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Evaluation of soil changes under agricultural management and irrigation in an arid region: the case of Ghardaïa (Zelfana)

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ABSTRACT

The sustainability of soils is a major concern as they provide multiple functions such as agricultural production, water filtration and biotope for living organisms. Crop sustainability in an arid environment requires the study of the components of this environment. Our work carried out in the region of Zelfana (Sahara Desert), 60 km far from the capital of Ghardaïa province, aims to diagnose and characterize the soil changes produced due to the cultivation of palm trees. For this purpose, systematic sampling was carried out and soil data measured on plots cultivated for 60 years, comparing with those of an uncultivated area (control). The undisturbed soils have coarse textured, low organic matter content, are moderately to highly calcareous, and present low to high salinity and alkaline. The results of the cultivated topsoil and the annual rate of change showed that there was a highly significant decrease in total limestone and pH, and a highly significant increase in electrical conductivity and organic matter due to the cropping system. These changes are justified by the effect of the years of cultivation and the farmers' management (i.e. addition of organic manure and the flood irrigation).

Key words: *Irrigation, Palm tree, Sahara Desert, Salinity, Soil organic matter*

Introduction

Soil is the most important resource in the earth system that contributes to the functioning of the planet (Larson and Pierce, 1991; Tessier, 2002; Steichen, 2013; FAO, 2015 and Fayolle, 2019). Fragile and threatened, which means that its loss and degradation are irrecoverable; it must be considered as a non-renewable resource (GIS, 2006; Martinez Chois, 2012; Jones *et al.*, 2015; Riah *et al.*, 2012; FAO, 2017). Highly diverse, it plays an essential role, produces food, regulates the water cycle and quality, stores carbon and reduces global warming, recycles organic matter, maintains biodiversity, provides materials for construction and industry, and contributes to the aesthetics of landscapes (Jones *et al.*, 2015;

FAO, 2017).

The development of agricultural production depends on all the elements that make up soil quality (Reid *et al.,* 2005). Soil quality is therefore a key element in assessing the sustainability of intensive agricultural development (Larson and Pierce, 1991). It is reflected in its capacity to store and return water and fertilizing elements, to maintain its biodiversity and to resist the effects of practices that can lead to its degradation (tillage, irrigation, etc.) (Jones *et al.,* 2015; Reid *et al.,* 2005). It is obvious that the quality of a soil for a particular use depends on its intrinsic properties, its geochemical and climatic environment, and its use by humans (Jones *et al.,* 2015; Arshad and Coen, 1992).

Land degradation is caused by unsustainable land use and management practices and extreme weather events due to various social, economic and governance factors (FAO, 2015; FAO, 2021). The current rate of land degradation threatens the capacity of future generations (FAO, 2015; Dubois, 2008). Among all the factors of land degradation that can be cited, one of them largely dominates all others because of the function assigned to land in our modern societies, namely agricultural intensification combined with unsustainable practices and extreme climatic events (FAO, 2015).

The risks posed by land degradation to food security and nutrition are even greater (FAO, 2015), influences not only the quantity harvested, but also the nutritional quality, size and shape of the fruits. To this end, in addition to reduced yields, soil degradation leads to a decrease in the commercial value of agricultural products (FAO, 2015).

According to FAO's Global Agro-ecological Zone System (GAZS) modelling tool, drylands covered 43.2% of the total area of the planet in 2020, and this is expected to reach 44.2% in 2050 (FAO, 2020). Drylands are home to indigenous plant species essential for food security and livelihoods (Jones *et al.,* 2015; FAO, 2016). Cultivated soils in these regions generally pose enormous development problems. They often have calcareous or gypsums crusts and are generally saline and subject to erosion and secondary salinization (FAO, 2015; Benbrahim, 2006; Cherief and Debbah, 2020).

In Algeria, more than two million square kilometers (87%) of the country are located in the Sahara region (Nedjraoui, 2001). The Sahara is one of the hottest and driest regions in the world (Jones *et al.,* 2015; FAO, 2017). In most of these regions, in order to establish a crop, it is essential to implement an irrigation system (Rognon, 1993; FAO, 2014). Extreme weather events that extend over longer periods in these regions increase the pressure on crop productivity and water resources (Jones *et al.,* 2015; Abbass *et al.,* 2018). The role of soils in adapting to climate change and mitigating its negative effects can no longer be ignored as regional climate projections show that significant warming and decreasing precipitation are expected in the coming years (Bucchignani *et al.,* 2018). In situations of extreme aridity and introduction of agriculture with poorly managed irrigation, overexploitation and other poor practices lead to loss of soil nutrients and result in soil degradation (Ambalam, 2014).

