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ORIGINAL PAPER

Mapping of soil organic carbon stock in the Arab countries to mitigate land degradation

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Abstract Soil organic matter is a key soil component that plays a critical role in ecosystem functioning including soil productivity and resilience to erosion and drought. Most Arab countries are located in semi-arid and arid areas with dominance of drylands soils with poor organic matter content and soil quality. In line with the efforts of the FAO Global Soil Partnership (GSP) and French initiative for carbon sequestration (4 par mille); the soil organic carbon (OC) stock in the Arab countries was assessed and mapped using the FAO-UNESCO Digital Soil Map of the World (DSMW). The outputs must serve awareness raising both at the level of land users and decision makers. Results were compared with the only available national OC map, recently produced in Lebanon. Other national OC maps are under processing by the GSP and Intergovernmental Technical Panel on Soils (ITPS) within the Global Soil OC Map. Produced maps showed low OC stock in the topsoil of more than 69% of the cultivated soils with dominance of xerosols, arenosols, and lithosols. The average soil OC stock in the Arab countries is 37 ± 36 ton/ha in the topsoil and 78 ± 69 ton/ha in the standard soil depth. The total OC stock in the arable lands of the Arab countries was estimated at 50.5 gigatons (GT) with Sudan, Saudi Arabia and Algeria placed on top. The average total OC stock per one Arab country is 0.8 ± 1.7 million tons. Large standard deviation points to different pedoclimatic conditions but also to variable management and land use history. Water erosion and chaotic urban expansion caused the irreversible loss of 25 and 53.6 GT tons of OC, respectively. With increased pressure on limited soil resources, policies must address soil conservation and C sequestration to support soil productivity and improve food production.

Keywords C sequestration · Landuse impact · Climate change · OC stock · Land degradation

Introduction

Terrestrial landscape and associated ecosystems are the most important living space for human beings, and soils are at the core of these terrestrial ecosystems. Long time interaction and carbon sequestration lead to a soil organic carbon (OC) stocks accounting nearly three times the stocks in the vegetation ecosystems (Post et al. 1990) and twice that of the atmosphere (Eswaran et al. 1993; Zdruli et al. 2017). Changes in SOC can affect the density of greenhouse gases in the atmosphere, possibly exacerbating the negative effects of global climate change (Lal 1999; Uri and Bloodworth 2000). Accurately assessing OC sequestration and quantifying SOC stores in soils and monitoring their changes are considered essential to global carbon budget (Quéré et al. 2015) and climate change modeling (Tan and Shibasaki 2003; Janzen 2004; Paustian et al. 2016) and to assess the state of land degradation and desertification (Zdruli et al. 2017).

The Arab countries are spread around the east and south Mediterranean Sea and Arabic peninsula, thus they are subject to the direct impact of arid climate dominating in the surrounding Sahara. The dominant geomorphologic and pedoclimatic conditions characterize the nature of prevailing soil types and rare vegetation cover causing low OC load and

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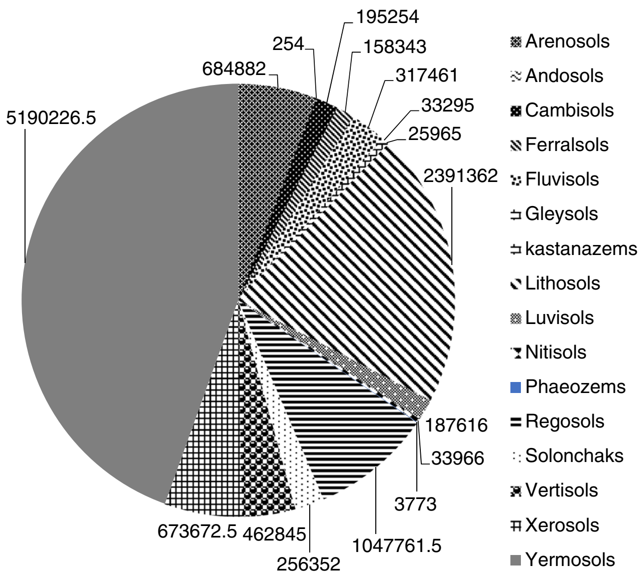

Fig. 1 Available soil resources in the Arab countries (km^2) (source: DSMW, FAO 2007)

accumulations in the soil (Atallah et al. 2015). Mismanagement disrupts the equilibrium of inherited characteristics of a given soil type, cumulatively built under prevailing land cover and climate and deteriorates soil health (Bhogal et al. 2008; Zdruli and Zucca 2018). Under Mediterranean conditions, the succession of dry summers and wet winters increases the emission of carbon dioxide by promoting the decomposition of SOC (Jarvis et al. 2007). Plowing and land-use change from native forest to crops are considered to cause a rapid loss of SOC (Guo et al. 2016). Both appropriate soil management and land abandonment may result in enhancing the soil carbon pool (Atallah et al. 2012; Cerdá et al. 2012; Zdruli et al. 2014; Boukhdoud et al. 2016).

Soil erosion and urban expansion may lead to irreversible loss of soil cover, soil OC, and other nutrients (Darwish et al. 2004). Quantifying SOC content in the Arab countries using available soil data is crucial, even at small scale, to assess the nature and potential of available soil resources and analyze the associated threats. Mapping the spatial distributions of national and regional OC stock can be used to monitor and model regional and global C cycles under different scenarios of soil degradation and climate change. The international scientific institutes, UN organizations and treaties (FAO-GSP, UNFCCC, SDGs), and political community are paying multiple interests to OC status in the soils and C sequestration in different agro climatic zones, including the developing countries, where poverty and additional problems of famine and political instability are associated with OC loss and land degradation. Mapping OC stock can serve as regional and national awareness platform for land users and as technical framework for policy introduction by local authorities. Therefore, the purpose of this work was to assess and map the soil OC stock in the Arab countries and loss from erosion and chaotic urban expansion in identified soil units and groups to enhance C sequestration and support soil resilience to biotic and abiotic factors.

