

Challenges of soil carbon sequestration in NENA Region

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Abstract

The Near East North Africa (NENA) region spans over 14% of the total surface of the Earth and hosts 10% of its population. Soils of the NENA region are mostly highly vulnerable to degradation, and food security will depend much on sustainable agricultural measures. Weather variability, drought and depleting vegetation are dominant causes of the decline in soil organic carbon (SOC). In this work the ~~situation-status~~ of SOC was studied, using a land capability model and soil mapping. The land capability model showed that most NENA countries (17 out of 20), suffer from low productive lands (>80%). Stocks of SOC were mapped (1:5 Million) in topsoils (0-30 cm) and subsoils (30-100 cm). The maps showed that 69% of soil resources present a stock of SOC below the threshold of 30 tons ha⁻¹. The stocks varied between ≈ 10 tons ha⁻¹ in shrublands and 60 tons ha⁻¹ for evergreen forests. Highest stocks were found in forests, irrigated crops, mixed orchards and saline flooded vegetation. The stocks of [soil inorganic carbon \(SIC\)](#) were higher than those of SOC. -In subsoils, the SIC ranged between 25 and 450 tons ha⁻¹, against 20 to 45 tons ha⁻¹ for SOC. **This paper also highlights the modest contribution of NENA region to global SOC stock in the topsoil not exceeding 4.1%.** The paper also discusses agricultural practices that are favorable to carbon sequestration. [Practices of conservation agriculture](#) **Organic amendment, no till or minimum tillage, crop rotation, mulching** could be effective, as the presence of soil cover reduces ~~the~~ evaporation, water and wind **erosions**. Further, the introduction of legumes, as part of a cereal-legume rotation, and the application of nitrogen fertilizers to the cereal, caused a notable increase of SOC after 10 years. The effects of crop rotations on SOC are related to the amounts of above and belowground biomass produced and retained in the system. Some knowledge gaps **exists** especially in aspects related to the [impact of climate change and](#) effect of irrigation on SOC, and on SIC at the level of soil profile and soil landscape. Still, major constraints facing soil carbon sequestration are policy relevant and socio-economic in nature, rather than scientific.

Keywords: Drylands, soil organic carbon, soil inorganic carbon, land capability, C stock, conservation practices.

1. Introduction

The Near East North Africa (NENA) region spans over 14% of the total surface of the Earth and hosts 10% of its population (Elhadi, 2005). The largest importer of wheat in the world, this region is also one of the poorer (FAO, 2015). A recent assessment of global hunger index (GHI), based on four indicators -undernourishment, child wasting, child stunting, and child mortality- showed that most of the NENA countries present low to moderate GHI. Countries suffering from armed conflicts, Syria, Iraq and Yemen, are at a

48 serious risk (von Grebmer et al., 2017). With the scarce natural resources and difficult
49 socio-economic conditions, it is questionable whether food security will be reached by
50 2030, unless a significant change in agricultural practices and governance occurs (FAO,
51 2017).

52
53 Most of the land area of the NENA region falls in the hyper-arid, arid and semi-
54 arid climatic zones. Climate change is expected to exacerbate the scarcity of water and
55 drought effect. Weather variability, drought and depleting vegetation are major concerns
56 in the loss of soil productivity and agricultural sustainability. **Instabilities in SOC** can
57 affect the **density** of greenhouse gases in the atmosphere and **negatively affect the global**
58 **climate change** (Lal, 2003). In fact, destructive land management practices are impacting
59 soil functions. Land use change, mono-cropping and frequent tillage are considered to
60 cause a rapid loss of SOC (Guo et al., 2016). These agricultural practices disrupt the
61 **stability of inherited soil characteristics**, built under local land cover and climate (Bhokal
62 et al. 2008). Thus, most NENA lands contain ~1 % of SOC, and frequently less than
63 0.5%.

64
65 **Despite the constraints of NENA pedo-climatic conditions, increasing SOC levels**
66 **is critical and challenging** (Atallah et al., 2015). To maintain soil productivity and land
67 quality, several technical and socio-economic measures need to be adopted. Additional
68 efforts oriented to maintaining and increasing SOC, can contribute to poverty reduction
69 and achieve food security (Plaza-Bonilla et al., 2015). Good agricultural practices, based
70 on low tillage or no tillage, may result in the reduction of SOC breakdown and the
71 enhancement of the soil carbon pool (Atallah et al., 2012; Cerdá et al., 2012;
72 Boukhoudoud et al., 2016).

73
74 Quantifying SOC content in the NENA countries using available soil data is
75 crucial, **even at a small scale**, to assess the nature and potential of available soil resources
76 and analyze the **associated threats**. **Mapping** the spatial distributions of national and
77 regional OC stocks can be **used to monitor and model** regional and global C cycles under
78 different scenarios of soil degradation and climate change. Accurately quantifying SOC
79 stocks in soils and monitoring their changes are considered essential to assessing the state
80 of land degradation. At the same time, the predominantly calcareous soils of NENA region
81 are rich in soil inorganic carbon (SIC). The dynamics of SIC and its potential in

82 sequestering carbon in soils **remain** largely unknown and as such deserves thorough
83 investigation. This paper analyzes the state of SOC and SIC in NENA countries and
84 outlines challenges and barriers for devising organic carbon sequestration in NENA's
85 impoverished and depleted soils. It also highlights several questions which scientists need
86 to resolve. Finally, it discusses practical agricultural measures to promote SOC
87 sequestration.

88 2. Materials and Methods

89 Data on SOC and soil inorganic carbon (SIC) contents in soils of the NENA region
90 were retrieved from the soil database of the FAO-UNESCO digital soil map of the world
91 (DSMW) at 1:5 Million. The database contains ~~large number of~~ 1700 georeferenced soil
92 profiles collected and harmonized from each member state. These were excavated,
93 sampled by horizon, down to the rock, and analyzed in the laboratory according to the
94 **standard world accepted methods** (FAO, 2007). The soil map was prepared using the
95 topographic map series of the American Geographical Society of New York, as a base, at a
96 nominal scale of 1:5,000,000. Country boundaries were checked and adjusted using the
97 FAO-UNESCO Soil Map of the World, on the basis of FAO and UN conventions. Soil
98 classification was based on horizon designation, depth, texture, **slope gradient** and soil
99 **physico-chemical and chemical** properties. Statistical (weighted) average was calculated
100 for the topsoil (0-30 cm) and for the subsoil (30-100 cm) for the full series of chemical and
101 physical parameters sufficient to assess main agricultural soil properties. To fill the gap in
102 some attributes and complete the fields for which no data were available, **an expert**
103 **opinion internationally known soil scientists** was used.

