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Soil organic matter amendments in date palm groves of the Middle Eastern and North African region: A mini-review

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Abstract: Countries in the Middle Eastern and North African (MENA) region are among the most water-scarce regions in the world, and their dryland soils are usually poor in organic carbon content (<0.5%). In this study, we summarize examples of how people in the few oases of the MENA region overcome environmental challenges by sustainably managing economically important date production. On the basis of the limited studies found in the existing literature, this mini-review focuses on the role of traditional soil organic matter amendments beneath the soil surface as a key tool in land restoration. We conclude that soil organic matter amendments can be very successful in restoring soil water and preventing the soil from salinization.

Keywords: review; Middle Eastern and North African (MENA); drylands; organic matter amendments; oasis agrosystem; date palm production

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The Middle Eastern and North African (MENA) region stretches from Morocco in the west to Iran in the east, including the majority of the Middle Eastern and Maghreb countries. It is characterized by high population growth, low erratic rainfall and severely limited water resources. Desertification and soil degradation by salinization, accelerated soil erosion, nutrient imbalances and soil organic matter (SOM) depletion are major problems threatening the economic livelihood of the population in the region (Dregne, 2002). Overall, the MENA region is home to 6.3% of the world's population. The population more than doubled between 1970 and 2001, rising from 173×10^6 to 386×10^6 people. This population increase has reduced the average amount of fresh water available per capita by more than half, to 1,640 m^3 per person per year (Roudi-Fahimi et al., 2002). Moreover, the population growth particularly threatens marginal lands with lower productivity and higher risk of desertification (Croitoru and Sarraf, 2010). The area of dry lands accounts for nearly 90% of the total land area in the MENA region. About 30% of the population lives in these dry lands, often in the few dispersed and intensively irrigated lands. Even more than in urban areas, poverty is widespread in the rural dry lands of the MENA region. This hardship is worsened by the lack of access to the high quality soils and water resources, and by the continuing degradation of natural resources (Dixon et al., 2001).

Nevertheless, approximately 4×10^6 people in the MENA region live within the more favorable

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oases agrosystems, where about 1.2×10^6 hm^2 irrigated land is used for the production of date palm (*Phoenix dactylifera* L.), fodder, fruit trees and vegetables (Jaradat, 2011). The sustainable management of these oases is decisive for human welfare and economic development. The main date-producing regions are concentrated in few areas within the MENA countries. Date palm is marketed all over the world as a high-value fruit crop and is an extremely important subsistence crop in most of the desert-like regions. MENA is one of the most water-scarce regions in the world. Although date palms are frequently grown under conditions of reduced water supply, the overall quantity of water shared for growing date palms is still strategically important for the nationwide water protection management in the MENA countries (Khan and Prathapar, 2012).

The dryland soils, including those for date palm farming, are usually characterized by low organic matter (OM) content (Dregne, 2002). Furthermore, plant productivity is low, yielding low OM inputs (El-Juhany, 2010). Additionally, due to the sandy texture of the dryland soils, its potential to sequester carbon is limited (Kösters et al., 2013), and its potential water-holding capacity is also low. Therefore, high amounts of irrigation water resources are wasted due to poor soil properties (Blanchart et al., 2007). Soil degradation can also be induced by the reduced water quality. In some date palm-farming areas, local groundwater quality is declining due to the urban waste-water discharge or the industrial sewage effluent containing inorganic salts, mostly chlorides and sulphates of Na, Ca and Mg, which are causing the accumulation of salts in the soil under the condition of arid climate and intense evapotranspiration (such as the Gabes oasis in Tunisia) (Chandoul et al., 2014; Hamed et al., 2014). In another example from Algeria, Samia and Boualem (2014) highlighted that urban waste water over the past 20 years was discharged into a canal used for the drainage flow from date palm groves in Oued Righ Valley, which resulted in the serious groundwater pollution in southeastern Algeria and the devastated loss of half of the date palms in the valley.

In view of these facts, the proper application of organic amendments to ameliorate soil is a critical issue in sustainable management of arid and semi-arid areas. Such OM amendments contribute to plant growth through their effect on the physical, chemical and biological properties of the soil (Maia et al., 2010). They also play a significant role in maintaining soil structure (Baldock and Skjemstad, 1999), enhancing water-holding capacity (Roy et al., 2006), providing metabolic energy that drives soil biological processes and supplying the nutrients to plants (Vanlauwe, 2004). These amendments will gain even more relevance for optimizing cropping strategies in the MENA countries, for which longer, more severe droughts have been predicted in the near future (Sardans and Peñuelas, 2005).

This review aims to shed light on the status of SOM in the drylands of the MENA region, with particular focus on its oasis agrosystems. We give special attention to the effect of SOM amendment on date production by improving water- and nutrient-use efficiencies. Some information and statistical data were obtained from literature published in Arabic or French that may have limited access for many readers. In addition, due to the scarcity of literature concerning the stocks and dynamics of SOM in the MENA region, some information was compiled from other published sources from the MENA region.

1 Oasis agrosystems and date palm (*Phoenix dactylifera* L.) production in the MENA region

There are very few and local reports on the origin and ancient history of oasis agrosystems in the MENA region. Tengberg (2012) collected data from several research regions, and indicated that the origin of oasis agriculture likely dates can back to the prehistoric times around the Persian Gulf. Tengberg (2012) also outlined that documented archaeological evidences showed that date palms were cultivated together in the same gardens with other crop species such as fruit trees and vegetables. This description of traditional oasis agriculture (Bustan in the Arabian Peninsula or Nakhlestân in Iran) is inevitably simplistic. No one date palm garden was really identical to any other one, even though they may be basically similar in their principle design (Battesti, 2005). The earliest examples of the use of date palm cultivation in the MENA region appeared later in

North Africa than in the Middle East, raising the suggestion that oasis agriculture was first introduced in the latter region. In any case, the first evidence of oasis agriculture in Arabia stems from the oasis of al-Aïn in the interior of the Oman Peninsula (Emirate of Abu Dhabi). Archaeological teams revealed the remains of oasis systems within settlements and tombs from the Bronze and Iron Ages (Tengberg, 2012). The fact that such old oasis production systems survived until today provides indirect evidence that ancient farmers found ways to manage these ecosystems over a long term. A micro-climate is established under the date palm trees in the oasis. Humidity, heat and light are favorable for optimized usage of the space for other crops (oranges, pomegranates, vegetables, fodder and cereals) to grow in an environment where fertile soil is scarce, such as a representative example for the Gabes maritime oasis in South Tunisia (Fig. 1).

Fig. 1 Intergration of date palm, fruit trees and herbaceous plants into a date palm grove in Chenini oasis, Gabes, Tunisia. The photo was imaged by Nadhem BRAHIM in 2014.

Reasonable oasis expansion in arid region is usually regarded as the opposite of desertification, referring to the process of transformation from desert to oasis in an arid region due to the combined action of anthropogenic actors and natural factors (Wang, 2009). Therefore, oases are partially man-made. Their construction should be assured for geomorphological features, such as optimized utilization of old and buried river beds, which minimize the risks of salinity, erosion and unwanted stagnant water on lithic soils after irrigation (El Bastawesy and Ali, 2013). Certainly, the design of oases also follows the (old) cultural and aesthetic traditions.

Date palms are among the most famous crops in the oases of the MENA region. They largely contributed to opening up vast desert territories for human activities and the development of oasis agrosystems in the MENA region (Tengberg, 2012; Zohary et al., 2012). The ideal climatic conditions for all date species are long summers with high daytime and low nighttime temperatures, and mild dry winters without prolonged frost (Burt, 2005). Date palm is a valuable plant that provides a significant source of income for both local farmers and governments in the MENA region.

