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Research Article

Amendment of Saline Soils by Adding Sand in the Old Oasis of Nefzaoua in Tunisia

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Abstract: This study examines the effects of the mixed mineral/organic amendment on the evolution of the Organic Matter (OM) content and Total Nitrogen (TN) in the oasis soil. The mineral amendment applied (sand from the dunes) was composted with organic matter (manure). Our study was carried out in the oasis of Om Rouss located in the Douz delegation in southwestern Tunisia. We selected two amended plots in this oasis, one that has been corrected for 10 years and located upstream (i) and another one which has been corrected for 2 years and is located downstream (ii) at the level of the Chott depression. These modified soils were compared to untreated soils (iii). The physicochemical characterization of the amended soils revealed that their functional properties, mainly materialized by organic matter and total nitrogen, are closely related to the topographic position, the general texture and the proximity of the sebkha, the natural exit of surface and irrigation water.

Keywords: Mixed amendment, oasis, organic matter, texture, total nitrogen, Tunisia

INTRODUCTION

Oases are developed thanks to the coexistence of two systems in a tough ecological and socio-economic environment. The relations between the steppe and the oases are always marked by two opposing trends: complementarity and competition. Regarding complementarity, this especially involves the trade and integration of the farming activity that benefits from the forage resources available in the oases and offers, in return, meat and manure in particular (Sghaier, 1999).

The exploitation of artesian sources has led to the establishment of an adapted agriculture in the oasis since the most ancient times in history (Ghazouani *et al*., 2007).

In the semi-arid Mediterranean regions, the abandonment of lands led to soil degradation due to severe weather conditions (high temperatures and scarce precipitation) and topography (Lesschen *et al*., 2007).

In Tunisia, soils affected by salts cover about 1.5 million ha, roughly 10% of the country's surface area. They are found throughout the territory but mainly in the center and south where the aridity of the climate causes their extension. In fact, several geological formations are sources of soluble salts. The variability of soil salinity is mainly the result of a hydrological process in relation to the topography (Marlet, 2013). Furthermore, oases are settled on the sand dunes where little deep salted groundwater results from natural drainage driven by the flows to the Chott (El Fekih and Pouget, 1966) and the inefficiency of artificial drainage systems (Marlet *et al*., 2009). The runoff and drainage waters, enriched in soluble elements, flow to the lower parts of the watersheds. Two cases arise from there: either the watershed has an outlet and the salts migrate lower, or the watershed is endoreic and a sebkha is formed in the lowest part. These phenomena occur throughout the year in the arid parts of Tunisia and during the dry season in the Mediterranean regions.

These phenomena are either natural or caused by irrigation. Geochemically, the surface water, groundwater or soil solutions evolve during their concentration according to the neutral saline way. Several irrigated perimeters are subject to serious problems which result in soil degradation and productivity decline; in this case the effects are: the groundwater table rising, soil salinization and the progressive decrease of yields. The perimeters most affected by these phenomena are the regions that cannot evacuate the excessive water, namely the Mejerda valley in the north and the oases in the south (Hachicha, 2002). Nearly 100,000 ha of irrigated perimeters are deeply affected by significant salinization. Seventy five percent of soils are moderately to highly sensitive to salinization (Ltifi, 2008). Throughout history, oases around the world have played different functions of stopover, exchange, refuge and production.

The south of Tunisia is characterized by a Saharan bio-climate with low precipitation, destructive winds and limited water resources. Dates are widespread in the continental and coastal oases. According to its

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geographical origin, the typology of the oasis system shows that continental oases predominate with 33,723 ha, that is 83% of the total oases. These oases contain more than 89% of the country's date palm total workforce and contribute to 85% of the date's national production. In the southwestern Tunisian oasis (the region of Nefzaoua), soils are gypsiferous, saline and sandy. They are developed on a slope directed toward the sebkha, favoring drainage and salt leaching (Kadri and Van Ranst, 2002). According to the FAO/UNESCO classification, Nefzaoua soils are of the lithosolic, regosolic, cambisolic and solonchaks type. Irrigation by flooding of these oases with a saline groundwater characteristic can lead to soil degradation (Moussa *et al*., 2002). These problems may worsen in the presence of a gypseous crust that prevents in-depth drainage and which constitutes a mechanical obstacle to root penetration (Hatira *et al*., 2005).