In this context, soils in the Saharan zone of Algeria contain relatively large amounts of accumulated soluble salts and often have calcareous or chalky crusts or both (Daoud and Halitim, 1994; Benbrahim *et al.,* 2016). The presence of this gypsum, calcareous and saline accumulations, in general, poses enormous problems for the agricultural development (Daoud and Halitim, 1994; Benbrahim *et al.,* 2016). These problems are in-creased under non-adequate management systems and mostly due to most irrigation waters in the Sahara contain excessive amounts of soluble salts. When these waters are used for irrigation, they cause soil degradation through salinization, alkalization and sodization and consequently low crop yields. Several studies have shown that irrigation with saline water leads to soil degradation (Daoud and Halitim, 1994).

Under these conditions, it is important to preserve soil resources from degradation and to restore degraded soils (UNGA, 2015). It is not easy to determine the changes produced by agriculture in desert areas, and this is the main objective of this work. It evaluates the effects of developing an intensive agricultural system, with constant flood irrigation for 60 years of cultivation, on a soil where palm trees were grown (phoeniculture), under an arid climate. These soils were compared to the same type of soil, the closest uncultivated soil, serving as a control to detect the changes in the Ghardaïa region. The objective is to assess the changes caused by agricultural intensification (irrigation) on some key soil properties that could be useful to know which will be an adequate and sustainable soil management in this arid region for the future and maintain the soil productivity and yield. In this sense, the irrigation water for the growing season where the soils were studied was also characterized.

Materials and Methods

Study area

The study area is located in the wilaya of Ghardaïa (Figure 1), in central Algeria, north of the Sahara, 600 km far from the capital of the country, Algiers (Cote, 1998). It is integrated in the northern part of the Saharan platform at 32° 30' north latitude and 30° 45' longitude (NARH, 2007).

The climate of the study area is typically Saharan, characterized by two seasons, one hot and dry and other temperate (NARH, 2012). The average annual temperature is 23.27°C, August is the hottest month with 34.74°C and January the coldest one with 12.12°C (ONM, 2018). Precipitation is very scarce and irregular, with a distribution characterized by almost absolute dryness from May to July and a maximum of 20.11 mm in September. The mean annual precipitation is about 80.10 mm. Evaporation is very intense, especially when reinforced by hot winds. It is about 2593.27 mm/year, with a monthly maximum of 377.72 mm in July and a minimum of 89.54 mm in January. The relative humidity is very low, about 21.45% in July, reaching a maximum of 55.36% in December and an annual average of 38.08% (ONM, 2018). The sunshine duration is 286.71 hours/month, with a maximum of 344.9 hours in July and a minimum of 232.9 hours in December, and mean annual sunshine duration is 3440.54 hours/year, about 9.42 hours/day. Winds are frequent throughout the year, with an average annual speed of 12.4 km/h and a maximum speed of 15.71 km/h (ONM, 2018).

According to the precipitation data and monthly temperature data over a period of 10 years, the rainfall can be established whose purpose is to determine the dry period. The umbrothermal diagram of makes possible to follow the seasonal variations of the water reserve. It is represented in Figure 2. In the region of Ghardaïa, we notice that this dry period is spread over the whole year.

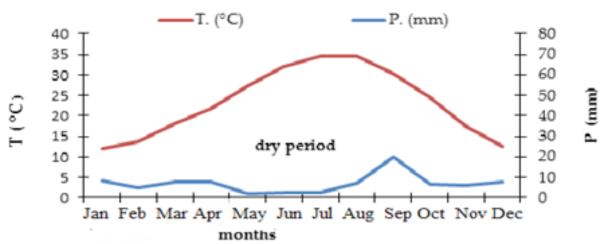


Fig. 2. Umbrothermal diagram of Gaussen of the region of Ghardaïa (2008 - 2018).

Study site and methodological approach

The experimental field is located in the municipality of Zelfana at a distance of 60 km NE from the capital of the province of Ghardaïa. It covers a total area of 45 ha, specialized in phoeniculture. Thus, we took into consideration the age of the crop, 60 years of cultivation, which gives us the opportunity to study the effect of agricultural intensification and flood irrigation on the cultivated soils.