According to the data of FAO (2012), the countries in the MENA region with higher yields of date palms are Egypt, Iran, Saudi Arabia and the United Arab Emirates, followed by Pakistan, Algeria, Iraq and Sudan (Fig. 2). Clearly, most of the date production in the world is concentrated in these countries in the MENA region.

The global demands for dates is increasing due to the increased awareness of food and health benefits. More than 80% of European Union (EU) imports are concentrated between October and December, corresponding to the harvesting time of dates in many of the supplying countries. Tunisia, with a market share of 48%, and Algeria, with 20%, are the major suppliers of EU, mainly with the Deglet Noor date variety (Liu, 2003). In 2012, Tunisian dates recorded the highest price of US$ 2,433 per ton, followed by Iran, Oman and Egypt (US$ 1,188 to US$ 1,430 per ton) (FAO, 2012). In many of the major date-producing countries (i.e. United Arab Emirates, Pakistan, Algeria and Iraq), the prices of dates were lower (US$ 338 to US$ 605 per ton).

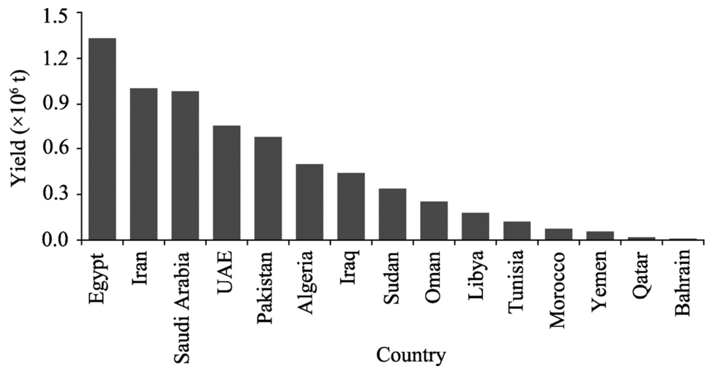

Fig. 2 Yields of date palm in the major date-producing countries of the MENA region for 2010. UAE, United Arab Emirates. The figure was modified based on the data of FAO (2012).

2 Organic matter and carbon sequestration potential in the MENA region

The harsh environment in desert areas of the MENA region makes this region vulnerable to desertification by erosion, salinization, nutrient exhaust and depletion of soil organic carbon (SOC) stocks (Dregne, 2002). Desertification is already severe in Sudan, Saudi Arabia, Algeria and Morocco (Conacher and Sala, 1998). The SOC content in the MENA region barely reaches 0.5% (Lal, 2002), thus limited organic material is available for humus amendments. Many date palm trees do not shed their leaves, so there is less natural surface litter in such vegetation systems. Drylands in the global continent comprise 27% of the global SOC reserves (Trumper et al., 2008). Lal (2009) estimated that dryland ecosystems contribute 0.23 to 0.29 Gt of carbon to the atmosphere each year, which accounts for 4% of the global carbon emissions. Overall, large amounts of SOC in the global stored in these arid soils are only due to the large area in which these soils are present, but not by their significant SOC accrual (as happens in peat soils). In Tunisia, total SOC stocks range from 1.03 to 1.13 Pg C in the 0–100 cm soil depth, while from 0.42 to 0.46 Pg C in the upper soil layer (0–30 cm) (Brahim et al., 2011). The sandy texture of soils in semi-arid regions makes SOC prone to erosion and rapid mineralization upon land-use changes (Lobe et al., 2001; Bruand et al., 2005). Up to 4.7% of SOC could be lost annually from the sandy soils in the Sahara region. Such losses of SOC average up to 2% per year, even from somewhat heavier textured sandy loam soils (Piéri, 1989). The largest SOC losses certainly occur when sites with permanent vegetation are converted to cropland. Lobe et al. (2001) observed that up to 65% of SOC was lost after breaking the savannah surface sod.

Several natural factors, such as drought, salinity, sand drift and groundwater quality decline also contribute to the lack of OM replenishment via standing vegetation in the MENA region (El-Juhany, 2010). This was enforced by human mismanagement due to inappropriate tillage practices, straw exportation, over-grazing and over-harvesting of wood for fuel (Anibat et al., 2003; Lal, 2006; Thomas, 2008). Pretty et al. (2004) identified that the environmental conditions in drylands may favor or hinder carbon sequestration. Figure 3 shows that the unfavorable conditions are mainly related to the harsh environment in drylands, whereas the significant carbon sequestration potential mainly stems from the globally large area of these drylands. Sequestered carbon is not necessarily stabilized in these sandy soil environments, but it may be temporarily retained/stored due to dryness, as microbial activity and associated carbon degradation require a certain level of soil water to occur (Reichstein et al., 2003; Curiel Yuste et al., 2007). Contact between the microbes and the available substrate, and the physiological performance of microbes, are limited at low soil-water contents. Therefore, droughts reduce soil carbon losses by inhibiting microbial decomposition (Robertson and Paul, 2000). Generally, there is less above- and below-ground surface litter in the dryland ecosystems compared to other ecosystems. There is limited organic material available for humus amendments in the drylands of the MENA region, therefore, if the SOM is lost as a result, it is difficult to replace.

Nevertheless, once cropland is converted back to the land with more permanent vegetation, at least parts of the SOM may be restored. In sandy soils, this SOM restoration is predominantly linked to accumulation of coarse plant debris in the coarse fraction, but it may take a decade or more and is often incomplete, compared to soils under the earlier and original native vegetation (Blanchart et al., 2007; Preger et al., 2010). The reasons for this may be manifold. Compacted soils may require decompaction treatment before grasses are reseeded. The lacking nutrients, such as N are usually not replenished before putting the soil back to quasi-natural conditions (Amelung et al., 2001). Soil aggregates may recover completely within one to two decades, yet without the full ability to sequester as much carbon as in native savannah ecosystems (Preger et al., 2010). Therefore, additional measures may be needed to establish perennial plants and plant-soil system protection, such as targeted restorative practices like prohibiting grazing (Deng et al., 2013). Lal (2001) added that improved control of desertification could globally sequester 0.9 to 1.9 Pg C/a over a period of 25 to 50 years. Lal (2002) also indicated that adoption of methods (including residue management techniques, use of cover crops in crop rotations, and water and nutrient recycling technologies) to restore the degraded soils has the potential to sequester 0.2–0.4 Pg C/a of soil carbon in the drylands of the MENA region.

3 Water scarcity and salinity

Apart from the losses in SOM that affect soil fertility, MENA is a water-scarce region. Water scarcity will likely be exacerbated in the future as a result of continuing population growth, climate change and degradation of water quality. Most of the renewable water resources of the region are already in use for agricultural and domestic use (Kuwait, Bahrain, Lebanon and Israel) (Gleick and Cain, 2004). Agriculture consumes approximately 80% to 90% of the freshwater resources (Hamdy and Trisorio-Liuzzi, 2004) (Fig. 4). In Saudi Arabia, agricultural development policies and irrigation practices adopted since the 1980s are linked with an estimated depletion of two-thirds of the country's fossil water supplies (Al-Shayaa et al., 2012). Water re-allocation under conditions of scarcity in the future will most likely be at the expense of the agricultural sector (Eid et al., 2007).