Desertification and land degradation by salinization, the acceleration of nutritional imbalances of soil erosion and the depletion of soil organic matter are the major problems threatening the economic sustenance of the population in the region. The date palm, the main source of income in the Tunisian oasis, with over 5 million feet of different varieties predominated by the "Deglat Noor" variety, constitutes the basis of the oasis economy and significantly contributes to the trade balance of the country through exports. The production of dates is the main agricultural activity in the Nefzaoua region. It represents more than 50% of the total date annual production in the country. The amendment of land appeared as a means that would allow the mitigation of the degradation effects and particularly the decline of soil fertility in the old oasis. The objective of this study is to restore the soil of degraded oases by adding manure and dune sand.

MATERIALS AND METHODS

Study area: The Om Rouss oasis is located in the northeast of Douz (southwest Tunisia). It extends over a 15 ha surface area (Fig. 1). It is part of the Nefzaoua continental oasis in the Governorate of Kebili and is located at 33.33° and 33.32° north latitude and 8.54° and 8.55° east longitude. This region is characterized by an arid Mediterranean climate with a high temperature which reaches up to 55°C and irregular precipitation with an average of 80 mm/year (Sghaier, 2010). The evapotranspiration is important and estimated at 1680 mm/year in the Kebili oasis. The annual needs for irrigation water are estimated at 1578 mm, with a maximum of 272 mm in the month of August. The region of Nefzaoua is under the influence of the hot winds (sirocco) of the west in summer, the cold and dry winds of the west and northwest in winter and the sand and winds of the north in spring. The latter are the most frequent (120 days/year).

We try to understand the necessary conditions for the success of this application. The main objective is to examine the viability of the amendment (these are mixtures of organic matter (manure) with minerals (sand)) and its effect on the variation of the organic matter content and the total nitrogen of the different soil horizons (from 0 to 120 cm). The objective of this study is also to see the effect of the amendment date on the plots studied: upstream plot amended for ten years (northern part) and the downstream plot amended for 2 years (southern part).

The experimental design included two treated plots and one untreated one. The plot amended upstream had a size of 8 ha and the oasis amended downstream had a surface area of 7 ha. The treatment for the two amended plots was: sandy soil + compost. This treatment was