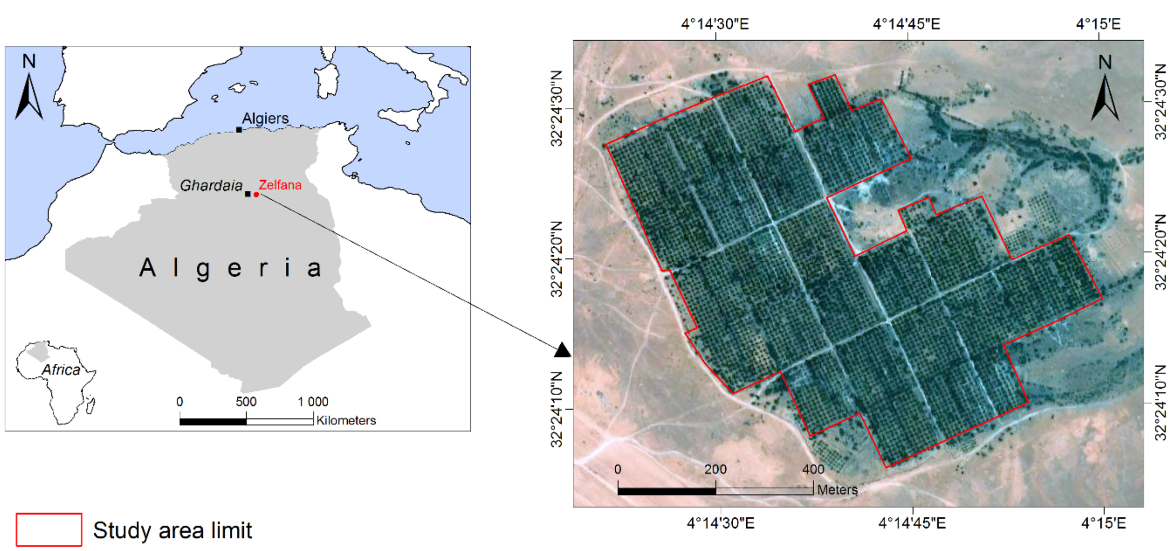


Fig. 1. Map of the geographical location of the study area.

The methodological approach chosen in our study allows us to characterize cultivated soils from the measured values of certain properties and to compare these values to a reference state of non-cultivated soil, in order to deduce the effect of agricultural intensification on the cultivated soils properties selected: total limestone, organic matter, pH and electrical conductivity.

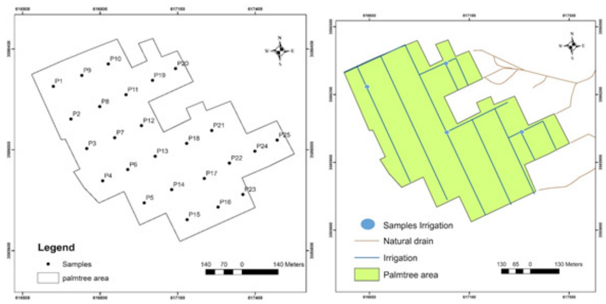
These traits were chosen because the Saharan soils of Algeria are characterized by the presence of large amounts of soluble salts, and often have gypsum or calcareous crusts, or both (Daoud and Halitim, 1994; Benbrahim *et al.,* 2016). Most of the irrigation waters in the Sahara contain excessive amounts of soluble salts. When they are used for irrigation, they lead to soil degradation through salinization, alkalization and sodization and consequently to low crop yields (Daoud and Halitim, 1994). Soils are poor in organic matter content and in important minerals for plant nutrition (Daoud and Halitim, 1994). For these reasons, we consider that these four properties play a role as indicators of soil quality under these extreme climatic conditions. Total lime content reflects carbonate accumulation, pH is used as an indicator of alkalinity, electrical conductivity is mostly used as an indicator of salinity and organic matter is related to the addition of organic fertilizers by farmers, among other relations like those associated to the increment of soil carbon to mitigate climate change (Navarro-Pedreño *et al.,* 2021).

Soil and water sampling

In order to characterize the soils and to deduce the effects of agricultural intensification in the soil, 25 soil samples were taken from irrigated plots (cultivated soils) and 25 samples from a non-irrigated area besides to the oasis agricultural system (control soils). Topsoil (0-30 cm) was sampled in each point. The positions of the samples are chosen after several field surveys, following a systematic sampling, for irrigated soils in order to have a good representation of the whole irrigated area and randomized for non-irrigated soils, considering the surrounding and undisturbed area of the cropping system situated at the SW and separating each soil sample between 10 to 15 meters. These soils keep their natural conditions and where close to the orchards (Fig. 3).