Materials and methods

Soil OC density was linked to each soil unit and corresponding map to produce maps of the soil OC stock and distribution in 22 Arabic States using the digital soil map of the world

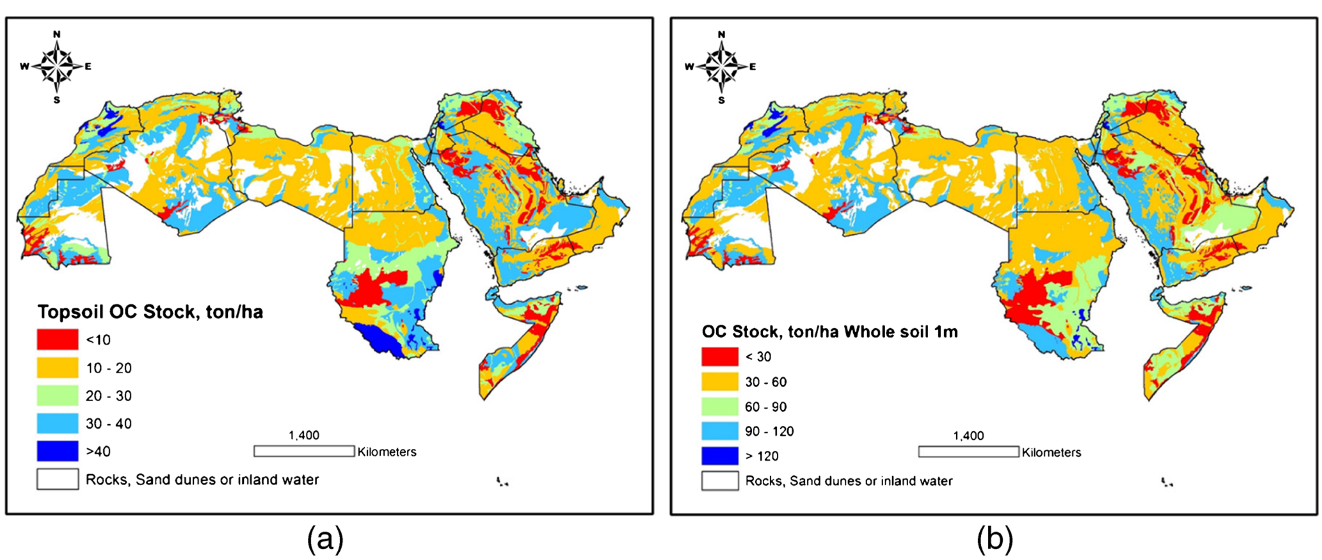

Fig. 2 Spatial distribution of OC stock in (**a**) topsoil (0.3 m) and (**b**) standard soil depth (1 m) of the Arab countries calculated from the soil information extracted from the DSMW, FAO 2007

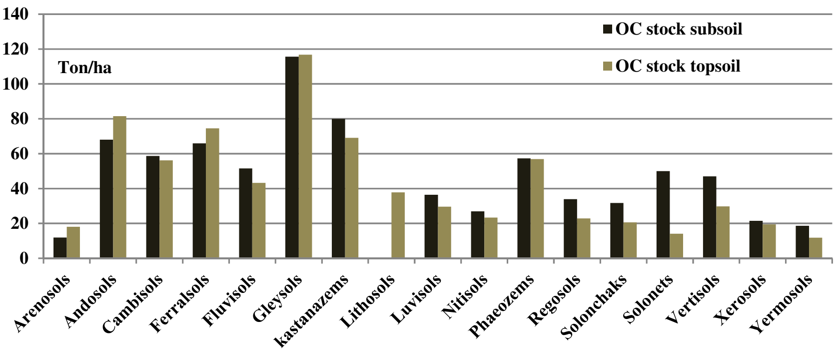

Fig. 3 OC stock in the major soil groups of the Arab countries. Compiled based on soil information from the DSMW, FAO 2007

(DSMW) and its attribute database (FAO 2007). However, the choice of scales when using soil maps to estimate national or regional SOC may lead to uncertainty (Darwish et al. 2012). In the absence of more detailed, accessible, regional, and national soil databases, the DSMW at 1:5 million scale (FAO 2007) was used in this study to produce the national and regional soil OC stock map. Despite the possible uncertainty related to the scale of mapping, the DSMW presents overview soil information based on 1700 soil profiles analyzed and grouped by FAO Soil Unit. Soil classification was based on horizon designation, depth, texture, slope gradient, and soil physico-chemical and chemical properties. Statistical (weighted) average was calculated for the topsoil (0–30 cm) and for the subsoil (30–100 cm) for the full series of chemical and physical parameters sufficient to assess main agricultural soil properties. To fill the gap in some attributes and complete the fields for which no data were available, an expert opinion internationally known soil scientists were used by FAO.

A comparison of results was made with the only available national OC stock map extracted from the soil database at 1:50,000 scale (Darwish et al. 2006). Both databases contain digital information on soil type geographic, physical, and physico-chemical characteristics, like area, perimeter, horizon depth, OC content, and bulk density, among others.