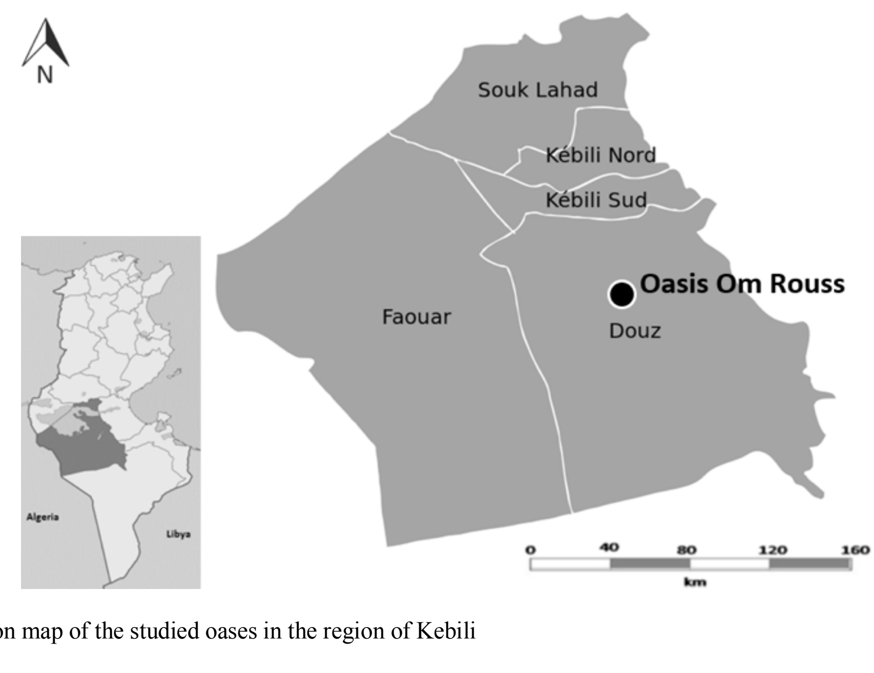

Fig. 1: Localization map of the studied oases in the region of Kebili

mixed in the upper 0-20 cm layer and then the soil was plowed up to 30 cm deep using traditional tools. Manure (M) was applied at a rate equivalent to 40 tones/ha. Compost (C) was applied at 20 tones/ha.

Approach and methodology: We collected soil samples in a specific location by choosing the points where the probe data recorded in the survey datasheet showed a large variability between series of data. Using a manual auger which drills the soil at low depths (0 to 1.20 m), soil samples were taken upstream towards downstream (i1, i2, i3, i4, i5, ii1, ii2, ii3, ii4, ii5) getting closer to the sebkha and they were taken at 6 different depths (0-20, 20-40, 40-60, 60-80, 80-100 and 100-120 cm, respectively). They were collected on September 10, 2018 from three different oases:

- One plot amended upstream
- Another plot amended downstream. These two previous plots were compared to
- An un-amended plot

All the samples were placed in plastic bags, labeled and taken to the laboratory. Each iteration soil was air dried, sieved and stored for its physicochemical analysis. The particle size analysis was performed to determine the overall texture of soil horizons using a series of sieves for sandy fractions and sedimentation in water with a Robinson eyedropper (Yoka *et al*., 2010) for the fine fractions. The soil pH was measured by the electrometric method using a pH meter with a glass electrode (Boudoudou *et al*., 2009). Organic soil matter in the soil samples was measured using the Walkley and Black method. The samples were oxidized with $K_2Cr_2O_7$ in concentrated sulfuric acid for 30 min, followed by the titration of excess $K_2Cr_2O_7$ with ferrous ammonium sulfate. The total nitrogen was determined with the Kjeldahl method (Lalmi, 2009) while the comparable phosphorus was determined according to the Olsen method (Pauwels *et al*., 1992). The extent of the Cationic Exchange Capacity (CEC) was studied using the Riehm-Ulrich method (Anderson and Ingram, 1993). The gypsum was measured with the double decomposition method in the presence of ammonium carbonate with a hot calcimeter whereas the Anne method was used for the measurement of organic matter.

RESULTS AND DISCUSSION

Soil properties of the plots studied: An analysis of the main physicochemical characteristics of the materials used in the amendment (sandy material) and manure was carried out. The results obtained are shown in Table 1 and 2.

The pH: These curves clearly confirm that the soils of the oasis surveyed are alkaline. Compared to the soil amended upstream, the average pH values (Fig. 2) for the soil amended downstream are generally higher due to the soil's fine texture. Consequently, the water can slowly diffuse in these soils and is retained in a high enough capillary potential. The decrease in pH with depth for the soil upstream may also be explained by the leaching limestone assets. Some authors explain this decrease with the oxidation of organic matter and the nitrification of ammonium in the soil (Abbas *et al*., 2007).