104
105
106 Using the DSMW and its updated attribute database maps of the SOC and SIC stock and
107 distribution in 20 NENA states were produced. ~~The scale used in the DSMW is 1:5~~
108 ~~Million~~ (FAO, 2007). ~~The soil map was prepared using the topographic map series of the~~
109 ~~American Geographical Society of New York, as a base, at a nominal scale of~~
110 ~~1:5,000,000. Country boundaries were checked and adjusted using the FAO-UNESCO~~
111 ~~Soil Map of the World, on the basis of FAO and UN conventions. To produce the maps~~
112 representing the spatial distribution of SOC and SIC, ArcMap 10.3 was used to **join the**
113 **symbolology of the C stocks and density** with quantities classified into five numerical
114 categories with natural breaks. The **global LC** maps at 300 m spatial resolution on an
115 annual basis from 1992 to 2015 **was** produced by ESA. The Coordinate Reference System

116 | [used is a geographic coordinate system based on the World Geodetic System 84 \(WGS84\)](#)
 117 | [reference ellipsoid. \(The legend assigned to the global LC map has been defined\) using the](#)
 118 | [UN-Land Cover Classification System.](#)

119 |
 120 | The SOC content in studied soils varied between values as low as 0.13% and
 121 | 0.16% and as high as 1.74% and 0.9% in topsoils and subsoils of Yermosols (Aridisols)
 122 | and Rendzinas (Mollisols) respectively (Table 1). [Worth noting that](#) less than 20% of soil
 123 | resources in NENA region have sequestered and accumulated SOC to an [extend](#) exceeding
 124 | 1.0%. The highest SIC was observed in Solonchaks, Rendzinas and Aridisols that can be
 125 | explained by the effect of the dominant calcareous rocks. The lowest SIC is detected in
 126 | Lithosols and Xerosols subject to regular water and wind erosion removing the surface
 127 | layer from eroded lands. The largest soil units are Yermosols (4670.6 Km²), Lithosols
 128 | (2914.3 Km²) and Regosols (1193.2 Km²). The first two soil classes and Xerosols (498.5
 129 | Km²) [are low resilient resistant](#) to erosion and degradation. The most vulnerable to
 130 | degradation soils are Solonchacks, Solonetz and Arenosols. Camboisosl, Fluvisols and
 131 | Regosols possess high [resilien resistance](#) to erosion.

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 133 |

134 | Table 1. [Soil organic carbonOC](#) and [soil Sinorganic ICcarbon](#) level in the major soil units
 135 | of [Near East North Africa](#) region*

Soil Type	Area, 1000 Km ²	ResilienceResistance to Land Degradation	SOC content, %		SIC content, %	
			topsoil	subsoil	topsoil	subsoil
Cambisols	178.9	Highly resilient	0.90	0.48	0.25	0.64
Fluvisols	232.7	Highly resilient	0.65	0.24	1.12	1.40
Kastanozems	26.0	Highly resilient	1.50	1.00	1.69	3.96
Regosols	1193.2	Highly resilient	0.76	0.41	1.18	0.23
Luvisols	121.6	Moderately resilient	0.63	0.35	0.02	0.11
Phaeozems	3.8	Moderately resilient	1.46	0.63	0.40	0.70
Rendzinas	25.6	Low resilience	1.74	0.90	2.80	4.80
Lithosols	2914.3	Low resilience	0.97	0.40	0.01	0.06
Vertisols	45.4	Low resilience	0.69	0.52	0.45	0.72
Xerosols	498.5	Low resilience	0.36	0.25	0.25	0.45
Yermasols (Aridisols)	4670.6	Low resilience	0.13	0.16	2.50	2.30
Solonchaks	230.1	Very Low-low resilience	0.49	0.36	3.60	3.90
Solonetz	31.2	Very Low-low resilience	0.65	0.48	0.06	0.36
Arenosols	384.0	Very Low-low resilience	0.87	0.10	0.00	0.00

136 | *Source: DSMW, FAO, 2007

137 |

138 To assess the potential soil productivity in the NENA region, a land capability
139 model proposed by USDA (1999), which includes the soil geomorphological features
140 (geology and topography), other soil **physic**-chemical parameters **conditioning** soil fertility
141 like soil depth, texture, organic matter content, salinity and sodicity hazards was adopted.
142 The soils of the area were classified into four classes of arable soils: class I (highly
143 productive), class II (medium productive), class III (low productivity) and class IV (very
144 low productivity) and **one non-arable soil class V, where lands suitable for wild vegetation**
145 **and recreation and lands with rock outcrops** were grouped.

146

147 Arc Map 10.1 was used for the mapping of soil types and OC stock and density of
148 each soil unit based on the **geographic or spatial** distribution of the soil type. **Total SOC**
149 **stocks and the stock of SOC** were calculated separately for the topsoil (0-0.3m) and
150 subsoil (0.3-1.0m) using the following equations:

151

152 Total **OC Stock** (ton) = [Area (m²)*Depth (m)*Bulk Density (ton m³)*OC content (%)]/100
153 equation 1

154

155 **Stock SOC** (ton ha⁻¹) = Stock **in** given soil unit (ton)/Soil **Unit** Area (ha) equation 2

156

157 The stocks of SOC under different land cover/land use were evaluated, as well.
158 Since 1990, the European Space Agency, (Climate Change Initiative project), started to
159 produce land cover (LC) maps of the NENA region. The version used in the study
160 (Website 1) corresponds to the second phase of the 2015 global LC. These maps have
161 300m of spatial resolution, using the Coordinate Reference System (CRS) in a geographic
162 coordinate system (GCS) based on the World Geodetic System 84 (WGS84) reference
163 ellipsoid. **The legend assigned to the global LC map has been defined** using the UN-
164 LCCS.