Arc Map 10.1 was used for the geometric mapping of soil types and OC stock. The calculation of OC stock (tons) and density (ton ha$^{-1)}$ in the upper topsoil (0–0.3 m) and subsoil (0.3–1.0 m), retrieved from the soil attribute table, was done using the equations implemented in Mu noz-Rojas et al. 2012:

$$\mathrm{OC}\ \mathit{Stock}\ (\mathrm{ton}) = \begin{bmatrix} \mathit{Soil\ Area}\ (\mathrm{m}^2) \times \mathit{Soil\ Depth}\ (\mathrm{m}) \\ \times\ \mathit{Bulk\ Density} \times \mathrm{OC}\ \mathit{content}\ (\%) \end{bmatrix} / 100 \qquad (1)$$

$$\mathrm{OC}\ \mathit{Density}\ \mathrm{ton\ ha}^{-1} = \mathrm{OC}\ \mathit{Stock\ of\ given\ soil\ unit}\ (\mathrm{ton}) / \mathit{Soil\ Area}\ (\mathrm{ha}) \qquad (2)$$

The model of soil water erosion risk considered four major soil geomorphological and physico-chemical parameters (slope, depth, texture, and organic matter content) according to Eq. 3, inspired from the work of Boukheir et al. 2006:

$$\begin{aligned} \mathit{Soil\ erosion\ risk} &= [\mathit{slope\ rate} \times \mathit{slope\ weight}\ (0.30)] \\ &\quad \times [\mathit{soil\ depth\ rate} \times \mathit{soil\ depth\ weight}\ (0.25)] \\ &\quad \times [\mathit{texture\ rate} \times \mathit{texture\ weight}\ 0.20] \\ &\quad \times [\mathrm{OM}\ \mathit{rate} \times \mathrm{OM}\ \mathit{weight}\ (0.25)]. \end{aligned} \qquad (3)$$

To count the OC loss by urban expansion, land capability model proposed by USDA 1999, which considers the soil geomorphological features (geology, topography, and slope gradient), soil parameters like the soil depth, texture, organic matter content, salinity, and sodicity hazards, was adopted. The soils of the Arab world were classified into five classes, the first four are arable: class I (highly productive), class II (medium productive), class III (low productivity), and class IV (very low productivity), and the fifth soil class was classified as non-arable (class V), where lands characterized by wild vegetation and rock outcrops suitable only for recreation were grouped.

Raster images downloaded from JRC Open Data repository[1] were used to estimate the urban expansion between 1990 and 2015 in the Arab world. JRC Open Data repository data packages contain an assessment of the REGIOOECD "degree of urbanization" model using as input of the population GRID cells in 2015 and 1990. Each grid has been generated by integration of built-up areas produced from Landsat image, and population data derived from the Center for International Earth Science Information Network, Gridded Population of the World (CIESIN GPW v4).

Raster images of the years 1990 and 2015 were processed using ArcGIS (commercial software by ESRI). Treated images were converted to vector data that contain attribute data about urban area for further comparison and estimation of urban expansion in the Arab countries.

[1] http://ghsl.jrc.ec.europa.eu/ghs_smod.php

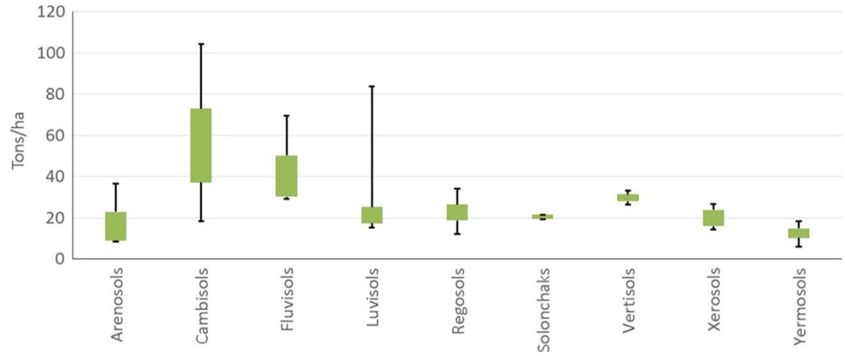

Fig. 4 Variability of OC stock in the upper soil layer (0.3 m) in the Arab countries

Results and discussion

Major soil groups

A total of 17 major soil groups and 66 soil units were identified for the Arab countries (FAO 2007). The identified major soil groups are yermosols, lithosols, regosols, arenosols, xerosols, cambisols, fluvisols, luvisols, solonchaks, solonets, andosols, vertisols, ferralsols, gleysols, kastanazems, and anthrosols. The total area of the arable soils in the Arab region is 11.6 million SQM (Fig. 1). The most abundant major soil group is yermosols with an area of 5.1 million SQM representing 44.5% of the soil cover in the Arab countries. This major soil group is characterized by low natural fertility and is found in several units: as gypsic, salic, luvic, calcic, and sodic yermosols.

The second most abundant major soil group in the Arab countries is lithosols followed by regosols having 2.3 and 1.05 million SQM, representing 20.5 and 9.0%, respectively. Arenosols and xerosols have almost equal area of 0.7 million SQM corresponding to 6.0%. The area of remaining major soil groups varies in increased order from 0.25 million SQM to 0.32 million SQM for andosols and fluvisols, respectively.

OC stock in Arab countries

Beside erosion and chaotic urban expansion, salinity represents one of the major threats to soil quality in the Arab countries. The area of major soil units affected by salinity and sodicity is equivalent to 0.3 million SQM, i.e., 2.5% of the total Arabic cultivated lands. Attribute data extracted from the FAO soil database (FAO 2007) revealed that the soil units ferralsols, andosols, kastanozems, and gleysols as the most enriched with OC both in the topsoil (0.3 m) and whole soil profile (1 m).

The OC stock throughout the whole soil profile varies from 69 and 140 ton ha^{-1} to 117 and 232 ton ha^{-1} in the topsoil and entire active soil profile, respectively (Fig. 2a, b). C enrichment of these soil groups is preconditioned by geographic location and climate conditions favoring denser and richer vegetation cover and background native fertility.

Fluvisols, cambisols, and phaeozems occupy intermediate place in OC stock ranging between 43–95 ton ha^{-1} and 56–114 ton ha^{-1} for the topsoil and entire soil, respectively (Fig. 3). These soils are affected by their nature, the origin of sediments, and history of agricultural practices.