The soil samples were collected, air-dried, homogenized and sieved to 2 mm. After that, they were analyzed according to the methodology referred to in UNE standards (AENOR, 2001; MAPA, 1986). The colour of the soil was described by using the Munsell table, the pH was measured in aqueous extract after mixing soil with distilled water (1:2.5 w/v), the electrical conductivity (EC at 25°C) was determined in aqueous extract 1:5 (w/v), equivalent calcium carbonate was determined by the gasometrical method (Bernard's Calcimeter), and the soil organic matter (SOM) by oxidation based on the Walkley-Black method (Nelson and Sommers, 1983). An estimation of the annual rate of change of the soil properties was calculated (ARC), considering the period of cultivation of 60 years. Although this estimation probably has no lineal variation, this helps us to understand how the changes have been produced along the years of the oasis development.

All soils are irrigated with the same water, which comes from the intercontinental Albian aquifer. The characterization of the irrigation water gives us the opportunity to verify the possible addition and accumulation of salts and its quality. Four samples of irrigation water were collected in June for the analysis (Fig. 3).



(a) (b)

Fig. 3. **(a)** Location of the cultivated soil samples in the study area **(b)** Distribution of irrigation water in the study area (main canals), and water sampling points are indicated.

Statistical analysis

One-factor analysis of variance comparing the soil samples from the control area (non -cultivated soils) and those from the cultivated area was done for each parameter. This analysis allows us to highlight the existence or not of differences between the means and the significance of these differences if they exist.

The descriptive statistics in our case concern the mean, the standard deviation, the minimum and the maximum. The software used for the statistical analyses is the Excel table and XLSTAT version 2019.1.1.

Results and Discussion

Irrigation water

In general, it is considered that the concentration of salts in the soil can reach two to six times the electrical conductivity of the irrigation water (Benslama *et al.,* 2020). After the characterization of the water used for irrigation, the results are presented in Table 1.

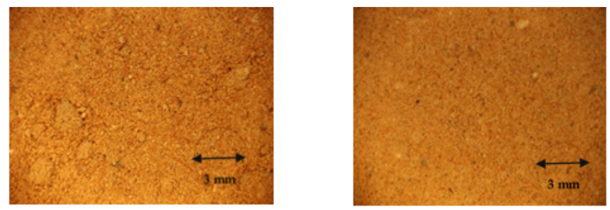
The pH of the irrigation water was neutral to slightly alkaline. On the other hand, the EC values are slightly high as it was expected due to the source. The amount of Na^+, Ca^{2+}, and Mg^{2+} can be considered high, which could prove that there is an important addition of these elements into the soil profile, favoring the mineralization and the salinization.

Soil characteristics

The soils sampled, both cultivated and non-cultivated, can be classified as Arenosols (Wrb, 2015). This type of soil is a sandy and deep soil resulting from an alteration of rocks rich in quartz in situ and recent sandy deposits, too young, with a low water retention capacity, a rapid permeability and a low content of nutrients. Covering about 10% of the earth's surface they are most extensive in desert regions. In dry regions, they are associated with Leptosols, Regosols, Gypsisols, Durisols and Calisols (Wrb, 2015).

The colour of the topsoil of the irrigated area in dry state is 5YR 6/6 (reddish yellow), not very compact, with a sandy-silty hand texture, with particulate structure, existence of coarse elements of angular shape and diameter between 0.5 and 6 cm, of calcareous nature, noticing the presence of palm roots and organic residues, whose dimensions go from millimeter to one centimeter. The topsoil has a strong effervescence to HCl and a biological activity is not visible.

The colour of the non-irrigated topsoil in dry state is 7.5YR 7/6 (reddish yellow), not very compact, with a sandy-silty hand texture, with particulate structure, existence of coarse elements of angular form and of diameter included between 0,5 and 6 cm, of calcareous nature, with weak presence of the roots whose dimensions are of few millimeters with a not visible biological activity and has strong effervescence to the HCl, like the soil of the cultivated area.



(a) (b)

Fig. 4. **(a)** Microscopic photography of the soil of the irrigated plots; **(b)** Microscopic photography of the soil of the not irrigated area.

The resume of the analytical results of the two soil areas, that cultivated and under surface irrigation system and the surrounding area where soils maintain their natural status, are shown (Table 2).