OM and TN content as a function of treatment time and soil depth: In comparison to the control soil, the concentration of OM and TN increased in the two amended plots after the application of the amendments. In the soil studied, the maximum OM value (Fig. 3) was found in the plot amended upstream (2.274 g/kg), followed by the plot amended downstream (0.845 g/kg) and the minimum value was found in the un-amended soil (0.145 g/kg). The highest TN values (Fig. 4) (0.057 g/kg) were found in the soil amended upstream. This observation indicates that the rapid mineralization of

Table 1: The chemical characteristics of the amendments used in treatments

Amendment type	Manure	Compost	Dune sand
OM (g/kg)	650	465	0
P (g/kg)	601	450	0
TN (g/kg)	76	69	0

Table 2: Grain size distribution

	Amended soil upstream						Amended soil downstream					
		Granulometry (%)						Granulometry (%)				
Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Texture	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Texture
0-20	10	17	24	39	10		13	17	23	38	9	Sandy-silt
20-40	12	19	23	37	9		13	18	24	37	8	
40-60	14	18	23	38	7	Sandy-silt	18	24	18	32	8	Silty-sand
60-80	15	19	21	37	8		24	23	19	28	6	
80-100	16	20	19	36	9		31	24	21	18	6	Silty-clay
100-120	18	22	19	34	7		33	23	25	14	5	