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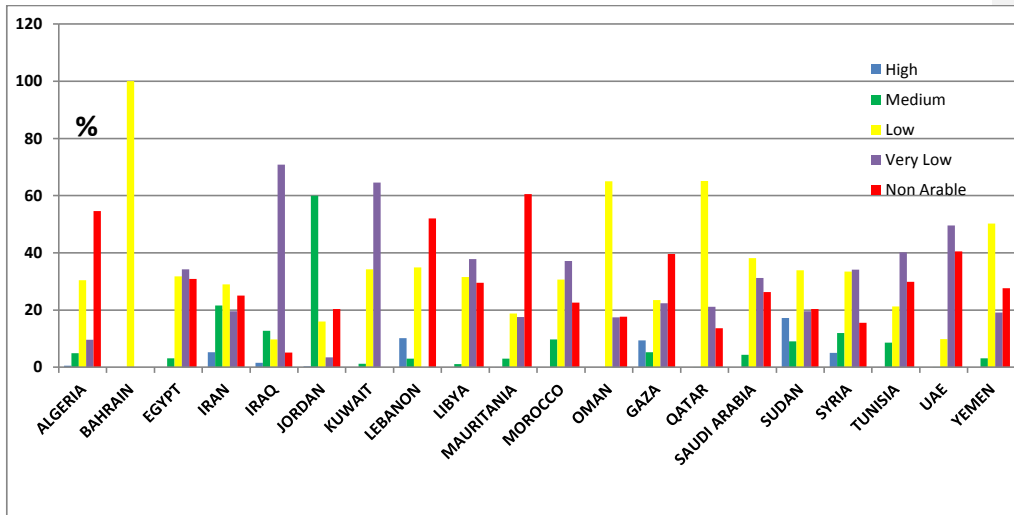
166 3. Results and Discussion

167 3.1. Land capability and SOC in NENA region

168 The most abundant soil classes in the NENA region are Arenosols, Xerosols and
169 Aridisols representing together more than 80% of available soil resources (FAO, 2007).

170 All three soil classes have low **resilienee resistance** to degradation (Table 1). According to
171 the model of land capability, **showing the proportion (%) of different soil -productivity**
172 **classes in each country of NENA region**, the majority of soils (40 to 100%) **belongs** to the
173 low, very low and non-arable classes (Figure 1).





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Figure 1. Land capability classification for the countries of NENA region, based on [USDA Model \(1999\)](#) and [DSMW, FAO, 2007](#).

179 Thus, the proportion of highly and medium productive soils varies between 0%
180 (Bahrain, Qatar, Oman and UAE) and 60% (Jordan). Countries like Iraq, Lebanon,
181 Morocco, Palestine, Somalia, Syria and Tunisia present between 9 and 20% of highly to
182 medium productive soils. The rest of NENA countries have less than 5% of their lands as
183 high and medium productive soils. Some of these countries belong to the **seriously**
184 **endangered** and food insecure nations.

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The potential medium productivity concept is based strictly on soil properties. But, with lack of water in drylands and prevalence of rainfed agriculture, the soil cannot show its full potential for food production. Similarly, irrigation with brackish and saline water restricts crop productivity due to the development of secondary soil salinity. When properly irrigated, the medium productive lands can provide moderately good harvests. For instance, our field observation in Jordan showed that due to climate change and climate variability, a large area of good lands was cropped with barley not because of land suitability but due to low rainfall (<200mm). In drought affected years, the land is converted into grazing area for small ruminants to make the minimal profit from the exploitation. The presence of kaolinite in red soils of Jordan developed from hard limestone under semi-arid climate points to the inheritance of material formed under more aggressive climate (Kusus and Ryan, 1985). The same was confirmed by Lucke et al.

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198 | [2013 for Red Mediterranean Soils of Jordan, which require new insights in their origin,](#)
199 | [genesis and role as a source of information on paleoenvironment.](#)

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201 The low productivity of the soil is reflected in the SOC contents. Two out of the
202 three predominant soil classes (Xerosols and Aridisols) have SOC contents below 0.5%
203 (Table 1). Overall, the NENA soils are poor in SOC, as less than 20% of soil resources
204 have SOC contents exceeding 1.0%. The accumulation of SOC in NENA region is
205 refrained by the high mineralization rate (Bosco et al., 2012). Climate change and
206 recurrent drought events affect SOC sequestration in the soil. It is estimated that a rise in
207 temperature of 3 °C would increase the emission of carbon dioxide by 8% (Sharma et al.,
208 2012). Among the soil properties affecting SOC, the clay and calcium carbonate contents
209 are most relevant. **Clay** fraction tends to counteract the decomposition of SOC, as found in
210 clay soils of Morocco and in Vertisols of northern Syria (FAO and ITPS, 2015). But the
211 dominant soil classes, Xerosols, Aridisols or Arenosols (Table 1) characterized by sandy
212 and sandy loam textures, are subject to fast decomposition.

213 Next to the clay texture, the presence of calcium carbonate decreased the
214 decomposition of composted organic material in sub-humid coastal Lebanon (Al Chami et
215 al., 2016). This slower turnover of organic matter was explained by the low porosity and
216 prevalence of micropores in soil macro-aggregates (Fernández-Ugalde et al., 2014). For
217 the SIC, the highest values are found in soil classes dominated by calcareous rocks, that is
218 the Solonchaks, Rendzinas and Aridisols (Table 1). The lowest stocks were detected in
219 Lithosols and Xerosols, subject to water and wind erosions that remove the surface layer
220 of eroded lands.

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222 3.2. Mapping of soil carbon stocks in the soils of NENA region

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224 | [The choice of scale when using or producing soil maps to show the spatial](#)
225 | [distribution and estimate national or regional C stock and density may lead to uncertainty](#)
226 | [in small countries and fragmented landuse \(Darwish et al. 2009\). In the absence of more](#)
227 | [detailed, accessible, regional and national soil databases, the use of **small scale** maps is](#)
228 | [justified. Only in December 2017, the GSP-FAO, ITPS launched the version ~~0~~1.0 of the](#)
229 | [global soil organic carbon map, showing the SOC stock in topsoil \(\[http://www.fao.org/3/a-\]\(http://www.fao.org/3/a-i8195e.pdf\)](#)
230 | [i8195e.pdf\). An overview, reconnaissance carbon stock and density mapping for NENA](#)
231 | [region in topsoil and subsoil is justified **to preliminary assess** regional SOC stock both in](#)

232 [topsoil and subsoil and compare and analyze the common problems and challenges in C](#)
 233 [sequestration using unified background information provided by member states and](#)
 234 [harmonized in the FAO-UNESCO DSMW. The recent attempt undertaken in this paper](#)
 235 [was done despite the uncertainty associated with the scale of mapping where small scale](#)
 236 [maps join polygons having area below the smallest mappable unit, considered equivalent](#)
 237 [to or less than 0.5 cm x 0.5 cm area, i.e., 0.25cm^2, with the neighboring mappable soil](#)
 238 [polygons. Thus, the need for more detailed and harmonized soil mapping and coding of](#)
 239 [available national information arises to downscale to national and local soil assessment](#)
 240 [and mapping, which is currently on the agenda of the Global Soil Partnership \(GSP\).](#)

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242 The majority of the countries of NENA region presents moderate to relatively low
 243 total stocks of SOC. This is especially relevant to the Gulf countries, Iran, Tunisia and
 244 Morocco, with values below 221 Mega tons (Figure 2). Such low OC sequestration
 245 potential can be explained by the prevalence of arid climate and rare natural vegetation
 246 and the reliance on irrigation to produce food and feed crops. A regional implementation
 247 plan for sustainable management of NENA soils appeared in 2017 ([Website 2](#)). In fact, the
 248 total stocks, in the topsoils (0-0.3 m) of NENA countries, represent only 4.1% of the world
 249 global stock ([Website 3](#)).