From these results, it can be deduced that the cultivated soil is alkaline (Mathieu *et al.,* 2003; Baize, 2018), moderately calcareous (Baize, 2018), and the organic matter content it is low (Baize, 2018). The electrical conductivity shows that the soil is salinized (Mathieu *et al.,* 2003). The properties of the soil of non-irrigated area are the following: moderately calcareous (Baize, 1988), with very low organic matter content (Baize, 2018), the pH is alkaline (Mathieu *et al.,* 2003; Baize, 1988), and non-saline (EC is more than two times less) that the irrigated one (Mathieu *et al.,* 2003). The analysis of variance of all these parameters showed that the differences were very highly significant ($P < 0.0001$).

The analysis of the annual rate of change (ARC)

Table 1. Descriptive statistics of the analysis of irrigation water.

	Irrigation water										
	pH	EC (dS/cm)	Salinity (mg/l)	Na^+ (meq/l)	Ca^{2+} (meq/l)	Mg^{2+} (meq/l)	K^+ (meq/l)	Cl^- (meq/l)	NO_3^- (meq/l)	SO_4^{2-} (meq/l)	SAR
Mean	7.6	1.9	911	6.1	9.1	5.6	0.4	10.4	0.4	2.9	2.25
Max	7.9	2.1	1191	6.5	12.5	7.5	0.4	12.9	0.5	3.0	2.41
Min	7.3	1.3	980	5.67	6.41	4.6	0.4	8.6	0.2	1.9	2.06
SD	0.31	0.389	305	0.4	2.7	1.3	0.1	1.8	0.1	0.5	0.25

Table 2. Mean values of the of soil analysis (cultivated soils and non-cultivated).

Characteristics	Cultivated soil				Non-cultivated soil (control)				
	Mean	Sd	min	max	Mean	Sd	min	max	TVA
Total equiv. CaCO3(%)	14.42	2.14	10.81	20.01	20.48	0.849	18.65	22.02	-0.101
pH 1/5	8.30	0.18	8.00	8.70	8.68	0.05	8.56	8.76	-0.006
EC at 25 °C (ds/m)	2.52	0.84	1.12	4.023	0.93	0.056	0.85	1.10	+0.026
Organic Matter (%)	0.352	0.092	0.252	0.671	0.007	0.011	0.000	0.034	+0.005

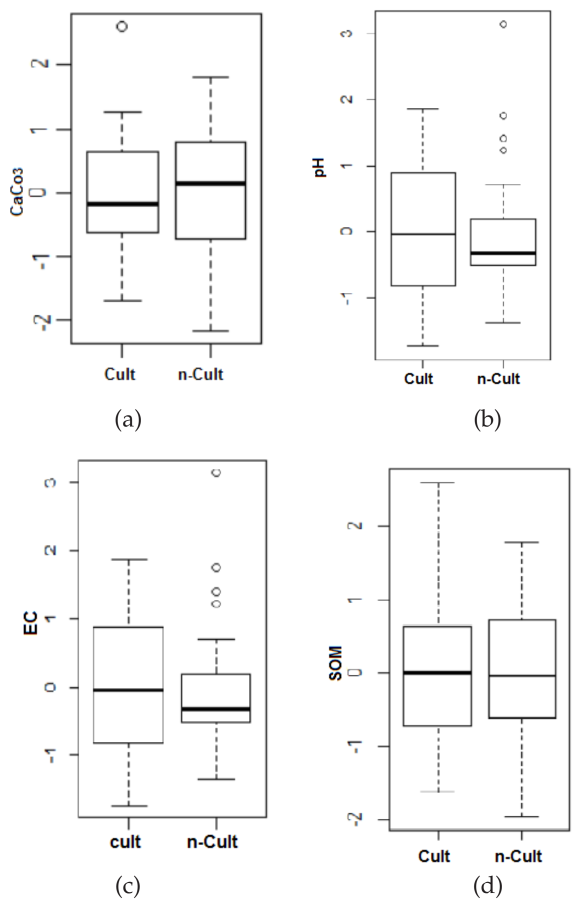


Fig. 5. (a) Box plot of total limestone variation of the surface horizon (0-30cm). (b) Box plot of the pH variation of the surface horizon (0-30cm). (c) Box plot of the variation of the electrical conductiv-ity of the surface horizon (0-30cm). (d) Box plot of the variation of the SOM of the surface hori-zon (0-30cm).