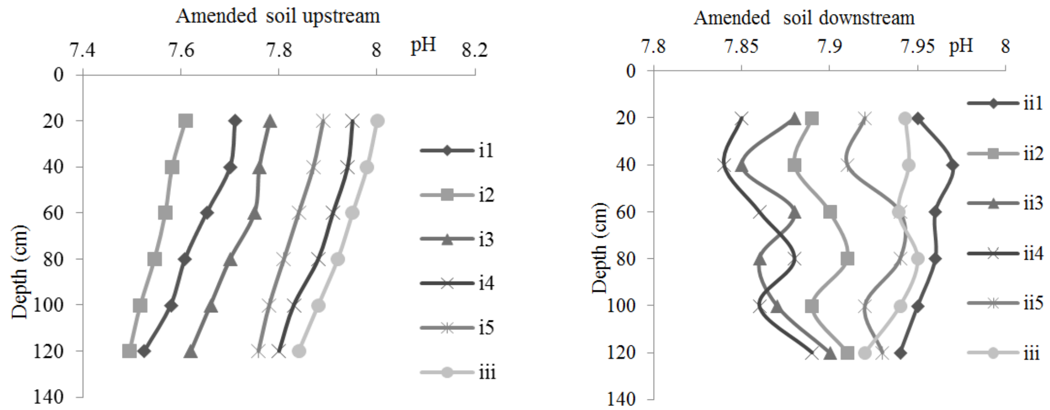

Fig. 2: Effect of the slope on the variation of the pH

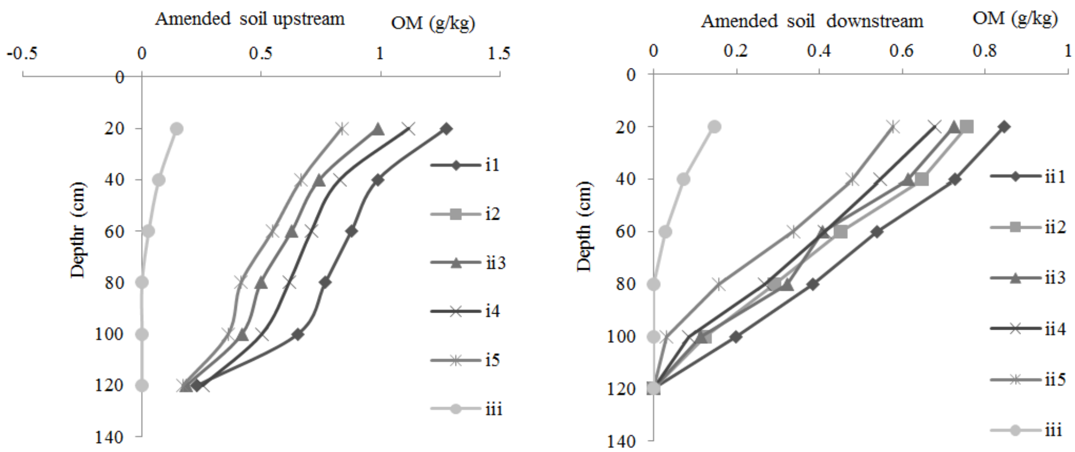

Fig. 3: Effect of the slope on the variation of the organic matter

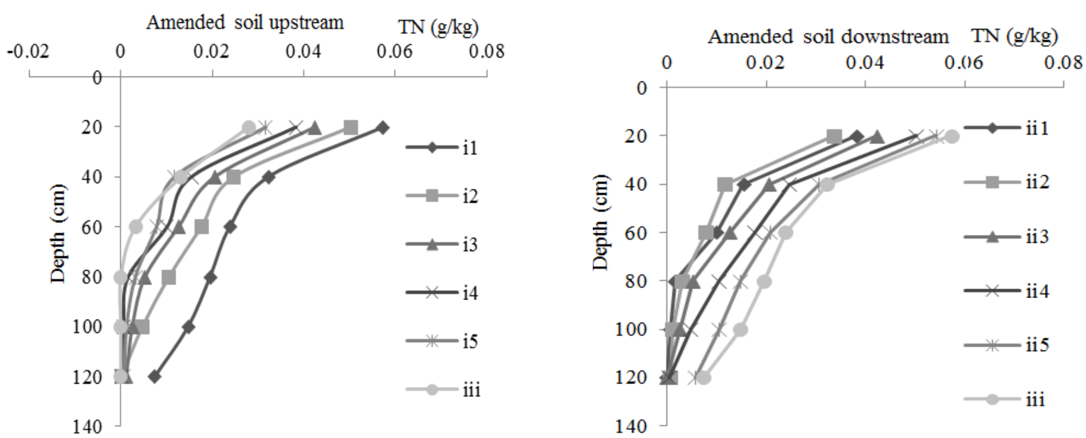

Fig. 4: Effect of the slope on the variation of total nitrogen

organic matter led to high concentrations of TN in the oasis soil (Jenkinson *et al*., 1990). Regardless of plot location, the trend of OM and TN accumulation was significantly affected by soil depth in general. The highest OM and TN values in all plots were mainly measured in the upper 0-20 cm soil layer, which is similar to the observations from other studies (Diacono and Montemurro, 2010). On the other hand, it can be suggested that the occupation of the oasis by fodder crops and soil tillage practices has favored the accumulation of OM in the shallow layers and increased TN and OM in the soil given that these practices provide a favorable environment for microorganisms. Low values of OM and TN in the plot amended downstream have been due to reduced or delayed microbial degradation of OM in the soils with high clay content (Xu *et al*., 2016).

OM and TN concentrations decreased with increasing depth, a similar result to that observed in other studies (Lal, 2007; Gregory *et al*., 2016). In addition, the concentration of OM and TN generally decreases in all treatments with increasing soil depth (0-120 cm), which is in agreement with the results of the study by Fronning *et al*. (2008). Compost mainly influenced OM levels at depths of 0-20 and 20-40 cm. The decrease is due to the rapid decomposition of organic matter in the subsoil which is probably caused by tillage practices in the oasis system (30 cm deep).

This has two main effects, namely increasing the concentration of OM and TN in the subsurface layer, because soil mixing is due to practical soil working. Guo *et al*. (2016) suggested that tillage practices increase TN and upper soil OM because tillage provides a favorable environment for microorganisms. The high level of TN concentrations indicates the rapid mineralization of organic matter which was most clearly observed in our study.

Phosphorus: Soil amended downstream has a higher phosphorus content than the soil amended upstream. This could be due to a leaching phenomenon. The evolution of the phosphorus content in the prospected soil horizons (Fig. 5) shows a significant difference; the sand applied on the surface is inert and poor in phosphorus. Phosphorous increases progressively in deeper horizons and reaches its maximum in the 100-120 cm horizon due to the phosphorus accumulated on the existing clay slipping into the deep horizons.

