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First Author Secondary Information:	
Order of Authors:	Philippe Lagacherie Jorge Álvaro-Fuentes Mohamed Annabi Martial Bernoux Sami Bouarfa Abdelkader Douaoui Olivier Grünberger Ali Hammani Luca Montanarella Rachid Mrabet Mohamed Sabir Damien Raclot
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	largely addressed and are still studied in current research projects. They should include changes in agricultural practices, soil-water management and vegetal material. As a pre-requisite for the site-specific adaptations of such mitigation strategies within viable Mediterranean agro-systems, it is highlighted that methodological advances are necessary in integrated assessment of agricultural systems and in finer resolution soil mapping.
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Managing Mediterranean Soil Resources Under Global Change: Expected trends and mitigation strategies.

Philippe Lagacherie¹, Jorge Álvaro-Fuentes², Mohamed Annabi³, Martial Bernoux⁴, Sami Bouarfa⁵, Abdelkader Douaoui⁶, Olivier Grünberger⁷, Ali Hammani⁸, Luca Montanarella⁹, Rachid Mrabet¹⁰, Mohammed Sabir¹¹, Damien Raclot^{7,8}

1 INRA, UMR LISAH Montpellier, France; Corresponding author
(philippe.lagacherie@supagro.inra.fr)

2 CSIC, Zaragoza, Spain

3 INRAT, Tunis, Tunisia

4 IRD, UMR Eco&Sol, Montpellier, France

5 IRSTEA, UMR G-EAU, Montpellier, France

6 Université de Khemis Miliana, Algeria

7 IRD, UMR LISAH Montpellier, France

8 IAV Hassan II, Rabat, Morocco

9 European Commission, DG JRC, Ispra, Italy

10 INRA, Rabat, Morocco

11 ENFI, Sale, Morocco

Abstract

The soils of the Mediterranean basin are the products of soil processes that have been governed by a unique convergence of highly differentiated natural and anthropogenic drivers. These soils are expected to be dramatically affected by future climate and societal changes. These changes imply that suitable adaptive management strategies for these resources cannot simply be transposed from experiments that are performed in other regions of the world.

Following a framework that considers the chain of “drivers – soil process – soil capital – Ecosystem Services/Disservices” the paper review the research undertaken in the Mediterranean area on three types of Mediterranean soil degradation than can be expected under Global Change i) soil losses due to the increase of drought and torrential rainfall, ii) soil salinization due the increase of droughts, irrigation and sea level and iii) soil carbon stocks depletion with the increase of temperature and droughts. The possible strategies for mitigating each of these degradations have been largely addressed and are still studied in current research projects. They should include changes in agricultural practices, soil-water management and vegetal material. As a pre-requisite for the site-specific adaptations of such mitigation strategies within viable Mediterranean agro-systems, it is highlighted that methodological advances are necessary in integrated assessment of agricultural systems and in finer resolution soil mapping.

Keywords

Soil, erosion, carbon, salinization, climate change

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1. Introduction

The Mediterranean Basin is the land region surrounding the Mediterranean sea that has a Mediterranean climate, with mild, rainy winters and hot, dry summers. It is the largest of the world's five Mediterranean climate regions (2,085,292 km²). It stretches west to east from Portugal to Syria and north to south from northern Italy to Morocco and surrounds the Mediterranean Sea, including parts of Spain, France, the Balkan states, Greece, Turkey, Syria, Lebanon, Israel, Palestine Authority, Jordan, Egypt, Libya, Tunisia and Algeria as well as five thousand islands that are scattered around the Mediterranean Sea

Along with its water, coastlines and biodiversity, soils constitute one of the Mediterranean basin's vulnerable natural resources. Their productivity enhancement and the care given to their conservation and management have been a big contributor to the spread of successive past civilisations. By contrast, their degradation has been a cause of crisis and constant decline in the past and has inflicted a high cost on most of its countries (World Bank, 2010). Even today, soil degradation in its various forms constitutes a significant threat to the future of the Mediterranean basin (De Franchis and Ibanez, 2003; Lahmar and Ruellan, 2007).

The Mediterranean basin hosts a unique combination of soil-forming factors, climate conditions, parent material and reliefs (Yaalon, 1997; Ryan et al, 2006). Furthermore, Mediterranean soils have been heavily impacted, if not built, by the most ancient agriculture in the world (De Franchis and Ibanez, 2003). This impact makes the Mediterranean soils and soil patterns very different from other regions of the world.

The Mediterranean basin is also a global change hotspot. Most general circulation models forecast drastic changes in temperatures and rainfall regimes for this area (Dubrovsky et al, 2014). Some of these changes have been observed recently (Lionello et al, 2014). In addition, increasing population and market pressures have induced important land use changes (García-Ruiz et al, 1996; Sluiter et De Jong, 2007) that could become even greater in the future (IPCC, 2014).

Both the Mediterranean's soil peculiarities and its strong regional dynamic relations with global change imply that suitable adaptive managing strategies for Mediterranean soil resources cannot be simply transposed from experiments that were performed in other regions of the world. Instead, research should be performed on strategies that specifically address Mediterranean soil conditions.