Large standard deviation in average values of OC accumulation was observed in the topsoil of the Arab countries (Fig. 4). Such output points to human effect on soil quality through different practices in heterogeneous land use patterns and management systems. In fact, luvisols, cambisols, and fluvisols are traditionally the most cultivated lands, continuously subject to intensive human pressure.

The assessment of the total soil OC stock in the superficial soil profile (1 m) revealed the dominance of soils with poor and moderate OC enrichment with more than 83% of the of

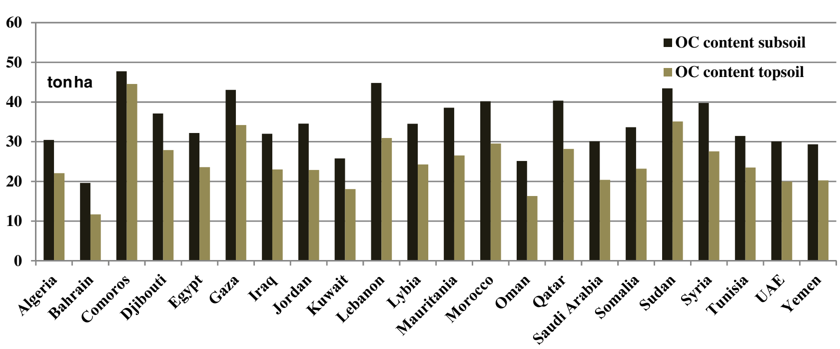

Fig. 5 OC stock in the Arab countries. Compiled based on soil information from the DSMW, (FAO 2007)

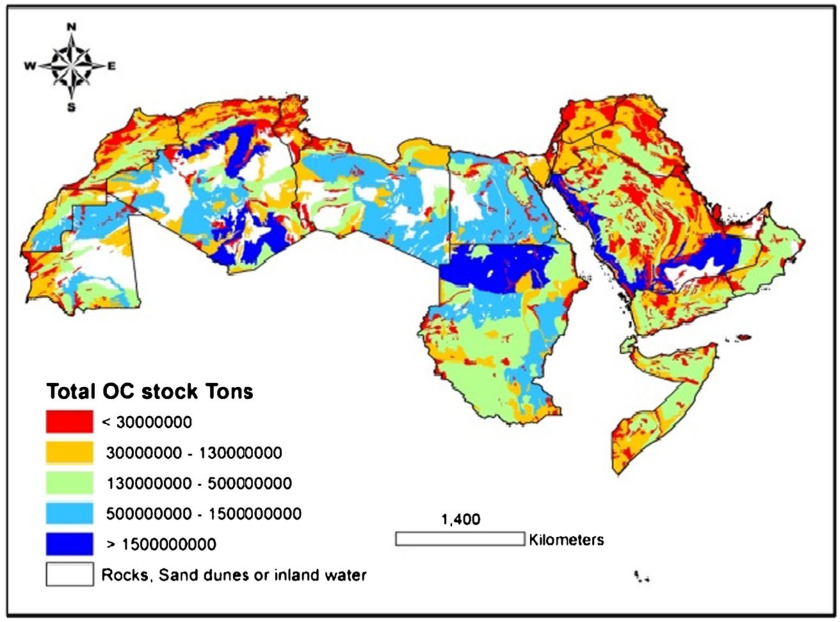

Fig. 6 Spatial distribution of total OC stock in the soils of the Arab countries

area of cultivated soil containing less than 60 ton ha^{-1} of total OC stock. These soils are in general lithosols, arenosols, regosols, solonchaks, saline, sodic, and gypsic soil units as well as rocky and stony versions of yermosols and xerosols with few representatives of luvisols, cambisols, and fluvisols.

Frequent tillage and restricted rotation of the soils of arid regions fastens the mineralization rate and restricts the accumulation of plant C into stable soil OC within the micro aggregates far from microbial activity (Batjes and Sombroek 1997), but, a recent study showed improved microbial metabolic activities in conservation tillage increased SOC in aggregates in the topsoil (Guo et al. 2016). At the national level, the lowest OC stock was observed in the Gulf countries, (Kuwait, UAE, Oman, Bahrain, Saudi Arabia), Yemen, and Somalia with a content varying between 11 and 57 tons ha^{-1} in the topsoil and entire soil profile, respectively (Fig. 5).

The assessment of the total soil OC stock in the entire soil profile to a depth of 1 m in the Arab countries revealed the dominance of soils with poor and moderate OC enrichment. Four Arab countries are placed on top concerning C sequestration and build up in the soil. These are Lebanon, Morocco, Sudan, and Comoros Islands with a soil OC stock varying between 30 and 92 ton ha^{-1} in the topsoil and entire soil, respectively. The geographic location and pedoclimatic conditions favor higher C sequestration in these countries despite the observed risk of soil water erosion. The Arab countries with intermediate range of OC stock are in increasing order Algeria, Djibouti, Egypt, Ghaza, Iraq, Jordan, Lybia, Mauritania, Qatar, Tunisia, and Syria with a soil OC stock varying between 20 ton ha^{-1} in the topsoil and 77 tons ha^{-1} in the entire soil (1 m).

Inadequate fertilizer application, frequent tillage, and removal of plant residues are the most frequent man-made causes of C loss from the soils (Batjes and Sombroek 1997). The soil groups yermosols, arenosols, lithosols, and xerosols contain the lowest C stock varying between 12–19 ton ha^{-1} for the lowest range and 30–40 ton ha^{-1} for the highest range. Long history of water and wind erosion affected the productivity of these soil groups, thus they require special management and anti-erosion measures.

The dominant part of the Arab countries represents semi-arid to arid climate with rare wetlands and ustic or udic soil moisture regime (Soil Survey Staff 2014). That is why 69% of the area of the cultivated soils has low OC stock not exceeding 30 ton ha^{-1}, considered by Batjes and Sombroek (1997) as threshold for poor soil OC content.