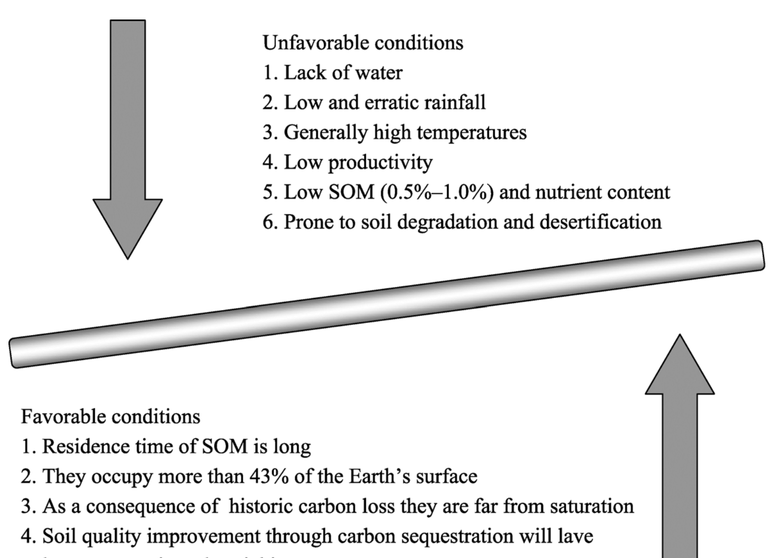

Fig. 3 Favorable vs. unfavorable conditions affecting carbon sequestration and re-establishment of soil organic matter (SOM) in the drylands of the MENA region. The figure was modified based on the study of Pretty et al. (2004).

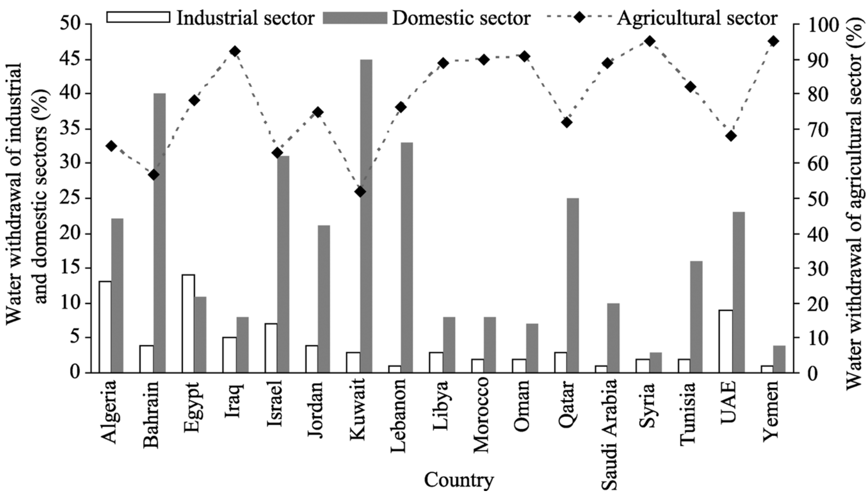

Fig. 4 Fresh water withdrawal by industrial, domestic and agricultural sectors for 17 countries in the MENA region in 2000. Data were collected from The World's Water, 2004–2005 (Gleick and Cain, 2004).

Although the contribution of agriculture to GDP is relatively low in many countries of the MENA region, especially oil-exporting countries, many people depend on agriculture for the livelihood. Political difficulties will also contribute to raising the costs of irrigation water (Sowers et al., 2011). Climate change will reduce the amount of water available through higher evapotranspiration and reduced groundwater recharge, and will further increase the need for water in the agricultural sector.

It is necessary to make the most efficient use of water resources to improve the allocation (Lelieveld et al., 2012) by adopting techniques that ensure the quality of water-use efficiency, such as increasing soil-moisture content by increasing water infiltration, managing soil evaporation, and increasing soil-moisture storage capacities. All these practices are combined with increasing SOM content.

Next to water scarcity, the increasing salinity in the water and soil (if used for irrigation) hampers microbial performance (Rietz and Haynes, 2003) and agricultural production (Al-Yassin, 2005; Anjum et al., 2005). Natural saline depressions are widespread at the Sahara margins of the Maghreb countries (Dregne, 1976). The coastal aquifers of the Levant and North Africa already suffer from seawater intrusion that has caused salinization in thousands of wells (Weinthal et al., 2005). Salinity in irrigated areas is also common from Morocco to Egypt, with peaks in Algeria, Tunisia, the Nile Valley and the Nile Delta. The construction of illegal wells may exacerbate salinization (Salgot et al., 2014). Hassine (2005) emphasized that in irrigated areas of arid Southwest Tunisia, secondary salinization has a double origin: irrigation water and the rising underground water table.

4 SOM amendments: A critical key in sustainable management of oasis agrosystem

A sufficient supply of soil with OM is decisive to sustain key functions of soil in the ecosystem, such as providing and storing nutrients, supporting underground biodiversity, and improving soil chemical and physical properties such as resilience against erosion or salinization (Baldock and Skjemstad, 1999; Wander, 2004; Kögel-Knabner and Amelung, 2014). Soils usually differ in their SOM stocks, properties and depthes (Baldock and Skjemstad, 1999; Batjes, 2014). In comparison, individual SOM molecule turnover depends to a small degree on its recalcitrance (Amelung et al., 1998), but largely on the properties of the ecosystem (Schmidt et al., 2011). The various SOM pools differentially sustain or contribute to the functions of OM in soils (Fig. 5). Therefore, maintaining or increasing SOM levels is a central management aim, and is also a knowledge bottleneck in many agro-ecosystems of the world, particularly in dryland and oasis production systems (Bot and Benites, 2005).

In arid regions, water is the most limiting factor for crop production, and soil management is mainly concentrated in small oasis areas near water resources such as springs and shallow groundwater. In contradiction to the common misconception among farmers that date palm is a resilient crop and can be productive with little water supply, actually date palms need enough amounts of water to sustain the growth through keeping all metabolic processes intact. The annual water requirement of a mature date palm may vary from 115 to 306 m^3, depending greatly on the climatic conditions and habitats (Table 1). In the extremely drylands of the MENA region (e.g. Saudi Arabia), the annual gross water used for date palm irrigation may reach 42,600 m^3/hm^2 according to the information from El-Bana and Ibrahim (2008). Thus, in these arid areas, the main benefits of SOM amendments to oases, apart from the supply of nitrogen (N) and phosphorus (P), are likely to be the gain in water holding capacity. SOM can critically govern cation exchange capacity (CEC), and helps assure soil fertility and sustainability of the system over time (Wichern et al., 2004).

Krull et al. (2004) stated that the positive effects of CEC may be negligible below a threshold value of 2% SOC content. Wolf and Snyder (2003) stated that an increase of 1% SOM content could add 1.5% soil-moisture content. Emerson and McGarry (2003) showed that a 50% increase in soil-water content was achieved per gram of additional carbon at –10 kPa suction. Zemánek (2014) showed that the application of compost in a dose of 100 t/hm^2 positively affects soil-moisture retention regardless of possible influence of soil type. Meier-Ploeger and Vogtmann (2003) indicated that an increase of humus content by 0.2% can cause an average increase of utilizable water capacity by 0.5% and pore volume by 1%. For sandy-textured soils where most of the MENA's date palms grow (Kassem, 2012), soils with an OM content of 4% to 5% can hold 10 times or more water and nutrients than sand soils with less OM according to the information provided by Davis and Wilson (2000). This in turn would contribute significantly to water saving efforts in the region and enable more efficiently water usage.

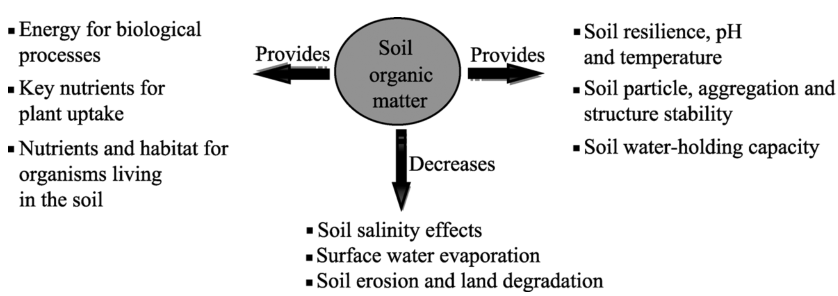

Fig. 5 Effects of soil organic matter on soil functions. This figure was modified base on the study of Baldock and Skjemstad (1999).

