48] Russell, C., Felker, P. (1987): The Prickly-pears (*Opuntia* spp., Cactaceae): a source of human and animal food in semiarid regions. – Economic Botany 41(3): 433-445. http://dx.doi.org/10.1007/ BF02859062.

[49] Sierra, M., Martinez, C., Sierr, C., Aguilar, J. (2009): Correlations between pedological parameters in relation to lithology and soil type in Almeria (SE Spain). – Journal of Arid Environments 73: 493-498. http://doi.org/ 10.1016/j.jaridenv.2008.10.014.

[50] Singh, K. P., Mandal, T. N., Tripathi, S. K. (2001): Patterns of restoration of soil physciochemical properties and microbial biomass in different landslide sites in the sal forest ecosystem of Nepal Himalaya. – Ecological Engineering 17(4): 385-401.

[51] Singh, S. K., Singh, A. K., Sharma, B. K., Tarafdar, J. C. (2007): Carbon stock and organic carbon dynamics in soils of Rajasthan, India. – Journal of Arid Environments 68: 408-421. http://doi.org/0.1016/j.jaridenv.2006.06.005.

[52] Sivakumar, M. (2007): Interactions between climate and desertification. – Agricultural and Forest Meteorology 142: 143-155.

[53] Smith, O., Peterson, G., Needdman, B. (2000): Environmental indicators of agro-ecosystems. – Advances in Agronomy 69: 75-97.

[54] Snyman, H. A. (2006): A greenhouse study of root dynamics of cactus pears, *Opuntia ficus-indica* and *O. robusta*. – J. Arid Environ. 65(4): 529-542.

[55] Soliveres, S., Eldridge, D. J., Hemmings, F., Maestre, F. T. (2012): Nurse plant effects on plant species richness in drylands: the role of grazing, rainfall and species specificity. Perspectives in Plant Ecology. – Evolution and Systematic 14(6): 402-410. http://dx.doi.org/10.1016/j. ppees.2012.09.003.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887

[56] Stintzing, F. C., Carle, R. (2004): Functional properties of anthocyanins and betalains in plants, food, and in human nutrition. – Trends Food Sci. Technol. 15(1): 19-38. http://doi.org/10.1016/j.tifs.2003.07.004.
[57] Su, Y., Zhao, H. (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.
[58] Tayi, M. (2011): Comparaison de la qualité des fruits d'*Opuntia ficus indica* dans quatre localités d'Ait Baâmrane. – Mémoire d'Ingénieur d'Agronomie. Institut d'Agronomie et Veterinaire, Rabat, 57p.
[59] Urioste, A. M., Hevia, G. G., Hepper, E. N., Anton, L. E., Bono, A. A., Buschiazzo, D. E. (2006): Cultivation effects of the distribution of organic carbon, total nitrogen and phosphorus in soils of the semi-arid region of Argentinian Pampas. – Geoderma 136: 621-630. http:/doi.org/10.1016/j.geoderma.2006.02.004.
[60] Wezel, A., Rajot, J. L., Herbrig, C. (2000): Influence of shrubs on soil characteristics and their functions in Sahelian agroecosystems in semi-arid Niger. – Journal of Arid Environments 44: 383-398. http://doi.org/0.1006/jare.1999.0609.
[61] Wilke, B. M. (2005): Determination of chemical and physical soil properties. – In: Margesin, R., Schinner, F., (eds.) Manual of soil analysis: monitoring and assessing soil bioremediation. Springer-Verlag, Berlin, Heidelberg, Vol 5, pp. 79-82.
[62] Xu, D., Li, C., Song, X., Ren, H. (2014): The dynamics of desertification in the farming-pastoral region of North China over the past 10 years and their relationship to climate change and human activity. – Catena 123: 11-22. http://dx.doi.org/10.1016/j.catena.2014.07.004.
[63] Zhang, J., Zhao, H., Zhang, T., Zhao, X., Drake, S. (2005): Community succession along a chronosequence of vegetation restoration on sand dunes in Horqin Sandy land. – J Arid Environ 62: 555-566. http://doi.org/10.1016/j.jaridenv.2005.01.016.
[64] Zhao, H. L., Zhou, R. L., Zhang, T. H., Zhao, X. Y. (2006): Effects of desertification on soil and crop growth properties in Horqin sandy cropland of Inner Mongolia, North China. – Soil Tillage Res. 87: 175-185. http://doi.org/10.1016/j.still.2005.03.009.
[65] Zhou, R. L., Li, Y. Q., Zhao, H. L., Drake, S. (2008): Desertification effects on C and N content of sandy soils under grassland in Horqin, northern China. – Geoderma 145: 370-375. http://doi.org/10.1016/j.geoderma.2008.04.003.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_869887