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251 The stock of SOC (ton ha^{-1}) was mapped [as well](#) (Figure 3). A large proportion
 252 (69%) of the soil resources presents a stock [inferior to](#) 30 tons ha^{-1} (Figure 3), value
 253 considered as a [threshold](#) (Batjes and Sombroek, 1997). [This could be linked to the relief](#)
 254 [of these countries, with rare mountainous landscapes that enjoy a more humid climate and](#)
 255 [a longer duration of soil moisture.](#)

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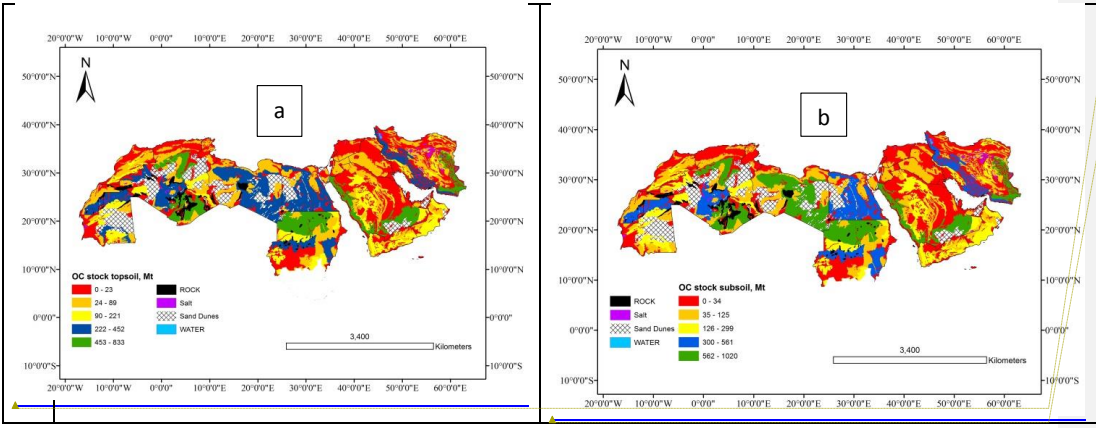


Figure 2. Spatial view of total soil organic carbon stock across the countries of NENA region, Mega ton (a-topsoil; b-subsoil).

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257 Mapping was done on a small scale, which could be a source of a loss of
 258 information. To test this, the results of the current estimation (1:5 Million) of SOC stocks
 259 in Lebanon, were compared with the large scale mapping undertaken recently to produce
 260 the unified soil map of Lebanon at 1:50,000 (Darwish et al., 2006:1:50,000). This
 261 comparison showed discrepancies between 11% for the topsoil and 14% for the subsoil
 262 (Darwish and Fadel, 2017). Therefore, the level of uncertainty falls within the admitted
 263 diagnostic power of soil mapping, estimated to be close enough to the reported range of
 264 map units' purity in reference areas, i.e., a matching between 65% and 70% (Finke et al.,
 265 2000). Loss of information related to small, non-mappable soil units in small scale
 266 mapping (1:5 Million or 1:1 Million) could be corrected by national and subregional large
 267 scale soil mapping (1:50,000 and 1:20,000).

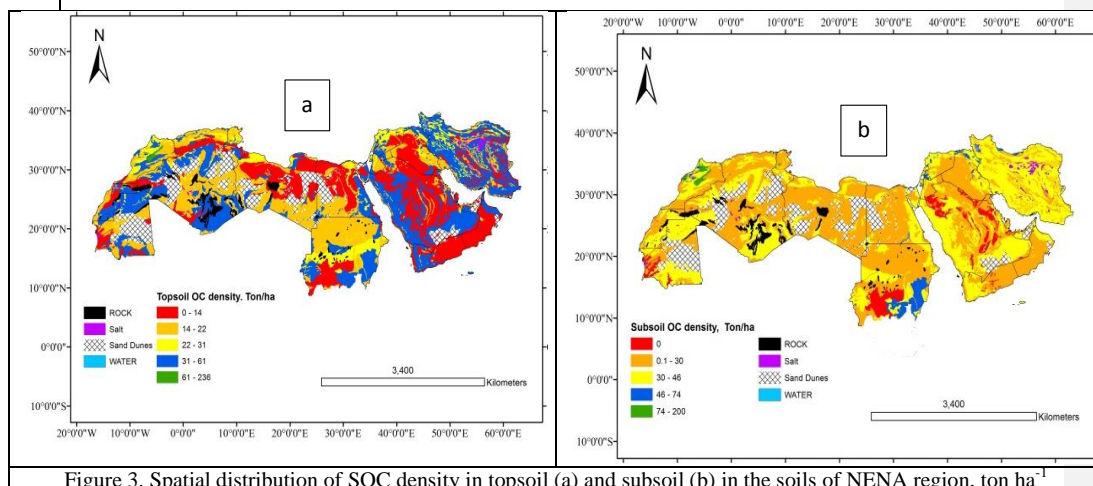


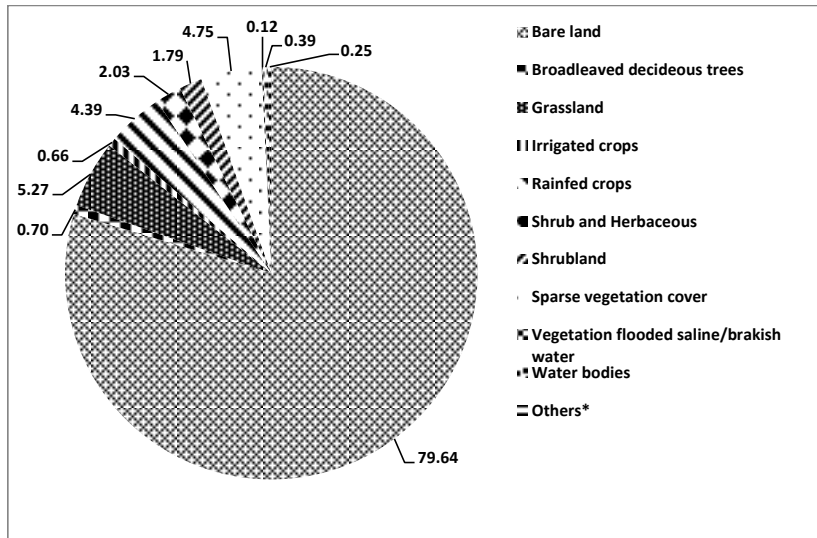
Figure 3. Spatial distribution of SOC density in topsoil (a) and subsoil (b) in the soils of NENA region, ton ha⁻¹