Table 1 Annual water requirements of date palm from different countries in the MENA region (El-Bana and Ibrahim, 2008)

Country	Annual gross water use	
	(m^3/tree)	(m^3/hm^2)
Egypt	86–124	10,280–14,880
Saudi Arabia	150–350	18,180–42,600
Iran	102–164	12,270–19,720
Algeria	43–210	5,200–25,400
Oman	183–240	21,950–29,320
Libya	183–240	7,200–29,700
Tunisia	100	12,000

Morocco	105–200	12,600–23,900
United Arab Emirates	130–173	15,500–20,740
Yemen	130–173	15,500–20,740

Many other studies also highlighted the effect of OM on increasing the storage and use efficiency of water in the extremely water-limited date palm groves (Hehmeyer, 1989; Bouhouach et al., 2009; Kouki and Bouhouach, 2009; Sadik et al., 2012; Navas et al., 2013). However, the accurate data for estimating the soil water storage after OM addition remains unquantified and needs to be investigated.

Since date palm farming in the MENA region is located in the arid zone, the growth of date plams should cope with the relatively high amounts of basic cations at the soil surface. However, date palms need sufficient nutrients in proper balance for normal growth and development. The final composition of date fruits resulting from the various development stages (known in their Arabic terms: Kimiri, Khalal, Rutab and Tamar) does consume a wide range of nutrients that must be substituted annually (El Mardi et al., 2006).

The addition of mineral fertilizers to soil plays an important role in sustaining date palm production and is widely used in date palm groves where organic resources for fertilization are limited. Previous studies have pointed out the positive effects of the inorganic fertilizers on fruit quality and date production (Table 2). Furr and Cook (1952) did already report that the addition of 2.7 to 3.6 kg N to Deglet Noor variety resulted in 20% increase in date production compared with unfertilized trees after 4-year experiment. Through a 5-year experiment in a date palm grove near Basra in Iraq, Popenoe (1973) reported that the addition of 1.2 kg N, 600 g P and 1.2 kg potassium (K) for a date palm tree increased the dates yield 2 to 3 times. Soliman and Osman (2003) showed that N and K fertilizers improved the nutritional status of the tree, and fruit set and quality for Samany date palm variety in Egypt. Osman (2010) reported that the application of 4.5 kg K at three doses yearly per date palm to Bartamoda date palm variety increased the date yield, bunch weight, fruit and flesh weight. Microelements, such as zinc (Zn), copper (Cu), iron (Fe) and manganese (Mn) do also play a vital role in improving the total yield and fruit quality of the date palm, whether they used as organic or inorganic form (Manickavasagan et al., 2012). Attalla et al. (2007) found that boron (B) leaf spray fertilizer in combination with soil application of micronutrient fertilizers (Fe, Mn and Zn) enhances fruit ripening of Zaghloul date palm variety. Dawoud and Fatima (2011) did indicate that the application of element sulfur (S) does enhance the availability of other nutrients in calcareous alkaline soil, and results in a higher leaf elongation and larger date production. However, the amounts of inorganic fertilizers needed by date palm tree do vary with the types and depths of soil and with the varieties and ages of the date palm tree. Hence, more specific experimental field based data from response of different date palm varieties to fertilizer additions and management remains an important requirement to improve the yield and quality of date palm.

OM amendments such as livestock manure are a key fertilizer in date palm groves of the MENA region. The application of organic amendments has been widely used to restore the degraded lands (Bastida et al., 2008). The use of organic amendments to compensate for OM losses as a common practice in arid and semi-arid soils will become even more important in the near future, especially when there are longer and more severe droughts (Sardans and Peñuelas, 2010). There are many examples for the success of OM amendments in date palm production. Several studies have highlighted the positive effects of OM fertilization on date palm, whether it was used alone or in combination with mineral fertilizers (Table 2). For example, a study on the Sewy date palm variety in Egypt showed that the application of N, P and K fertilizers combined with sheep manure increased the number of leaves, number of bunches, total fruit sugars and leaf mineral content of data palm (Ibrahim et al., 2013). In Saudi Arabia, Bacha and Abo-Hassan (1983) found that organic manure mixed with N, P and K fertilizers increased the date yield, number of bunches and leaf N concentration in the Khudari date palm variety. Marzouk and Kassem (2011) stated that organic manure (including chicken manure, cow dung and domestic refuse compost) application increased the date yield and enhanced the fruit color compared to the mineral fertilization only. El Mardi et al. (2006) showed that organic peat in combination with N, P and K fertilizers could improve the physical and chemical characteristics of fruits for Khalas and Khasab date palm varieties.

Based on the above-mentioned information on the beneficial application of both inorganic and organic fertilizers, it is evident that appropriate fertilization is needed in date palm groves to sustain the crop yield and quality. However, we are not aware of any long-term field experiment in the oasis environments that clearly test these treatments neither against another nor even against traditional alternative management options. Thus, establishing such long-term field trials within oases should be a major research focus for future researches in the MENA region.

Table 2 Inorganic and organic fertilizers and their effects on different date palm varieties

Soil type	Fertilizer type	Application rate per date palm (kg/a)	Variety	Effect	Source
NR	N	2.7 to 3.6	Deglet Noor	(1) 20% increase in date production (2) Increasing trunk growth and leaves number (3) Increasing number of branches and fruits per punch	Furr and Cook (1952)
NR	N/P/K	1.2/0.6/1.2	NR	(1) Two to three times increase in yield (2) Doubled the number of leaves per tree	Popenoe (1973)
NR	N/K	1.5/1.5	Samany	(1) Increasing the contents of leaf N and K	Soliman and Osman (2003)
NR	K	4.5 (three times a year)	Bartamoda	(1) Increasing date yield, bunch weight and fruit weight	Osman (2010)
NR	N/P	1.0/0.6	Piarom	(1) Increasing date yield and leaf K content	Saleh (2009)
Calcareous soil	S	0.4	Mishrig wad laggai	(1) Availability of other nutrients (2) High leaf elongation (3) Increasing fruit quality	Dawoud and Fatima (2011)
Calcareous alkaline soil	Fe B Mn Zn	0.2 0.1 0.1 0.04	Zaghloul	(1) Enhancing fruit ripening (2) Positive correlations between N and K, between Fe, Mn and B, and between Mn and Zn	Attalla et al. (2007)
Calcareous loamy sand	N/P/K	1.0/0.7/0.5	Zaghloul	(1) Increasing fruit yield (2) P and K enhanced the physical-chemical characteristics of the fruit (3) Increasing leaf N, P, K, Fe and Zn contents	Kassem (2012)
Sandy and loamy sand	Sheep manure+ N/P/K	40 1.5/0.6/0.4	Sewy	(1) Increasing number of leaves and number of bunches per date palm (2) High fruit yield and sugar contents	Ibrahim et al. (2013)
Clay loam	Organic manure (unspecified)+ N/P/K	25 1.5/0.5/0.5	Khudari	(1) Increasing number of bunches and leaf N content (2) No appreciable effect on yield and fruit quality	Bacha and Abo-Hassan (1983)
Clay soil	Chicken manure+ Cow dung+ Composted domestic refuse+ N/P/K	30 47 58 3.0/1.1/1.1	Zaghloul	(1) Increasing yield and fruit quality	Marzouk and Kassem (2011)
NR	Organic peat+ N/P/K	– 1.0/0.5/0.8	Khalas and Khassab	(1) Better physical and chemical characteristics of fruit (2) Good growth and development of fruit	El Mardi et al. (2006)

Note: NR, not reported; –, no data. N, nitrogen; P, phosphorous; K, potassium; S, sulfur; Fe, iron; B, boron; Mn, manganese; Zn, zinc.