Gypsum: Gypsum accumulates on the surface and at depths (Fig. 6) overcoming the gypsum encrustation. Its presence is due to the fact that the solutions are concentrated on the one hand, on the surface of the soil amended downstream by evaporation and, on the other hand, at the base of the profile amended upstream where the sandy-silt soil texture promotes the leaching of elements in solution up to the base of the profile. The

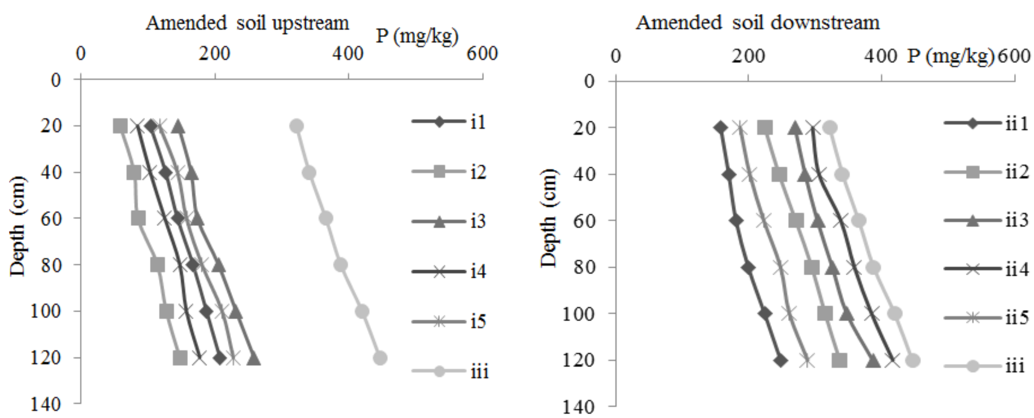

Fig. 5: Effect of the slope on the total variation of phosphor

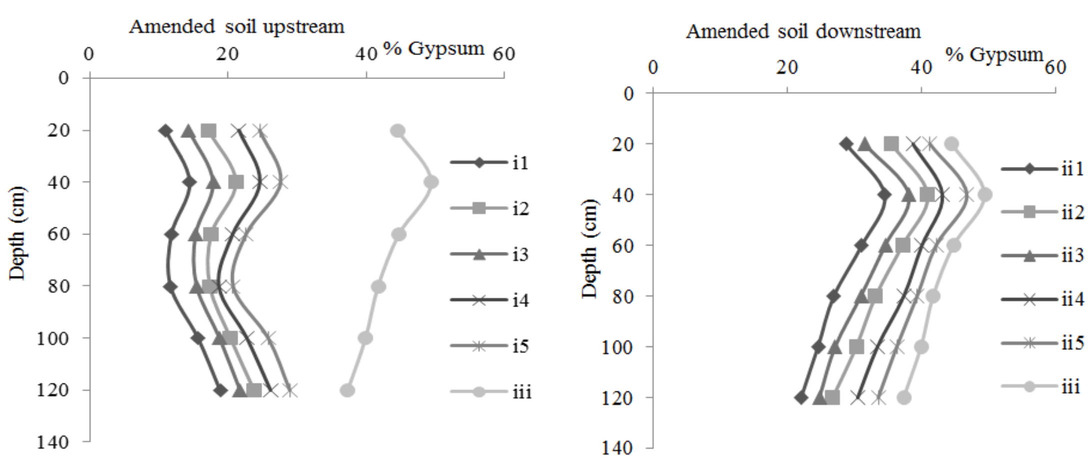

Fig. 6: Effect of the slope on the variation of the gypsum

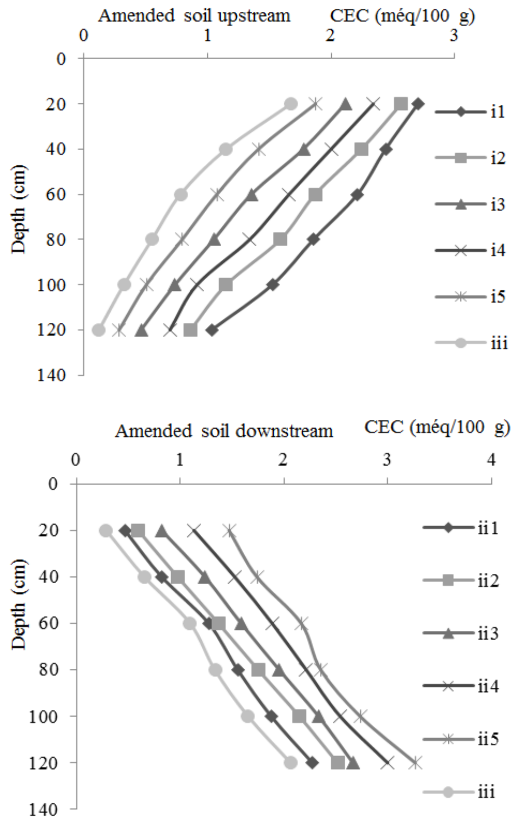

Fig. 7: Effect of the slope on the variation of the capacity of cation exchange

accumulation of gypsum in the superficial horizon of the steep amended soil can also be linked to the type of gypsum amended with sand and to the fact that the soil initially contains gypsum incrustations mixed with the exogenous sand when plowing.

Cation Exchange Capacity (CEC): The soil cation exchange capacity is low (Fig. 7). It varies between 0.12 and 2.74 meq/100 g for the soil amended upstream while it varies between 0.28 and 3.26 meq/100 g for the soil amended downstream. The decrease of the CEC value with depth in the amended soil upstream could be due to the decreasing amount of organic matter with depth. In contrast, the CEC of the downstream amended soil increases with depth due to the variation of the soil texture and more specifically due to its clay content which reaches 30% at a depth of 120 cm. These results confirm those found by Poussin *et al*. (2002), indicating that the CEC is strongly correlated to the clay content.

The results for the menus trials in our oasis, showing that the restoration of oasis soils that are poor soils in organic matter, affected by salinity and in a desert climate, can be protected and even sustainable beings with such practices addition of dune sands and manure. Adding sand makes the roots immune to the capillary rise of the saline waters of the water table, but also sequesters the organic matter by preventing the heat that degrades easily, but also wind to transport them by wind erosion.