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269 3.3. Land cover mapping and effect on SOC stock

270 Land cover map of NENA region shows nearly 80% of the area is covered with
 271 bare lands (Figure 4a, b). Grassland, sparse vegetation cover and rainfed agriculture are
 272 close by area varying between 4.39% and 5.27%. The irrigated crops do not exceed 0.66%
 273 of the total area. Apparently for this reason, The region is becoming increasingly
 274 dependent on food imports, because of demographic pressure, rapid urbanization, water
 275 scarcity and climate change (FAO, 2015).

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*Others: Mixed trees, Needleleaved evergreen trees and Urban

Figure 4a. Proportion of main land cover and land use in NENA region (Source: ESA, 2015)

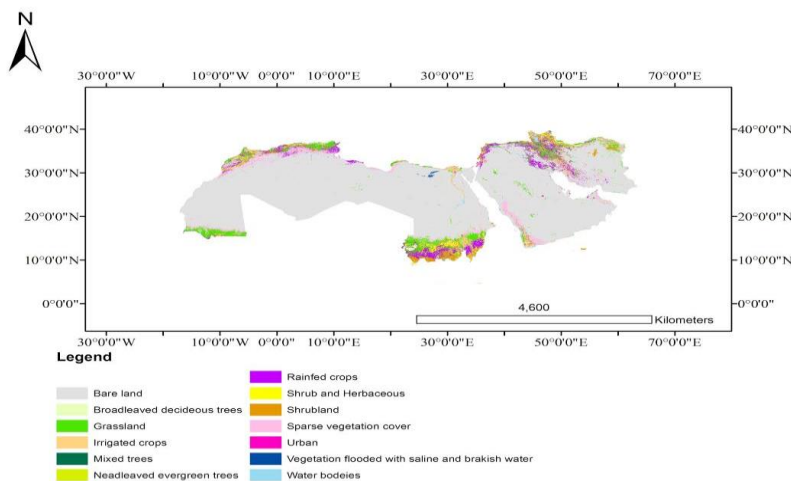


Figure 4b. Land cover map of NENA region (Source: ESA, 2015; <http://maps.elie.ucl.ac.be/CCI/viewer/index.php>)

Comparing our results with the global SOC map produced by Hengl et al., (2014), based on soilGrids1km layers showing the soil organic carbon content in permille in 0-5 cm and the predicted global distribution of the soil organic carbon stock in tonnes per ha for 0–200 cm (to be beyond the followed by FAO methodology of SOC stock estimation and presentation). In this paper the standard methodology of the measured SOC stock and density in topsoil (0-30 cm) and subsoil (30-100 cm) was followed. The first Global SOC Map was launched on December 5, 2017. However, a comparison of values of SOC

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291 | content (%) and SOC stock revealed comparable trends values for the C content and stock
292 | (1-2% and 20-204 ton/ha), with higher upper density in Hengel et al approach.

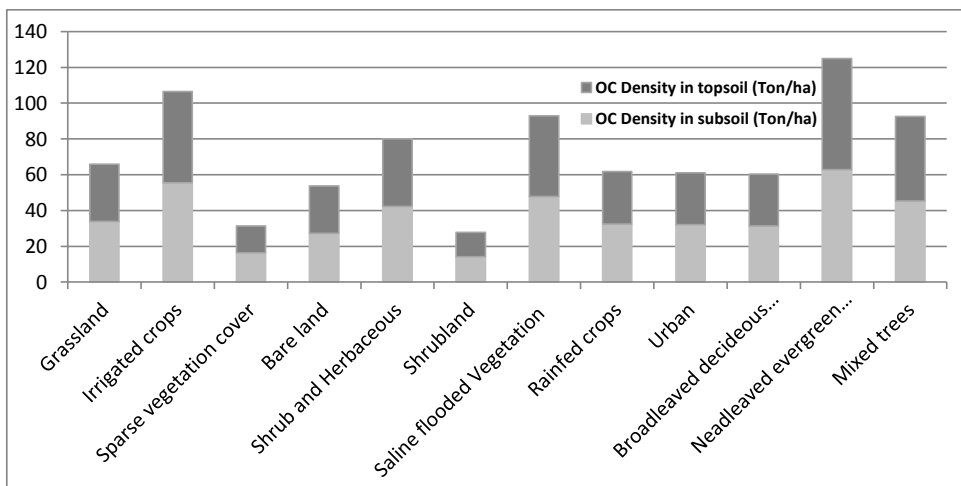
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294 | ~~Further~~In our study, the combination of SOC stock map with the land cover map
295 | ~~showed, the significant effect of land cover on SOC stocks in NENA region. of SOC were~~
296 | ~~studied in relation to land cover/land use. As can be expected,~~ Shrublands, sparse
297 | vegetation and bare lands gave the smallest values, between 14 and 26 ton ha⁻¹ (Figure 45).
298 | In a mixture of shrublands and herbaceous vegetation, the SOC increases to 40 ton ha⁻¹.
299 | The highest density (30 and 60 ton ha⁻¹) is found under forest stands.

300

301 | Despite the expected impact of frequent plowing, the soils under mixed trees and irrigated
302 | crops have higher density than rainfed crops. The highest SOC stock was observed under
303 | evergreen forest land whose area is very limited (3380 km² corresponding to 0.02% from
304 | the total area). Surprisingly, the stock found under urban soils (≈ 30 tons ha⁻¹) was
305 | moderate. This could be related to the urban encroachment on prime soils. Between 1995
306 | and 2015, rapid urban growth caused the loss of over 53 Million tons of soils, 16% of
307 | which correspond to prime soils (Darwish and Fadel, 2017). The assessment of SOC
308 | content in time and space in relation to land cover showed a decline of OC content in
309 | topsoil by up to 1% between 2001 and 2009 (Stockmann et al., 2015). Land cover change
310 | was considered as the primary agent that influences SOC change overtime, followed by
311 | temperature and precipitation.