To a certain degree, the applied OM may still originate from the oasis itself, such as agricultural residues (crop residues and animals manure) and nonagricultural by-products (domestic refuse). Nevertheless, the actual vegetation cover in the MENA oases is low and localized to small areas. Indeed, significant amounts of residue are produced by the date palms. In Saudi Arabia, each date palm tree produces about 20 kg dry leaves per year (Alkoaik et al., 2011). In Iran, an individual date palm tree yields approximately 40 kg organic waste annually (Mallaki and Fatehi, 2014). In Tunisia, oases farmers estimate that the annual biomass residue production from crops grown under date palm trees may reach up to 150 kg/hm^2 for vegetables (farmers' field observations). Yet, farmers rarely quantify their estimations into accepted standardized units of measurement.

Kouki and Bouhouach (2009) estimated the organic waste loss in Gabes oases of Tunisia to be more than 5,700 t/a. In different locations of Oman oases, although many farmers raise livestock next to the crop farms, they still use mineral fertilizers instead of livestock dung to fertilize their crops (Buerkert and Schlecht, 2010), indicating that awareness about the beneficial impacts of SOM is lacking among many farmers within these oases.

Interestingly, other evidence from an oasis in Oman, where 3.7% of SOC content found at 0–15 cm depth and 3.0% at 15–45 cm depth, suggested that this is the consequence of a long-term annual manure application of up to 12 t/hm^2 (Buerkert et al., 2005). Clearly, manuring practices are being used in parts of Oman, but how consciously this is done remains unclearly from this evidence alone. The quality of manure is highly variable depending on the quality of feed of livestock, manure collection and storage methods (Müller-Sämann and Kotschi, 1994). Probert et al. (1995) estimated manure production level in semi-arid areas of 1 t per livestock unit per year for unimproved local cattle. MENA oases include approximately 2.7×10^6 cattle and shepherds (Erskine et al., 2004), indicating that an estimation of 2.7×10^6 t livestock manure could be produced annually in these agrosystems.

5 Design of local practices for applying OM fertilizers in date palm groves

For the OM amendments, farmers frequently follow the methods used by their ancestors in fertilization of date palm trees. These application methods differ from one country to another one and, in many cases, also from one district to another in the same country. One of the more prominent methods is making a circular ditch of 3- to 4-m diameter around the tree. The ditch must be shallow near the trunk but become deeper to reach the local shallow water table on the outside. The application of manure should be done in autumn and winter once every 4–5 years. However, the manure is still exposed to sunlight and is susceptible to rapid decomposition and drying. This method has been used since ancient times in dates palm groves in South Iraq (Al-Rawi, 1998).

For another method, a semi-circular ditch (50-cm depth) is made around the tree from one side. The ditch is then filled with manure and covered with a light soil layer, which may consist of desert sand. The manure in the subsoil layer can store water for plant growth and, when moist, it also supplies nutrients via an active soil microbial community. The sand on the top of the incorporated manure has two additional positive effects. First, it protects the manure from the direct heat of the sun and rapid drying, sustaining microbial life. Second, it elevates the land surface and increases the distance to the ground water. The latter finally helps prevent the salt accumulation from capillary rise and the evaporation of the groundwater. Overall, this type of management cleverly combines the advantages of the (novel) fertilization with traditional management practices of desert soils. Figure 6 shows an OM layer underlying the sand layer next to a date palm tree trunk. Another OM layer is beneath, also covered by sand. The fertilization practice has been repeated, and soil genesis is already caused by anthropogenic factors. This method is the most popular practice in date palm groves in the Kebili oases of Tunisia, and it has derived its popularity in the surrounding date palm groves from the remarkable effects based on the local farmers' experience. However, there are no available evidences or studies in the literature about whether this method is used in other desert areas in the MENA region or worldwide. Hence, the available information about this practice tentatively (in the absence of specific hard experimental data) suggests that this method does enhance yield security in those groves and therefore it is traditionally practiced in parts of Tunisia.

Although the above-mentioned processes mainly refer to the single-tree benefits of OM amendments, the whole oasis requires an overall management strategy that preserves the optimized OM management structures. In other words, the spatial arrangements and allocations of fields should consist of an inherent structure that is stable against erosion, extreme weather events, or cultural changes. For centuries, oases have played an important role in providing local inhabitants with shelter, food and shade in the middle of deserts and hyper-arid areas. The locals have sustained their oases through traditional fertilization, using sheep or goat manure and traditional management practices, which can now be extended with other novel approaches for OM application and preservation in these soils. Hussein (2004) reported that the quantities of animal manure used in these traditional methods are varying to a great extent, in a range of 5 to 15 t/hm^2 depending on the manure source. Sheep manure is preferred, due to its relatively higher N content (about 2.0%), compared to cow or horse manure (0.5% to 1.0%). However, under dry and low rainfall conditions, manure disappearance occurs very quickly. Sahel Esse et al. (2001) showed that in sandy soils of semi-arid West African, 75% of applied manure disappeared during the first 10 weeks after application with no significant difference in disappearance rates among different manure types.

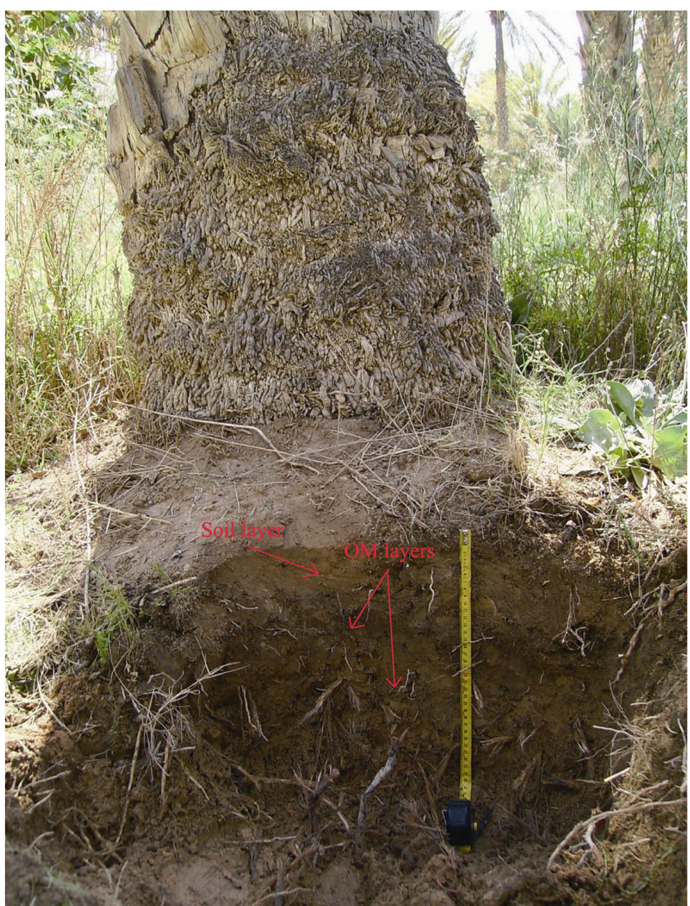

Fig. 6 Organic matter (OM) amendment topped with sand underneath the date palm trunk in Kebili oasis of Tunisia. The photo was imaged by Nadhem BRAHIM in 2014.

A study from Oman showed that fertilization of date palm in the past was only based on green and animal manures, and its rate usually varied with soil types and the sizes of date palm (Al-Yahyai, 2006). Most of date grovers in Oman oases apply manure mixed with straw twice a year per date palm.

Buerkert and Schlecht (2010) emphasized that one of the most important components of oases sustainability in Oman is the maintenance of SOM on man-made and silt-filled terraced fields. Although year-round high temperatures and regular irrigation lead to high mineralization of OM, as evidenced by large soil-respiration rates, carbon losses are effectively balanced in these systems by annual additions of up to 30 t/hm^2 of composted animal manure. The terraces are designed to control leaching to uniquely avoid salinization. Moreover, a certain degree of (partly pastoral) animal husbandry is required to guarantee the supply of livestock dung as the main source of nutrients and a water-harvesting tool.