Due to their large geographic distribution, yermosols, lithosols, and regosols represent the major soil groups with the highest total OC stock reaching 16, 9, and 7 GT tons,

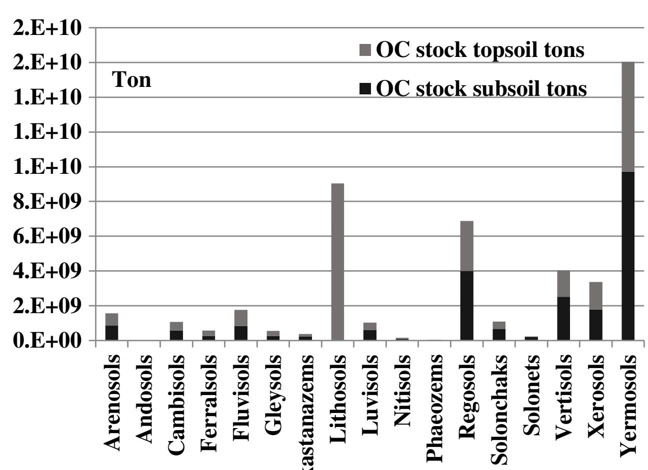

Fig. 7 Total OC stock in the soils of the Arab countries. Compiled based on soil information from the DSMW, FAO 2007

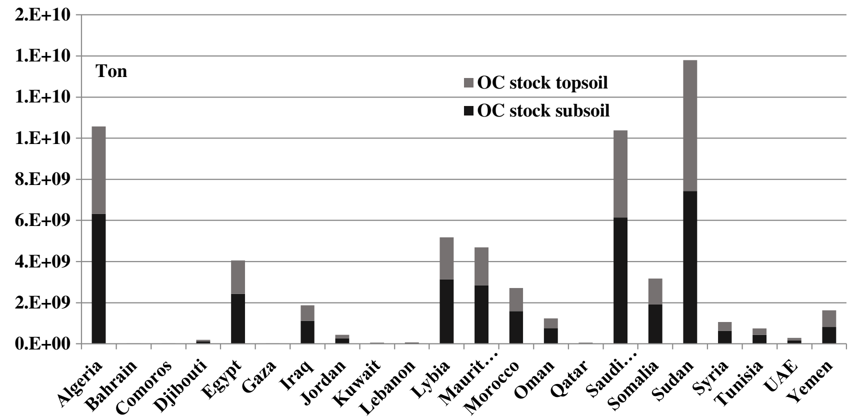

Fig. 8 Total OC stock in the Arab countries. Compiled based on soil information from the DSMW, FAO 2007

respectively (Figs. 6 and 7). Despite the high OC content in the soil, gleysols, fluvisols, and cambisols represent low total OC stock due to their restricted area. Despite their frequent occurrence, arenosols and xerosols represent the lowest OC storage which is affected by vegetation cover, soil texture, and arid climate. These soils belong to the arid soils groups with close OC budget to yermosols, solonchaks, and solonetz. This is in agreement with the findings of Minasny et al. (2017).

Because of their larger territory, Sudan, Algeria, and Saudi Arabia represent the Arab countries with the richest stock in total soil OC among the 22 Arab countries with a total stock varying between 14 and 10 GT tons, respectively (Fig. 8). Libya, Mauritania, Egypt, Somalia, and Morocco represent the intermediate group among Arab countries with a total OC stock ranging in decreasing order between 5 and 2.7 GT tons, respectively. Gulf countries represent the lowest total OC stock reaching as low as 53 thousand tons in Qatar.

Poor soil quality and the need to produce more food for increased population justify good soil management and conservation notably crop rotation, application of manure, and compost to improve C sequestration and hasten background soil productivity and resilience to drought. Similar good practices resulted in the improvement of C content in the soil after the sowing of legumes between the fruit trees (Darwish et al. 2012) and following the application of composted material including treated sludge (Atallah et al. 2011, 2012) in the semi-arid and dry sub-humid area of Lebanon. In the Arab world, the lowest OC storage was found in arenosols and xerosols despite their large area and frequent occurrence.

Potential soil water erosion

In the Arab countries, a total of 12.849,356 SQM is subject to different degree of potential soil water erosion. Two speculated scenarios of sheet soil erosion from arable lands were considered; in the worst case, annual erosion rates vary between 5 and 40 ton/ha/year depending on slope, soil type, land use, and rainfall intensity. In the best scenario with anti-erosion measures, this rate can be reduced by 50%. The average rate of soil erosion in the region from arable lands is 21 ton/ha/year. Under worse scenario, this rate can reach 40 ton/ha/year, and the total potential annual soil loss by water erosion in the region accounts for 25 GT tons with Algeria and Saudi Arabia on top (5.3 and 4.22 GT tons, respectively). Somalia, Mauritania, Libya, and Sudan can lose between 1.5 and 2.7 GT tons of soil annually (Fig. 9). The lowest annual soil loss by water erosion is detected in Bahrain (below 1 million tons), followed in increasing order by Comoros Islands, Qatar, Kuwait, and Lebanon.