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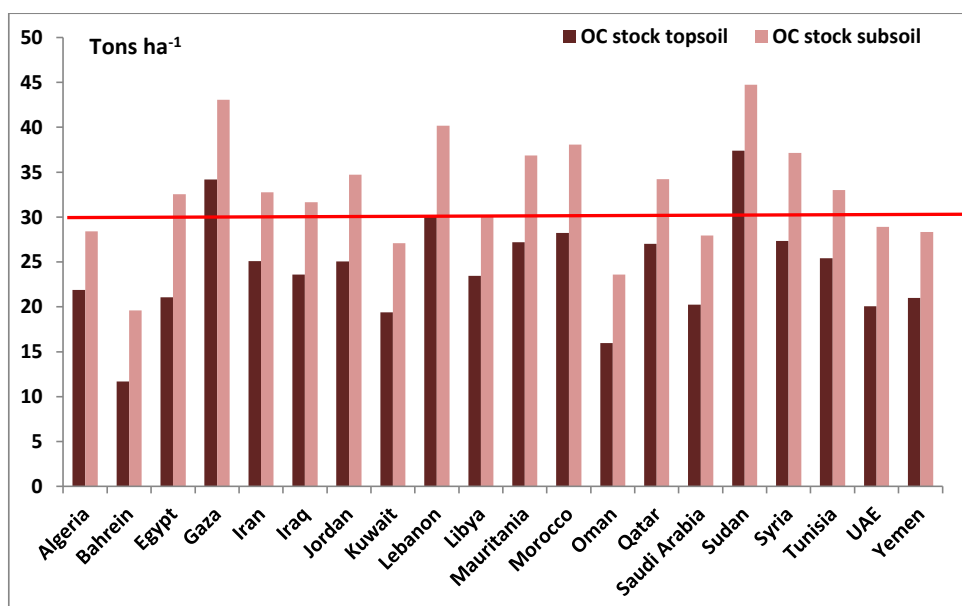
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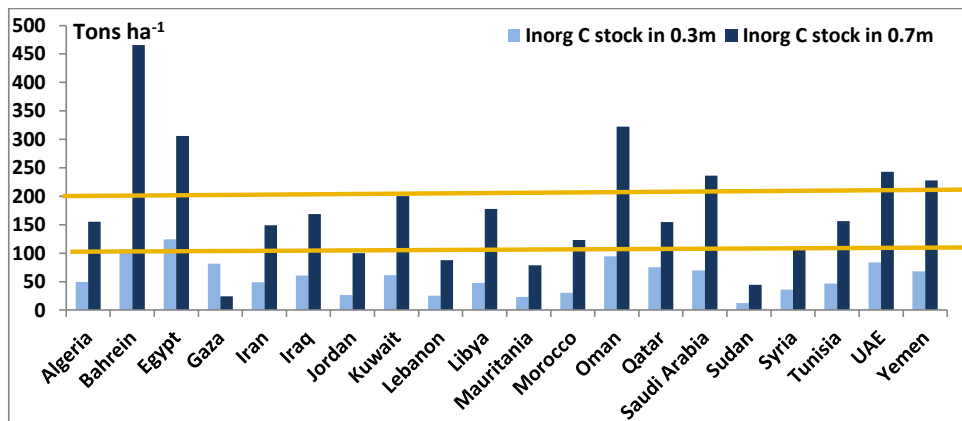
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314 **Figure 45.** SOC ~~stock~~ density (tons ha⁻¹) in the topsoils (0-0.3m) and subsoils (0.3-1.0m),
 315 [calculated from the FAO DSMW \(FAO, 2007\) on corresponding land cover](#)
 316 [\(http://maps.elie.ucl.ac.be/CCI/viewer/index.php\)](http://maps.elie.ucl.ac.be/CCI/viewer/index.php) as related

317
 318 In addition to the stocks of SOC in relation to land cover/land use, the stocks of
 319 SOC and SIC were established per country (Figure 65). The stock of SIC was compared to
 320 that of SOC (Figure 5). The range of SIC stocks is very wide, from less than 25 tons ha⁻¹
 321 (Gaza subsoil) to 450 tons ha⁻¹ (Bahrein subsoil), while that of SOC varied between ≈ 20
 322 tons ha⁻¹ (Bahrein subsoil) and 45 tons ha⁻¹ (Sudan subsoil). Based on the stocks of SIC in
 323 the subsoils, the countries were separated into three groups. The first, represented by six
 324 countries (Bahrein, Oman, Egypt, Saudi Arabia, UAE and Yemen) was dominated by
 325 calcareous parent materials, with values in the subsoil exceeding 200 tons ha⁻¹ (Figure 5).
 326 The second group, with eight countries (Kuwait, Libya, Iran, Iraq, Algeria, Qatar,
 327 Morocco and Tunisia), presents a SIC density between 100 and 200 tons ha⁻¹. Finally, the
 328 third group (Gaza, Jordan, Lebanon, Mauritania, Syria and Sudan) has less than 100 tons
 329 ha⁻¹.



330



331

332 | Figure 65. Stocks of soil organic carbon and soil inorganic carbon (tons ha⁻¹) in the
 333 | topsoils (0-0.3 m) and subsoils (0.3-1.0 m) of the 20 countries in the NENA region. The
 334 | red line represents the threshold for organic carbon, and the yellow lines correspond to the
 335 | limits of classes.
 336

337 3.3. Challenges of carbon sequestration in NENA agroecosystems

338 Climatic conditions characterized by wetting/drying cycles, a long dry and hot
 339 | season (Boukhoudoud et al., 2016) promote the decomposition of SOC. Further, [frequent](#)
 340 | [cultivation, irrigation with saline water, and soil salinity rise in coastal areas](#) ~~the~~
 341 | ~~prevailing agriculture practices (Boukhoudoud et al., 2017)~~ exert significant effects on soil
 342 | microbial functional properties (Boukhoudoud et al., 2017). In this section, there **will be**
 343 | presentation of major practices affecting SOC followed by a discussion of preventive and
 344 | remediation measures.
 345

345

346 3.3.1. Tillage and SOC

347 Tillage practices contribute to the vulnerability of soils to water erosion. If not
 348 | properly managed, some 41 million hectares would be affected by water erosion (FAO and
 349 | ITPS, 2015). The erosion of soil surface layers can affect the soil carbon in two possible
 350 | ways. The greater exposure of carbonates to climatic elements could increase the loss of
 351 | SIC to the atmosphere and ground water. [Compared to stable soils, Also](#), the higher
 352 | decomposition of SOC in eroded soils decreases the productivity of cultivated crops [and](#)
 353 | [can reduce SOC stock if not properly managed](#) (Plaza-Bonilla et al., 2015).
 354