6 Conclusions

This mini-review summarizes the role of SOM dynamics in the drylands of the MENA region, with a special focus on the importance of OM amendments in improving date palm production. As the MENA region is one of the most water-scarce and food import-dependent regions in the world, the continuous depletion of OM in the drylands of the MENA region has significant negative implications for the economic production and social stability of the region. However, sustainable management is possible. Good examples can be found in those date palm plantations in oasis agrosystems which are still traditionally and sustainably managed according to the experience of ancestors and more closely to local cultures and resources. Local farmers, who are usually aware of linking date palm production to proper OM management, have succeeded to improve the sustainability of the systems. OM amendments, preferably buried below added soil, help preserve and harvest water, providing nutrients needed for crop growth in these date palm production systems. Learning from and building upon such indigenous knowledge for other cash-crop production systems appears valuable in such sensitive ecosystems.

Our review indicates that the estimates of OM stock and soil management relationships to organic carbon in oases agrosystems in the MENA region are too few. There is little or inaccurate data is available on soil carbon loss in these commercially and socially important agricultural systems. In addition, no formal national programs are currently implemented for conservation and restoration of SOM in the MENA region.

The lack of know-how and technology is a major problem, especially in more resource-scarce countries in the MENA region, which can easily rely on external expertise. Thus, bridging the gap between farmers and scientists is crucially important, as sustainable soil management is brought about by increasing farmers' understanding of soil dynamics and how to use techniques ensuring the proper soil function. Therefore, agricultural extension work, especially in some of the marginalized oases, is the main channel of direct communication that might connect farmers with scientists to enhance their knowledge.

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References

Al-Rawi A A H. 1998. Fertilization of date palm tree (*Phoenix dactylifera*) in Iraq. In: Proceedings of the First International Conference on Date Palm, 8–9 March, 1998. Alain, United Arab Emirates, 320–327.

Al-Shayaa M S, Baig M B, Straquadine G S. 2012. Agricultural extension in the Kingdom of Saudi Arabia: Difficult present and demanding future. The Journal of Animal & Plant Sciences, 22: 239–246.

Al-Yahyai R. 2006. Improvement of date palm production in the Sultanate of Oman. In: Zaid A, Hegarty V, Al Kaabi H H S. ISHS Acta Horticulturae 736: III International Date Palm Conference. Abu Dhabi, United Arab Emirates, 337–343.

Al-Yassin A. 2005. Influence of salinity on citrus: A review paper. Journal of Central European Agriculture, 5: 263–272.

Alkoaik F N, Khalil A I, Alqumajan T. 2011. Performance evaluation of a static composting system using date palm residues. Middle-Eastern Journal of Science Research, 7: 972–983.

Amelung W, Kimble J M, Samson-Liebig S, et al. 2001. Restoration of microbial residues in soils of the conservation reserve program. Soil Society of America Journal, 65: 1704–1709.

Amelung W, Zech W, Zhang X, et al. 1998. Carbon, nitrogen, and sulfur pools in particle-size fractions as influenced by climate. Soil Science Society of America Journal, 62: 172–181.

Anibat I, Bessam, F, El-Brahli A, et al. 2003. No-tillage technology: research review of impacts on soil quality and wheat production in semiarid Morocco. In: Cantero-Martínez C, Gabiña D. Mediterranean Rainfed Agriculture: Strategies for Sustainability. IAMZ Mediterranean Agronomic Institute of Zaragoza–ciheam, Options Méditerranéennes: Série A. Séminaires Méditerranéens, 60: 133–138.

Anjum R, Ahmed A, Rahmatullah M J, et al. 2005. Effect of soil salinity/sodicity on the growth and yield of different varieties of cotton. International Journal of Agricultural Biology, 4: 606–608.

Atalla A M, Etman A A, El-Kobbia A M, et al. 2007. Influence of foliar boron spray and soil spplication with some micronutrients in calcareous soil on 2 yield, quality and mineral content of Zaghloul dates in Egypt. In: The 4th Symposium on Date Palm. Date Palm Research Center, King Faisal University, Al-Hassa, Saudi Arabia (Challenges of Processing, Marketing and Pests control).

Bacha M A, Abo-Hassan A A. 1983. Effects of soil fertilization on yield, fruit quality and mineral content of Khudari date palm variety. In: Proceedings of the First Symposium on Date Palm in Saudi Arabia. Al-Hassa, Saudi Arabia, 174–180.

Baldock J A, Skjemstad J O. 1999. Soil organic carbon/soil organic matter. In: Peverill K I, Sparrow L A, Reuter D J. Soil Analysis: An Interpretation Manual. Melbourne: CSIRO Publishing, 159–170.

Bastida F, Kandeler E, Moreno J L, et al. 2008. Application of fresh and composted organic wastes modifies structure, size and activity of soil microbial community under semiarid climate. Applied Soil Ecology, 40: 318–329.

Batjes N H. 2014. Total carbon and nitrogen in the soils of the world. European Journal of Soil Science, 65: 10–21.

Battesti V. 2005. Gardens in desert: evolution of oasian knowledge and practice: Tunisian Jerid. IRD Editions, Paris, 440. https://halshs.archives-ouvertes.fr/halshs-00004609v2. (In French)

Blanchart E, Albrecht A, Bernoux M, et al. 2007. Organic matter and biofunctioning in tropical sandy soils and implications for its management. In: Management of Tropical Sandy Soils for Sustainable Development. In: Proceedings of the International Congress Management of Tropical Sandy Soils for Sustainable Agriculture. Bangkok: FAO Regional Office for Asia and the Pacific, 224–241.

Bot A, Benites J. 2005. The importance of soil organic matter: key to drought-resistant soil and sustained food production. FAO Soils Bulletins, 80: 94.

Bouhouach H, Culot M, Kouki K. 2009. Composting and recycling of oasis waste to ameliorate soil and improve its productivity. In: International Symposium "Sustainable Agriculture in the Mediteranean Region" (AGDUMED). Rabat, May 2009. IAV Hassan II Rabat, INRA Morroco, FUSA Gembleux Belgium and Agricultural Society of Morroco, 14–16. (In French)

Brahim N, Gallali T, Bernoux M. 2011. Carbon stock by soils and departments in Tunisia. Journal of Applied Sciences, 11: 46–55.

Bruand A, Hartmann C, Lesturgez G. 2005. Physical properties of tropical sandy soils: A large range of behaviours. In: Management of Tropical Sandy Soils for Sustainable Agriculture. A Holistic Approach for Sustainable Development of Problem Soils in the Tropics. Khon Kaen, Thailand. http://www.documentation.ird.fr/hor/PAR00007514.

Buerkert A, Nagieb M, Siebert S, et al. 2005. Nutrient cycling and field-based partial nutrient balances in two mountain oases of Oman. Field Crops Research, 94(2): 149–164.

Buerkert A, Schlecht E. 2010. Oases of Oman: Millenia Old Livelihood Systems at the Crossroads (2rd ed.). Muscat: Al Roya Press & Publishing House, 50–51.

Burt J. 2005. Growing date palms in Western Australia. Farm Note No. 55/99. South Perth, Australia: Government of Western Australia, Department of Agriculture and Food. http://www.agric.wa.gov.au/objtwr/imported_assets/content/hort/fn/cp/strawberries/f05599.pdf.

Chandoul I R, Bouaziz S, Dhia H B. 2014. Groundwater vulnerability assessment using GIS-based DRASTIC models in shallow aquifer of Gabes North (South East Tunisia). Arabian Journal of Geosciences, doi: 10.1007/s12517-014-1702-6.