The average estimated loss of OC in the Arab countries by soil water erosion is 112 kg/ha/year. The highest OC loss by potential soil water erosion is 35, 26, and 23 million tons for Algeria, Sudan, and Saudi Arabia, respectively. On the contrary, Bahrain and Kuwait represent the lowest total annual

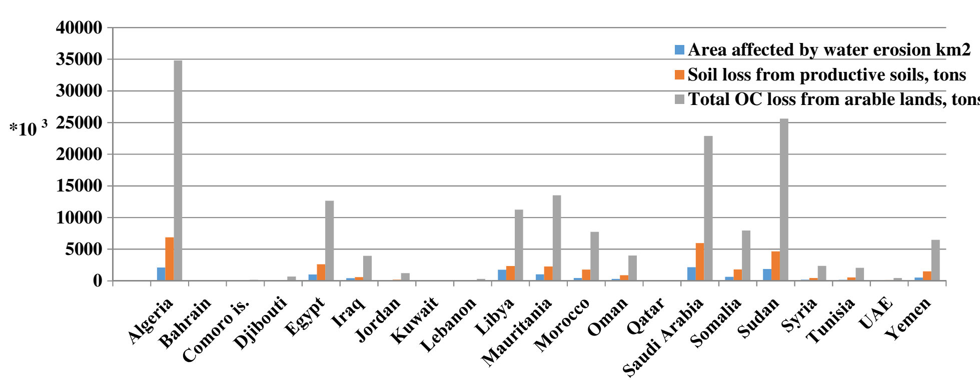

Fig. 9 Estimated soil degradation and nutrient loss by potential soil water erosion under worse scenario in the Arab countries (calculated from the adapted USDA model applied to soil information using the Digital Soil Map of the World (data source Land and Water Development Division, FAO, Rome, 2007))

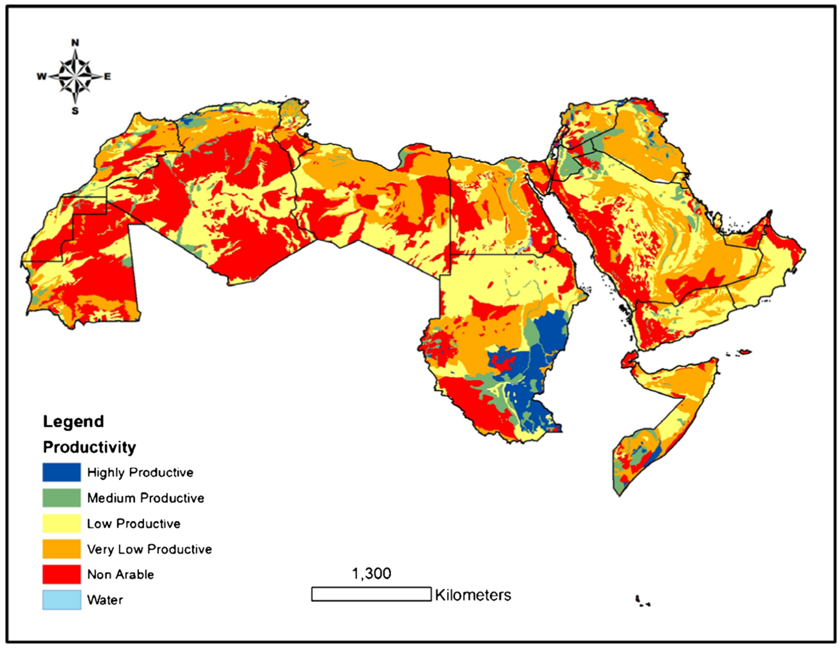

Fig. 10 Land capability in the Arab countries (SQM), (calculated from the adapted USDA model applied to soil information using the Digital Soil Map of the World (data source Land and Water Development Division, FAO, Rome, 2007 http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116)

organic carbon (OC) loss from the soil (5761 tons and 81,938 tons/ha, respectively).

Land capability in the Arab countries

The produced map in GIS revealed the quasi absence of very high productive soils and limited occurrence of highly productive soils (2.2% of total territory) in the Arab countries (Figs. 10 and 11). The proportion of highly productive soils in the Arab countries from the total land area is restricted in decreasing order to Sudan (17.19%), Palestine and Lebanon (9.41 and 10.14%, respectively), Syria (5.05%), Somalia (3.65%), and Iraq (1.59%). The proportion of medium productive soils represents 7.5% of the total land area. More than 91% of the Arabic soils are low (33.5%), very low (26.5%), and non-arable soils (30.1%).

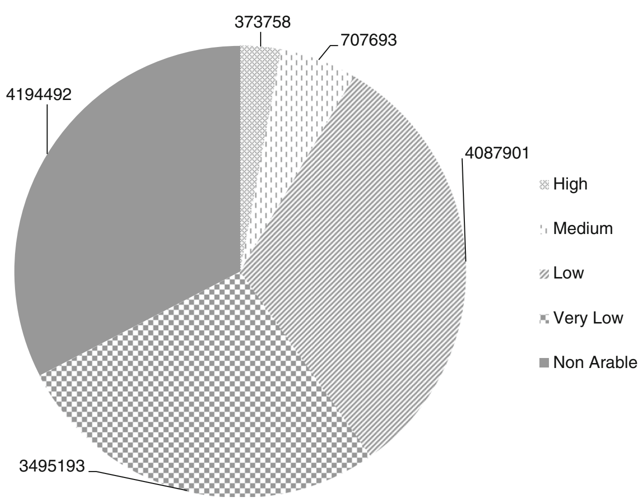

Fig. 11 Distribution of land capability classes in the Arab countries

Urban sprawl on productive lands

The chaotic urban expansion was observed on highly and moderately productive lands (Fig. 12), notably in Jordan (91.5%), Sudan (72.8%), Egypt (36%), and Syria (25.2%). A total of 14% of urban expansion in Palestine occurred on the account of highly productive soils versus average values ranging between 9% (Algeria), 8% (Somalia and Sudan), 4% (Lebanon, Syria, and Iraq), and 0.3% (Jordan).

In many cases, the excavated soil material for the construction of human settlements is not associated with the reuse of the soil material. The removed soil material is often left aside or used to coat the open solid waste dumping sites which undergo burning or they are subject to erosion to end up in open water bodies and seas. In some cases, the soil material is sold to other farmers to terrace mountain or marginal lands. In any case, urban expansion on productive arable lands damages agricultural production, fragment landscape and affects soil ecosystem functions.