354

355 | A possible measure to reduce the risk of erosion is **the** no-tillage. No-tillage
 356 | [coupled with mulching, to reduce weed development and omit herbicide application, as](#)
 357 | part of conservation agriculture (CA), aims to [keep more plant residues on soil surface](#), **on soil**

358 | [enhance C sequestration](#), increase soil aggregates, [improve water infiltration](#) and to
359 | provide a protection to soil carbon from decomposers (Palm et al., 2014).– Through a
360 | modification of common practices, such as the frequency and depth of tillage, changes in
361 | the SOC could be promoted in most soils. Experiments conducted by ICARDA, Syria,
362 | showed that no-tillage performed well in terms of energy and soil conservation (Plaza-
363 | Bonilla et al., 2015). Elsewhere, in Palestine soil conservation was found to pay, with a net
364 | profit 3.5 to 6 times higher than without conservation measures (FAO and ITPS, 2015). In
365 | dryland regions, agricultural activities based on CA practices are beneficial as crop
366 | residues are left on the soil surface (Plaza-Bonilla et al., 2015). The presence of residues
367 | would protect the soils from high evaporation, water and wind **erosions**. This is especially
368 | relevant to soils that are sensitive to degradation, such as the very shallow Lithosols, the
369 | [easily periodically wetted \(swelling\) and dry \(shrinking\)](#) Vertisols, Gypsic Yermasols
370 | (Aridisols), the poorly-structured Solonchaks and Solonetz, the sandy-textured Arenosols,
371 | and the desert soils (Xerosols).

372

373 | Major constraints facing soil conservation measures, in East Mediterranean, were
374 | **due to** knowledge and perception, [prevailing practice of complete removal and some times](#)
375 | [burning of residues after harvest](#), land tenure and type of landscape (FAO, 2012; FAO and
376 | ITPS, 2015). These major factors are socio-economic in nature, rather than scientific.
377 | They are related to the ability of growers to accept new techniques and adopt them. In
378 | many situations, the transfer from the research stations to the farmers was not smooth. For
379 | instance, CA was successfully tested in experimental stations in Morocco and Lebanon,
380 | but several social and technical barriers prevented it from reaching farmers (Mrabet et al.,
381 | 2012; FAO, 2012).

382

383 | A debate has been taking place about the effect of no-tillage on SOC. ~~Most~~ [Many](#)
384 | authors agree that under CA, SOC increases near the soil surface, but not necessarily
385 | throughout the profile. A study compared 100 pairs, where no-tillage has been practiced
386 | for over 5 years. The absence of tillage lead to higher C stocks (0-30 cm soil depth) in
387 | 54% of pairs, while 39% showed no difference in stocks (Palm et al., 2014). In the
388 | absence of tillage, the slower decomposition of residues would result in higher
389 | ~~belowground~~ C accumulation [on the soil surface](#). Over a period of 5 years, zero tillage
390 | promoted an increase in SOC equal to 1.38 Mg ha⁻¹ as compared to the conventional
391 | tillage in northern Syria (Sommer et al., 2014).

392

393 3.3.2 Agricultural practices and SOC

394 Practices, such as the application of N fertilizers, ~~of the~~ organic amendments, the
395 incorporation of residues and crop rotations, influence the levels of SOC. The lack of
396 accessible nutrients and soil mining make most crops entirely reliant on accumulated SOC
397 (Plaza-Bonilla et al., 2015). In East Africa, 14-years of continuous cultivation without any
398 inputs, decreased SOC from 2% to 1% (Sharma et al., 2012). The application of N
399 fertilizers was associated with increased levels of soil C, as compared to the absence of N
400 fertilizers (Palm et al., 2014). In a 10-year rotation of wheat-grain legume (vetch) in
401 northern Syria, the application of nitrogen fertilizers to the cereal caused a notable
402 increase of SOC, in the top 1m of soil, equal to 0.29 Mg ha⁻¹ year⁻¹ (Sommer et al., 2014).
403 Similarly, the growth of intercropped ~~erocrop legumes~~ (Vicia
404 ~~sp., Lathyrus sp.†~~) alone or with barley (*Hordeum vulgare*), between cherry trees in semi-
405 arid Lebanese area (Jourd Aarsal, eastern Lebanese mountains),—increased SOC
406 significantly notably when legumes were mixed with barley (Darwish et al., 2012). Results
407 showed that the sites were supplemented with OM varying between 140 and 250 kg ha⁻¹
408 season⁻¹ resulting from the decomposition of plant root residues. The above ground plants
409 provided the orchards with 95-665.7 kg ha⁻¹season⁻¹ of OM. Plant residues provided
410 additional feedstuff for small ruminants; the soils were enriched with OM and fixed
411 nitrogen with more efficient use of surface soil moisture.

412

413 The effects of crop rotations on SOC are related to the amounts of above and
414 belowground biomass produced and retained in the system. In a study conducted in semi-
415 arid northern Syria, a 12-year rotation gave higher SOC in wheat-medic (12.5 g SOC kg⁻¹
416 soil) and wheat-vetch (13.8 g SOC kg⁻¹ soil) rotations, as compared to continuous wheat
417 (10.9 g SOC kg⁻¹ soil) or wheat-fallow (Masri and Ryan, 2006). In this rainfed system, the
418 introduction of a forage legume (vetch/medic) with wheat, over a decade, was able to
419 significantly raise the level of SOC. Further, the combination of crop rotations and no-
420 tillage was found to sequester more C than monocultures (Palm et al., 2014). One means
421 of building up biomass is through cover winter crops. Their beneficial impact on C
422 sequestration and water infiltration has been demonstrated. The presence of a cover on the
423 soil surface protects the soil against erosion. In the NENA region, their cultivation is
424 restricted to sub-humid to humid areas (> 600 mm of rainfall). Still, more research is

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425 needed about the best species to be used, the optimum termination strategies of the cover
426 crop as well as the best date (Plaza-Bonilla et al., 2015).

427

428 In poor dryland regions ~~Poverty~~, especially in the rainfed agricultural systems,
429 ~~prevents~~ some practices leads to the removal of all such as the incorporation of residues.
430 Overall, crop residues serve as fodder or for household cooking or heating, leaving little
431 remains on the soil surface. Even animal dung is used as cooking fuel in many regions.
432 The low SOC content could be improved by increasing the crop residues produced and
433 incorporated. Such an approach requires the application of fertilizers in order to avoid the
434 depletion of soil nutrients (Plaza-Bonilla et al., 2015).