shows that the total limestone con-tent has decreased in the surface horizon of the irrigated plots after 60 years of irrigation, with an annual average change of -0.101± 0.03%/year. This shows the impact of agricultural intensification on the distribution of limestone in the soil, knowing that irrigation is a non-negligible contamination factor (Bresson, 1978). However, limestone is soluble, and in many situations, there is a sequence of phenomena of dissolution and precipitation of carbonate and calcium, in a first stage, limestone is dissolved. It is the decarbonation that releases calcium ions into the environment, these ions are moved by the percolation of water or by diffusion over variable distances, both within a horizon or the various horizons of the profile (Bresson, 1978; Laverdière *et al.,* 1980; Pouget, 1980). This phenomenon can produce the formation of a calcareous crust in depth and, after a long-term period of irrigation, facilitates the salinization and waterlogging, which produces losses in yield and poses in risk the cultivated plants.

The annual rate of change of pH after 60 years of irrigation shows a decrease in pH of the order of -0.006± 0.003%/year, parallel to the reduction of equivalent calcium carbonate content but moderately. The main cause of this decrease is associated to the leaching of alkali and alkaline earth cations following irrigation (MAPA, 1986), and the decrease of limestone as it was found a highly significant relationship between limestone and pH (MAPA, 1986; Floate and Enright, 1991).

Other causes can contribute to the decrease of pH in the study site, like the use of fertilizers (organic amendments from goat cattle are added on the surface and close to the palm tree stipe as it is an annual input and traditional common practice) which has an acidifying effect on the soil (MAPA, 1986; Bussières, 1978). The vegetation also acts on the decrease of the pH in-directly by the biomass and the formation of humic compounds made up of organic acids, and directly by absorbing more cations than anions from the soil solution, which leads to the release of hydrogen ions and the implementation of an acidolysis (Halitim, 2006). However, the organic matter content of the cultivated soil is low, maintaining low levels after the 60 years of cultivation as the sandy texture of the soil facilitates the degradation (i.e. oxidation) of the organic matter.

The analysis of the ARC of the electrical conductivity in the surface horizon after 60 years of irrigation shows an increase in the salinity of +0.015 ± 0.014 dS/m/year. The difference in soil salinity could be the result of the use of irrigation with salty water and high evaporation. It should be noted that salinity is related to the quality of the irrigation water used (FAO, 2020; Nedjraoui, 2001; Halitim, 2006; Djili *et al.,* 2003). Irrigation often has a negative effect on salinization, especially in arid regions, where irrigation water is often charged of salts. Several authors reported that the practice of irrigation leads in most cases to secondary soil salinization (Daoud and Halitim, 1994; Benbrahim *et al.,* 2016, Aubert, 1976; Condom, 2000; Rachachi, 2017). Semi-arid regions are often characterized by high temperatures favoring high evapotranspiration and a consequent, the increase in the salinity of the soil surface horizon (Rouabhia and Djabri, 2010).

The analysis of the annual rate of change of SOM after 60 years of irrigation shows a slightly increase in SOM of about +0.005± 0.001%/year. This increase in SOM is explained by the addition to the soil of organic amendments, dyed plant residues, and animal debris (Moughli, 2000). However, as it is expected in this type of soil and under the environmental conditions of the desert, it is very difficult to accumulate and storage soil organic matter even after 60 years of cultivation.

Conclusion

This study was focused on the evaluation and characterization of some soil proper-ties (electrical conductivity, pH, total limestone, and organic matter) and their changes due to the impact of agricultural management after 60 years of cultivation with palm trees, which has a great agrifood of interest in Algeria. This was done with the aim of achieving sustainable and environmentally friendly palm cultivation and prevent risks of salinization. According to the observations made, the results showed that the agricultural management practiced after 60 years of cultivation have an impact on the physical-chemical properties of the soil in the surface horizon, from 0 to 30 cm depth. Indeed, there was a very highly significant decrease in total limestone and pH and a significant increase in electrical conductivity (EC) and organic matter. This is due to the effect of the years of cultivation and the agricultural practices adopted by the farmers, such as the addition of organic manure, which is usually of animal origin, and also that resulting from the degradation of palm residues (roots and leaves). The combined effect of irrigation and climate, which added a strong evaporation, lead to a great necessity of irrigation and, an excess of water, produces the movement of water in the sandy soil profile, accompanied by the soluble salts. It is so positive to consider that, even in sandy desert soils, organic matter can be accumulated under agricultural management in the soil profile and can contribute to the mitigation of climate change

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Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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