The estimated total OC loss by urban expansion on prime lands in the Arab countries between 1995 and 2015 exceeded 53 Million tons, 16% of which is relevant to the loss of prime soils (Table 1). Around 30% of OC loss in the Arab countries is derived from Egypt whose delta and river banks witnessed intensive urbanization during the last two decades. Iraq, Jordan, Saudi Arabia, and Syria represent the group with OC loss by urban expansion varying between 12 and 7.5% from

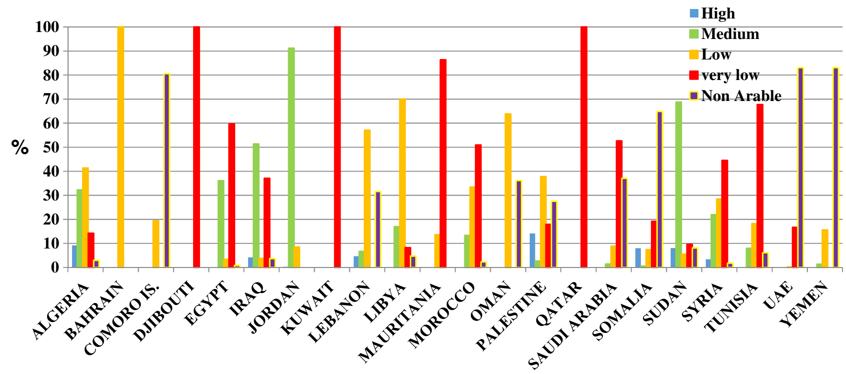

Fig. 12 Urban sprawl on productive lands calculated from the urban layer and based on soil information adapted from the DSMW, 2007 (source Land and Water Development Division, FAO, Rome)

total loss, respectively. It is obvious that these OC losses are irreversible and result in erosion-sedimentation and transportation of C and other nutrients to wadis and surface water bodies and end in the Mediterranean Sea causing eutrophication of aquatic ecosystems.

Precision of used soil database

The OC stock in Lebanese soils was mapped and determined for each soil unit considering the geomorphological and climatic characteristics of the great soil groups from the digital soil map of Lebanon at 1:50,000 scale (Darwish et al. 2006). Results are shown in fig. 13a, b, Table 2 for the first top horizon (0.3 m) and for the top three horizons (1 m).

The total amount of SOC in ton for the upper 30 cm and for the top three horizons is about 38,047,122 and 83,184,528 tons, respectively for the Lebanese territories; a spatial representation of the SOC is exposed in Figs. 3 and 4 for both depths.

To test the precision of the used soil database, a comparison between the number of identified major soil groups in recent large-scale soil information at 1:50,000 scale (Darwish et al. 2006, 2009) and in the small-scale soil information derived from the DSMW (1:5 million) was performed.

Results showed the comparable number of identified major soil groups of 13 versus 17 major soil groups in the first and

Table 1 Total irreversible OC loss of nutrient from soil sealed by urban expansion (tons)

Country	High	Medium	Low	Very low	Total
Algeria	17,988	525,710	2,875,791	337,021	3,756,511
Bahrain	0	0	1,401,361	0	1,401,361
Comoro Is.	0	0	19,280	0	19,280
Djibouti	0	0	0	7552	7552
Egypt	0	1	837,484	17,225,959	18,063,444
Iraq	19,299	1,711,204	64,329	5,035,435	6,830,268
Jordan	0	4,012,545	68,255	0	4,080,799
Kuwait	0	0	0	1,520,124	1,520,124
Lebanon	24,900	9376	642,694	0	676,969
Libya	0	15,216	1,276,640	194,634	1,486,489
Mauritania	0	0	17,208	109,807	127,014
Morocco	0	9712	521,331	1,039,607	1,570,650
Oman	0	0	545,938	0	545,938
Ghaza	0	0	0	16,807	16,807
Qatar	0	0	0	334,991	334,991
Saudi Arabia	0	20,166	740,835	3,889,044	4,650,046
Somalia	26,389	4401	95,376	597,435	723,601
Sudan	274,295	1,107,452	225,053	246,664	1,853,464
Syria	338,126	464,270	1,150,941	1,981,135	3,934,471
Tunisia	0	64,131	246,322	2	310,455
UAE	0	0	1033	454,967	455,999
Yemen	0	4609	1,268,727	0	1,273,336
Total	700,997	7,948,794	11,998,595	32,991,183	53,639,569