Conacher A J, Sala M. 1998. Land degradation in mediterranean environments of the world: nature and extent, causes and solutions. Biodiversity and Conservation, 8: 1717–1718.

Croitoru L, Sarraf M. 2010. The Cost of Environmental Degradation: Case Studies from the Middle East and North Africa. Washington: World Bank, 3–4.

Curiel Yuste J, Baldocchi D D, Gershenson A, et al. 2007. Microbial soil respiration and its dependency on carbon inputs, soil temperature and moisture. Global Change Biology, 13: 2018–2035.

Davis J G, Wilson C R. 2000. Choosing a soil amendment. Gardening Series: Basics. Colorado State University Cooperative Extension. Fort Collins: Colorado State University.

Dawoud H D, Fatima A A. 2011. Effect of different levels of elemental sulfur fertilizer on the growth, fruit quality, yield, and nutrient levels in the leaves of Mishrig Wad laggai date palm cultivar under Al Mukabrab conditions. In: Arab Plam Conference 2011, 4–7 December. Ryiadh, KSA.

Deng L, Shangguan Z P, Sweeney S. 2013. Changes in soil carbon and nitrogen following land abandonment of farmland on the Loess Plateau, China. PloS ONE, 8(9): e71923, doi: 10.1371/journal.pone.0071923.

Dixon J A, Gibbon D P, Gulliver A. 2001. Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World. Rome: Food and Agriculture Organization of the United Nations (FAO), 1–412.

Dregne H E. 1976. Soils of Arid Regions. Amsterdam: Elsevier, 1–231.

Dregne H E. 2002. Land degradation in the drylands. Arid Land Research and Management, 16: 99–132.

Eid H M, El-Marsafawy S M, Ouda S A. 2007. Assessing the Economic Impacts of Climate Change on Agriculture in Egypt: A Ricardian approach. CEEPA Discussion Paper No. 16. Special Series on Climate Change and Agriculture in Africa. Pretoria: Centre for Environmental Economics and Policy in Africa.

El-Bana A, Ibrahim H A. 2008. Irrigated date palm production in egypt. In: Workshop on "Irrigation of Date Palm and Associated Crops", 27–30 May, 2007. Damascus, Syrian Arab Republic.

El-Juhany L I. 2010. Degradation of date palm trees and date production in Arab countries: causes and potential rehabilitation. Australian Journal of Basic and Applied Sciences, 4: 3998–4010.

El Bastawesy M, Ali R R. 2013. The use of GIS and remote sensing for the assessment of waterlogging in the dryland irrigated catchments of Farafra Oasis, Egypt. Hydrological Processes, 27: 206–216.

El Mardi M O, Al Julanda Al Said F, Bakheit Sakit C, et al. 2006. Effect of pollination method, fertilizer and mulch treatments on the physical and chemical characteristics of date palm (Phoenix dactylifera) fruit I: Physical characteristics. Acta Hortic. (ISHS), 736: 317–328. doi: 10.17660/ActaHortic.2007.736.30. http://www.actahort.org/books/736/736_30.htm.

Emerson W W, McGarry D. 2003. Organic carbon and soil porosity. Australian Journal of Soil Research, 41: 107–118.

Erskine W, Moustafa A T, Osman A E, et al. 2004. Date palm in the GCC countries of the Arabian Peninsula. Regional Workshop on Date Palm Development in the Arabian Peninsula. Abu Dhabi, UAE. http://www.icarda.org/APRP/Datepalm/ introduction/intro-body.html.

Esse P C, Buerkert A, Hiernaux P, et al. 2001. Decomposition of and nutrient release from ruminant manure on acid sandy soils in the Sahelian zone of Niger, West Africa. Agriculture, Ecosystems & Environment, 83(1–2): 55–63.

Food and Agriculture Organization of the United Nations (FAO). 2012. FAOSTAT. [2014-04-13]. http://faostat.fao.org/site/339/default.aspx.

Furr J R, Cook J A. 1952. Nitrogen content of pinnae, fruit, and seed of Deglet Noor and Khadrawy date palms as related to nitrogen fertilization. In: 29th Annuual Conference Date Grswers Institute Report. Coachella, 29: 13–14.

Gleick P, Cain N. 2004. The world's water, 2004–2005. Washington DC: Island Press.

Hamdy A, Trisorio-Liuzzi G. 2004. Water scarcity management towards food security in the Middle-East region. In: Hamdy A, Monti R. Food Security Under Water Scarcity in the Middle East: Problems and Solutions. Bari: CIHEAM, Options Méditerranéennes: Série A. Séminaires Méditerranéens, 65:15–28.

Hamed Y, Ahmadi R, Hadji R, et al. 2014. Groundwater evolution of the Continental Intercalaire aquifer of Southern Tunisia and a part of Southern Algeria: use of geochemical and isotopic indicators. Desalination and Water Treatment, 52(10–12): 1990–1996.

Hassine H B. 2005. Effects of groundwater table on soil salinization or five irrigated areas in Tunisia. Soil Study and Management, 12(4): 281–300. (In French)

Hehmeyer I. 1989. Irrigation farming in the ancient oasis of Mārib. In: Proceedings of the Seminar for Arabian Studies. Oxford: Seminar for Arabian Studies, 33–44.

Hussein F. 2004. Nutrient requirments of date palm and fertilizer use. In: Proceedings of the Regional Workshop on Date Palm Development in the Arabian Peninsula, 29–31 May. Abu Dhabi, UAE, 168–172.

Ibrahim M M, El-Beshbeshy R T, Kamh N R, et al. 2013. Effect of NPK and biofertilizer on date palm trees grown in Siwa Oasis, Egypt. Soil Use and Management, 29(3): 315–321.

Jaradat A A. 2011. Biodiversity of date palm. In: Encyclopedia of Life Support Systems: Land Use, Land Cover and Soil Sciences. Oxford, UK: Eolss Publishers, 31.

Kassem H A. 2012. The response of date palm to calcareous soil fertilisation. Journal of Soil Science and Plant Nutrition, 12(1): 45–58.

Khan M M, Prathapar S A. 2012. Water management in date palm groves. In: Manickavasagan A, Mohamed-Essa M, Sukumar E. Dates Production, Processing, Food, and Medicinal Values. Boca Raton: CRC Press, 44–66.

Kögel-Knabner I, Amelung W. 2014. Dynamics, chemistry, and preservation of organic matter in soils. In: Treatise on Geochemistry (2nd ed.). Oxford: Elsevier, 157–215.

Kösters R, Preger A C, Du Preez C C, et al. 2013. Re-aggregation dynamics of degraded cropland soils with prolonged secondary pasture management in the South African Highveld. Geoderma, 192: 173–181.

Kouki K, Bouhaouach H. 2009.Study of the traditional oasis of Chenini Gabes in the south east of Tunisia. Tropoculture, 27(2): 93–97. (In French).

Krull E S, Skjemstad J O, Baldock J A. 2004. Functions of soil organic matter and the effect on soil properties. In: Report for GRDC, Project CSO00029. http://users.datarealm.com/treepower/soils/organicmatter.html.

Lal R. 2001. Potential of desertification control to sequester carbon and mitigate the greenhouse effect. Climatic Change, 51(1): 35–72.

Lal R. 2002. Carbon sequestration in dryland ecosystems of West Asia and North Africa. Land Degradation & Development, 13(1): 45–59.

Lal R. 2006. Enhancing crop yields in the developing countries through restoration of the soil organic carbon pool in agricultural lands. Land Degradation & Development, 17(2): 197–209.

Lal R. 2009. Sequestering carbon in soils of arid ecosystems. Land Degradation & Development, 20(4): 441–454.

Lelieveld J, Hadjinicolaou P, Kostopoulou E. et al. 2012. Climate change and impacts in the Eastern Mediterranean and the Middle East. Climatic Change, 114(3–4): 667–687.