435

436 Some authors question the validity of remediation measures to build-up SOC in
437 most of the NENA region. ~~Results~~ from research stations in Egypt and Syria provide
438 evidences to the contrary. In a trial in north-east Cairo, Egypt, the irrigation of a sandy soil
439 with sewage water, for 40 years, changed its texture to loamy sand (Abd el-Naim et al.,
440 1987). This modification of the soil texture leads to a significant improvement of the soil
441 physical properties. Further, within the same long-term trial, the irrigation with sewage
442 water, for 47 years, increased SOC to 2.79%, against 0.26% in the control (Pescod and
443 Arar, 2013). This rather slow accumulation could be related to the sandy soil texture and
444 ~~to the input of the organic matter in labile, soluble forms.~~ ~~The addition of more stable~~
445 ~~composted materials was tested in semi-arid north Syria. The amount of compost, 10 Mg~~
446 ~~ha⁻¹ every two years, needed to raise the SOC, was too large in these rainfed systems.~~
447 Rather than relying on composts, the authors found that a combination of reduced tillage
448 and a partial retention of crop residues moderately increased SOC (Sommer et al., 2014).
449 The quality of residues seems to affect the SOC on the short-term but on the medium-term
450 it is the quantity that matters (Palm et al., 2014).

451

452

453 3.3.3. Impact of irrigation on agricultural soils

454 The irrigated land might represent a minor fraction of agriculture in NENA region,
455 but irrigated crops are essentially found on prime soils (Figure 4). Frequent wetting of
456 irrigated soils make them more likely to lose C as compared to dry soils. Lack of moisture
457 limits soil mineralization (Sharma et al., 2012). Irrigated soils promote intense microbial
458 activity and a rapid decomposition of SOC. In the fertile region of Doukkala, Morocco,

459 known for producing wheat and sugar beet, a decade of irrigated farming decreased SOM
460 by 0.09% per year (FAO and ITPS, 2015). This loss could have been reduced through the
461 incorporation of crop residues. But, in these mixed farming systems, residues are
462 consumed by farm animals.

463

464 The irrigation of soils in NENA region is expected to affect the SIC. Dryland soils
465 were considered to contain, **at least**, as much SIC as SOC (Sharma et al., 2012). **However**,
466 this study showed much higher SIC than SOC, notably in the subsoils. Despite this large
467 stock, there is a major knowledge gap regarding the effects of land use and management
468 on the dynamics of SIC. This is especially relevant to the irrigation with calcium or
469 sodium-enriched groundwater (Plaza-Bonilla et al., 2015). In these conditions, the
470 formation of calcium carbonate could be accompanied by some release of carbon dioxide
471 while the development of sodicity can cause irreversible SOC loss.

472

473 4. Conclusions

474 ~~The NENA area consisting of 14% of the earth surface area contributes only 4.1%
475 of total SOC stocks of in SOC (0-0.3m) topsoil showed a small contribution to global
476 SOC stock in the topsoil (4.1%), against 14% of the earth surface area. The soil resources
477 of s of the NENA region are developed under dry conditions with prevailing of rainfed
478 agriculture. mostly highly vulnerable to Achieving land degradation neutrality degradation,
479 and food security will depends much on land stewardship and sustainable agricultural
480 measuresmanagement of soil resources. The land capability model showed that most
481 NENA countries (17 out of 20), suffer from low productive lands (>80%). To obtain an
482 idea of the status of the soil carbons, the spatial distributions of SOC and SIC stocks for
483 the NENA region were mapped (1:5 Million). This small scale mapping was compared
484 with a larger scale mapping (1:50,000) for Lebanon. A moderate discrepancy (11% to
485 14%) was found between the two scales. The results of the mapping Mappingcurrent
486 mapping of the stocks of SOC and SIC density showed that 69% of soil resources present
487 a SOC stock of SOC below the threshold of 30 tons ha⁻¹. The stocks density varied
488 between ≈ 10 tons ha⁻¹ in shrublands and 60 tons ha⁻¹ for evergreen forests. Highest stocks
489 were found in forests, irrigated crops, mixed orchards and saline flooded vegetation. The
490 moderate stock density (≈30 tons ha⁻¹) in urban areas indicates that some urban growth
491 was at the expenses of prime soils. The stocks of SIC were higher than those of SOC~~

492 | [density, indicating the calcareous nature of soils](#). In subsoils, the SIC ranged between 25
493 | and 450 tons ha⁻¹, against 20 to 45 tons ha⁻¹ for SOC.

494

495 | ~~Decomposition of SOC is accelerated by climatic conditions, high temperatures,~~
496 | ~~wetting/drying cycles, and by sandy soil textures. Although~~ OC sequestration in the
497 | NENA region is **problematic, this task is still possible**, requiring the protection of the
498 | topsoils [and sustainable land management](#). Practices of conservation agriculture (no-
499 | tillage, [intercropping and agro-pastoral system, presence of winter soil cover, proper](#)
500 | [rotation...](#)) could be effective as the presence of residues reduces the evaporation, as well
501 | as water and wind erosions [and promote the aboveground biomass production](#). This is
502 | especially relevant to soil classes that are susceptible to degradation. ~~Further, the~~
503 | ~~combination of crop rotations and no tillage was found to sequester more C than~~
504 | ~~monocultures.~~ **In semi-arid regions, the introduction of legumes, as part of a cereal-**
505 | **legume rotation, and the application of nitrogen fertilizers to the cereal caused a notable**
506 | **increase of SOC, after 10 years. The effects of crop rotations on SOC are related to the**
507 | **amounts of above and belowground biomass produced and retained in the system. A faster**
508 | **result was achieved through winter cover crop consisting of fruit trees-legume-barley**
509 | **intercropping system.**

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510

511 | ~~Some k~~ Knowledge gaps exist, especially in aspects related to the effect of
512 | irrigation on SOC, as well as on SIC ~~at the level of soil profile and soil landscape~~. Still,
513 | major constraints facing soil conservation measures and carbon sequestration are socio-
514 | economic in nature, rather than scientific. They are related to the ability of growers to
515 | accept new techniques and adopt them. Awareness raising and capacity building at the
516 | level of stakeholders and decision-makers [in the NENA region](#) can contribute to alleviate
517 | the pressure on ~~vulnerable~~ soil resources, improve SOC sequestration, ~~and~~ maintain soil
518 | [resilience-resistance](#) to degradation ~~and strengthen food security~~.

519

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523

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