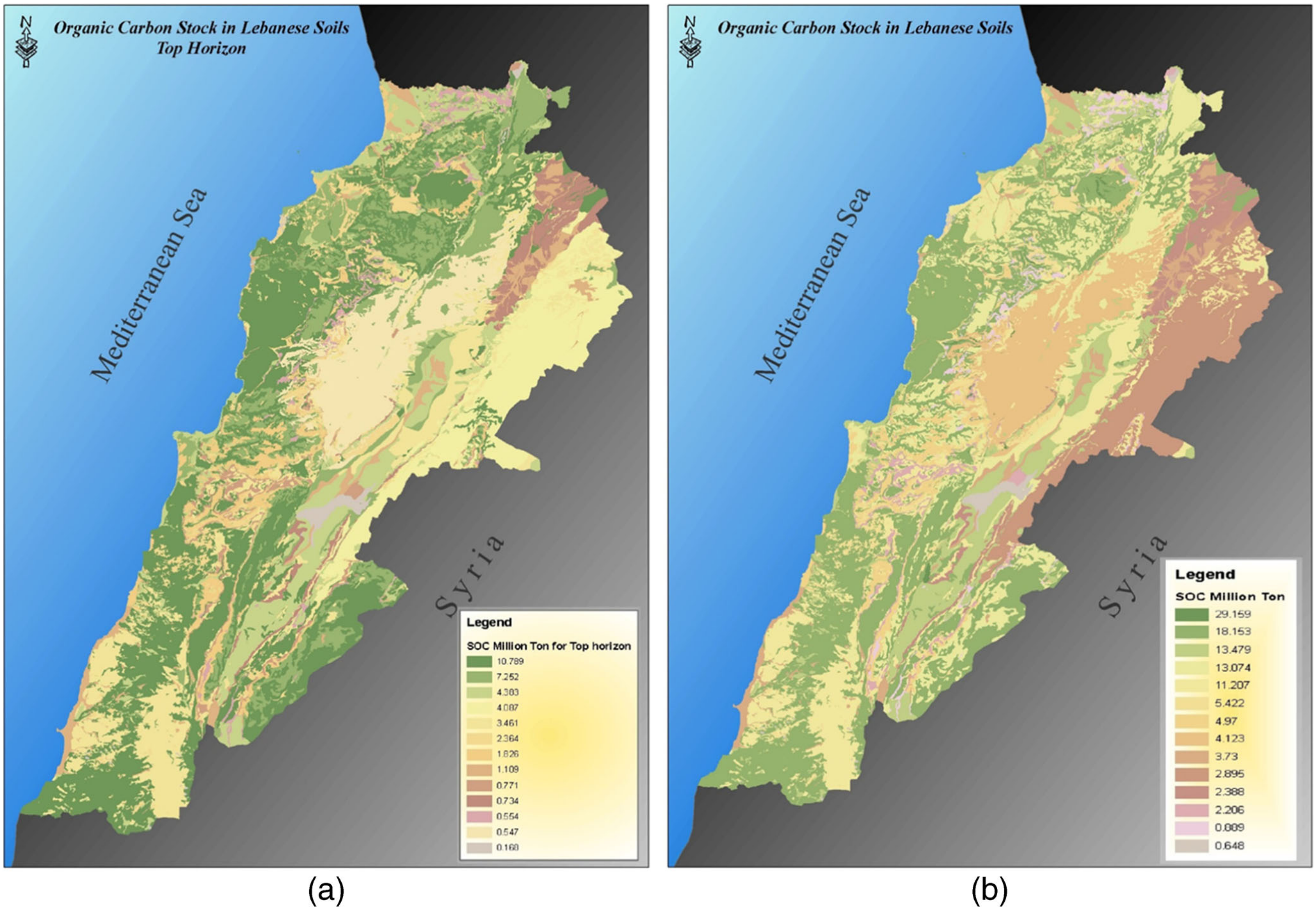

Fig. 13 Spatial distribution of soil OC density in (**a**) first top horizon (0.3 m) and (**b**) top three horizons (1 m)

second soil classification, respectively. Topsoil OC stock was assessed for Lebanon using both soil information and indicated close total OC stock for the topsoil in both results (38,047.122 tons compared to 42,845,404 tons) representing 11% overestimation in the FAO soil data. Comparing the total soil OC stock in the entire soil profile

Table 2 Soil organic carbon stock in the Lebanese soils

Great soil group	*N* of profiles	Area, km^2	Mean OC content (ton ha-1) Topsoil (0.3 m)	SD	Total, ton	Mean OC content (ton ha^{-1}) Soil profile (1 m)	SD	Total, ton
AN	7	158	35	16	554,088	56.24	24.66	889,323
AR	7	372	49	40	1,826,373	133.62	90.11	4,970,263
AT	13	427	55	37	2,364,494	127.09	86.29	5,422,295
CL	11	321	23	21	734,195	74.36	59.16	2,388,220
CM	33	972	45	32	4,383,359	138.68	83.38	13,478,587
FL	21	354	31	24	1,109,485	105.42	80.94	3,729,654
GL	7	166	46	52	771,036	132.8	131.85	2,205,808
LP	28	2978	36	50	10,788,895	60.96	36.81	18,153,217
LP East Mountain	3	977	42	26	4,087,391	29.63	14.04	2,894,584
LP Middle Mountain	1	857	6	1	546,811	48.11	1	4,123,364
LV	22	1329	55	81	7,252,481	98.39	83.32	13,073,866
RG	21	1194	29	25	3,460,855	93.88	58	11,207,488
VR	9	73	23	17	167,659	88.18	40.54	647,858
Total	183	10,178	–	–	38,047,123	–		83,184,528,67

in the country showed an underestimation by the FAO soil database of 14% (72,686,080 million tons versus 83,184,528 tons).

This difference is due to the adopted in the FAO database lower values of OC content in the topsoil (31 versus 37 ton/ha) and notably in the subsoil (75 versus 91 ton/ha) for the two soil databases, respectively. Changes in soil classification systems require the updating of both geometric and attribute database of the DSMW.

Conclusions

Estimation of soil OC stock in the Arab countries using the small-scale soil database of the DSMW showed acceptable results for the regional assessment. Alarming figures regarding the low OC stock were found in more than 80% of the area of the studied soil groups. Poor soil quality can affect soil productivity and resilience to drought and erosion. Enormous standard variation values of soil OC stock within the major soil groups were found in intensively managed arable soils indicating human pressure and impact on CO2 emission. In the frame of poor awareness on the role of OC in soil and ecosystem functions, attention must be paid to awareness rising to improve policies and practices oriented to increase C sequestration and meet the sustainable development goals. Although the used information is based on small-scale soil mapping, the results showing the regional and national OC stock in the Arab countries is just a beginning. It must be complemented by a new assessment based on the grid sampling (1-km resolution) for the production of higher resolution OC map of the world, which is currently under compilation by the FAO Global Soil Partnership and Intergovernmental Technical Panned on Soils. The results of this paper can represent a first regional technical framework for decision makers and awareness platform for land users to contribute to the joint efforts to improve regional and national carbon budget in the Arab countries.

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Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflict of interest.

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