Liu P. 2003. The marketing potential of date palm fruits in the European market. In: FAO Commodity and Trade Policy Research Working Paper (FAO). Rome: Food and Agriculture Organization of the United Nations (FAO).

Lobe I, Amelung W, Du Preez C C. 2001. Losses of carbon and nitrogen with prolonged arable cropping from sandy soils of the South African Highveld. European Journal of Soil Science, 52(1): 93–101.

Maia S M F, Ogle S M, Cerri C C, et al. 2010. Changes in soil organic carbon storage under different agricultural management systems in the southwest Amazon region of Brazil. Soil and Tillage Research, 106(2): 177–184.

Mallaki M, Fatehi R. 2014. Design of a biomass power plant for burning date palm waste to cogenerate electricity and distilled water. Renewable Energy, 63: 286–291.

Manickavasagan A, Essa M M, Sukumar E. 2012. Dates: Production, Processing, Food, and Medicinal Values. Boca Raton: CRC Press.

Marzouk H A, Kassem H A. 2011. Improving fruit quality, nutritional value and yield of Zaghloul dates by the application of organic and/or mineral fertilizers. Scientia Horticulturae, 127(3): 249–254.

Meier-Ploeger A, Vogtmann H. 2003. Quality aspects of fertilization with biowaste. In: 64. Briefing of ANS e. V. The Future of Biowaste Collection, 20 years Biotonne Witzenhausenline Positioning, 225–238. (In German).

Müller-Sämann K M, Kotschi J. 1994. Sustaining Growth: Soil Fertility Management in Tropical Smallholdings. Weikersheim: Margraf Verlag, 498.

Navas A, Machin J, Gaspar L, et al. 2013. The soil of Ziz lands (South east Morroco). AECID, 369–394. (In French)

Osman S M. 2010. Effect of potassium fertilization on yield, leaf mineral content and fruit quality of Bartamoda date palm propagated by tissue culture technique under Aswan conditions. Journal of Applied Sciences Research, 6(2): 184–190.

Piéri C. 1989. Fertility of savannah lands: Assessment of 30 years of agricultural research and development of the south sahara. Montpellier, France: CIRAD-IRAT. (In French)

Popenoe P. 1973. The Date Palm. Miami: Field Research Projects, Coconut Grove, 1–259.

Preger A C, Kösters R, Du Preez C C, et al. 2010. Carbon sequestration in secondary pasture soils: a chronosequence study in the South African Highveld. European Journal of Soil Science, 61(4): 551–562.

Pretty J, Olsson L, Farage P, et al. 2004. Carbon sequestration in dryland soils. In: World Soil Resources Report. Rome: Food and Agriculture Organization of the United Nations.

Probert M E, Okalebo J R, Jones R K. 1995. The use of manure on smallholders' farms in semi-arid eastern Kenya. Experimental Agriculture, 31(3): 371–382.

Reichstein M, Rey A, Freibauer A, et al. 2003. Modeling temporal and large-scale spatial variability of soil respiration from soil water availability, temperature and vegetation productivity indices. Global Biogeochemical Cycles, 17(14), doi: 10.1029/2003GB00202035.

Rietz D N, Haynes R J. 2003. Effects of irrigation-induced salinity and sodicity on soil microbial activity. Soil Biology and Biochemistry, 35(6): 845–854.

Robertson G P, Paul E A. 2000. Decomposition and soil organic matter dynamics. In: Sala O E, Jackson R B, Mooney H A, et al. Methods in Ecosystem Science. New York: Springer, 104–116.

Roudi-Fahimi F, Creel L, De Souza R M. 2002. Finding the balance: Population and water scarcity in the Middle East and North Africa. In: Population Reference Bureau Policy Brief. Washington DC: Population Refrence Bureau.

Roy R N, Finck A, Blair G J, et al. 2006. Plant Nutrition for Food Security: A Guide for Integrated Nutrient Management. Rome: Food and Agriculture Organization of the United Nations (FAO).

Sadik M W, Al-Ashhab A O, Zahran M K, et al. 2012. Composting mulch of date palm trees through microbial activator in Saudi Arabia. International Journal of Biochemistry and Biotechnology, 1(5): 156–161.

Saleh J. 2009. Yield and chemical composition of 'Piarom' Date-Palm *Phoenix dactylifera* as affected by nitrogen and phosphorus levels. International Journal of Plant Production, 3(3): 57–64.

Salgot M, Torrens A, Casanova P, et al. 2014. Management of water resources in the oasis of Figuig, Morocco. Desalination and Water Treatment, 52(13–15): 2841–2849.

Samia B L, Boualem R. 2014. The releases of wastewater in the Oued Righ Valley: the palm groves in decline. Desalination and Water Treatment, 52(10–12): 2187–2192.

Sardans J, Peñuelas J. 2005. Drought decreases soil enzyme activity in a Mediterranean *Quercus ilex* L. forest. Soil Biology and Biochemistry, 37(3): 455–461.

Sardans J, Peñuelas J. 2010. Soil enzyme activity in a Mediterranean forest after six years of drought. Soil Science Society of America Journal, 74(3): 838–851.

Schmidt M W I, Torn M S, Abiven S, et al. 2011. Persistence of soil organic matter as an ecosystem property. Nature, 478(7367): 49–56.

Soliman S S, Osman S M. 2003. Effect of nitrogen and potassium fertilization on yield, fruit quality and some nutrients content of Samany date palm. Annals of Agricultural Science Cairo, 48(1): 283–296.

Sowers J, Vengosh A, Weinthal E. 2011. Climate change, water resources, and the politics of adaptation in the Middle East and North Africa. Climatic Change, 104(3–4): 599–627.

Tengberg M. 2012. Beginnings and early history of date palm garden cultivation in the Middle East. Journal of Arid Environments, 86: 139–147.

Thomas R J. 2008. Opportunities to reduce the vulnerability of dryland farmers in Central and West Asia and North Africa to climate change. Agriculture, Ecosystems & Environment, 126(1–2): 36–45.

Trumper K, Ravilious C, Dickson B. 2008. Carbon in drylands: Desertification, climate change and carbon finance. In: A UNEP-UNDPUNCCD Technical Note for Discussions at CRIC 7, 03–14 November. Istanbul, Turkey, 1–12.

Vanlauwe B. 2004. Integrated soil fertility management research at TSBF: the framework, the principles, and their application. In: Bationo A. Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa. Nairobi, Kenya: Academy Science Publishers, 25–42.

Wander M M. 2004. Soil organic matter fractions and their relevance to soil function. In: Magdoff F, Weil R R. Soil Organic Matter in Sustainable Agriculture. Boca Raton: CRC Press, 67–102.

Wang T. 2009. Review and prospect of research on oasification and desertification in arid regions. Journal of Desert Research, 29(1): 1–9. (In Chinese)

Weinthal E, Vengosh A, Marei A, et al. 2005. The water crisis in the Gaza strip: Prospects for resolution. Groundwater, 43(5): 653–660.

Wichern F, Lobe I, Amelung W, et al. 2004. Changes in amino acid enantiomers and microbial performance in soils from a subtropical mountain oasis in Oman abandoned for different periods. Biology and Fertility of Soils, 39(6): 398–406.

Wolf B, Snyder G H. 2003. Sustainable Soils: The Place of Organic Matter in Sustaining Soils and Their Productivity. New York: Food Products Press.

Zemánek P. 2014. Evaluation of compost influence on soil water retention. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 59(3): 227–232.

Zohary D, Hopf M, Weiss E. 2012. Domestication of Plants in the Old World: The Origin and Spread of Domesticated Plants in Southwest Asia, Europe, and the Mediterranean Basin (4th ed.). Oxford: Oxford University Press.