CONCLUSION

With reference to recent studies on the soil of traditional oases and the collected data, some degradation phenomena which have affected some oases and their exploitation have been noticed in this study. Among these phenomena we find hydromorphic soils, soil salinization, the decline in fertility and the decline in yields. Therefore, to rectify the lack of fertility of these soils and to deal with the degradation of their structures as a result of the excessive salts, to combat the hydromorphic soils and to improve the performance of the palm groves, farmers resort to sandy and organic amendments. The study of amended soils in the Om Rouss oasis in the Tunisian south has demonstrated that soil reconstruction of marginal lands situated near the sebkha-type closed depressions using sandy and organic amendments has had a beneficial effect on the improvement of the functional properties of soils.

Indeed, the results of the soil analysis and diagnosis have revealed the presence of a very permeable level on the surface from upstream to downstream and a level which is rich in fine particles, slightly permeable at greater depths, especially downstream near the sebkha. Concerning the biochemical properties of the soil, it is clear that the contribution of manure by farmers to sustain the soil organic matter and nitrogen and phosphorus too despite its small amount, have been sufficient to improve the fertility of the soils and the performance of date palms, especially in the upstream end of the perimeter. These results confirm the role of sandy amendments as an effective action to combat the degradation of soils, the improvement of production and, moreover, the preservation of agricultural activity, in particular in the old oasis.

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