In this paper, a multidisciplinary group of soil scientists reviews the current research on managing Mediterranean soil resources through a common framework (Dominati et al, 2010), highlighting the primary challenges that should be faced to conserve the ability of these resources to provide their expected services.

2. Specificities of Mediterranean soil resources

The soils of the Mediterranean region are products of soil processes that have been governed by a unique convergence of highly differentiated natural drivers (climate, relief, and parent material) and strong historic human activity. These drivers have provided some remarkable characteristics to the Mediterranean soil cover that are highlighted in the following section. We use in the following the World Reference Base for Soil Resources terminology and classification system (IUSS Working Group WRB, 2006).

Shallow soils

Leptosol, and Regosol, cover a large part of the Mediterranean region (European Soil Bureau Network, 2005, Jones A. et al, 2013, Zdruli, 2011). These characteristics reflect the natural predominance of erosion processes, which are enhanced by the conjunction of i) a marked relief in

104 which 45% of the areas have slopes greater than 8% because of active tectonics at the contact of the
105 African and Eurasian plates (De Franchis and Ibanez, 2003), ii) the high frequency of very intense
106 rainfall events (> 100 mm/h) during the autumn and winter seasons and iii) lesser protection by
107 vegetation against erosion because of the severe summer droughts, burning, overgrazing and
108 deforestation that reduce the vegetation coverage (García Ruiz et al, 2013). The evolution towards
109 shallow soils is often counterbalanced by human practices such as terracing in hilly areas (Tarolli et
110 al, 2014). Conversely, farming is known to greatly accelerate the erosion rates relative to soil
111 production (Amundson et al, 2015), particularly when cultivated fields replaced the natural
112 vegetation that was originally dominated by Mediterranean scrublands and forests. Finally, shallow
113 and skeletal soils in Mediterranean landscapes are often closely associated with Cambisols –young-
114 aged soils- that have formed on the downhill colluvium of eroded material and represent large areas
115 in this region too.

116 *Soil carbon contents*

117 Mediterranean soils have not been consciously managed to store or sequester carbon. Hence, most
118 of these soils exhibit low to very low soil organic carbon (SOC) contents. This information is
119 particularly well-documented for the European countries in the Mediterranean basin (Jones et al.,
120 2005; Zdruli et al, 2004). For countries along the southern side of the Mediterranean sea, Henry et
121 al. (2009) calculated a mean SOC content of 1.1% in the top 0-30 cm for the North Africa region,
122 with mean national SOC values ranging from 0.67-0.79% for Morocco, Tunisia, Algeria and Egypt.
123 National-scale studies have confirmed those values, e.g., for Tunisia, Brahim et al. (2012) organized
124 a soil database with 238 soil profiles corresponding to 707 soil horizons. The authors reported that
125 the mean and median SOC contents of the top-soils (depth < 40 cm, 249 horizons) were 1.17% and
126 0.86%, respectively.

127 Limited SOC content is the result of several biotic and abiotic processes and factors, with climate
128 and management being the two most influential factors in the Mediterranean region. Rainfall
129 shortage limits the net primary productivity, and, in turn, soil C buildup. Low C inputs driven by
130 limited soil moisture availability are exacerbated by the adoption of certain management practices.
131 Crop residue competition for livestock feeding or the introduction of long fallowing in the crop
132 rotation are two examples of typical management practices in the Mediterranean region that have
133 contributed to the reduction of C inputs that are returned to the soil. In addition to decreases in C
134 inputs, agricultural management may also boost SOC losses. In the Mediterranean region, the use of
135 intensive deep-tillage implements (e.g., mouldboard ploughing) has been a common practice for
136 centuries. Inversion tillage generates favourable soil conditions for microbial activity (i.e., it
137 homogenizes the moisture content along the soil profile, favours soil oxygenation and incorporates
138 crop residues into the soil), thus accelerating soil organic matter mineralization and loss.

139 Another important consideration is that those soils usually contain an important amount of
140 inorganic carbon, most of which is present as carbonates as a result of the dissolution of calcareous
141 parent material by winter rainfalls and precipitation during dry summer periods (Yaalon, 1997).
142 This composition results in soils with calcareous material accumulations in their profiles (Calcisols,
143 Kastanozem), which are more frequent in the Mediterranean basin than everywhere else in the world
144 (Ryan et al, 2006). However, there have been few investigations concerning the short-term pattern
145 of inorganic C stocks because of complex interactions and balances between atmospheric C and
146 organic and inorganic forms of soil C (Bernoux and Chevallier, 2014).

147 *Irrigation and salinity*

148 The Mediterranean basin is also characterized by a large surface of irrigated soils, usually in the flat
149 areas. In the Near East/North Africa countries, the irrigated area is estimated by the FAO to be 31
150 million hectares (2012). This figure does not take the north side of the Mediterranean into account.
151 The International Commission of Irrigation and Drainage estimates a lower area of 25 Mha for all
152 Mediterranean countries that are equipped with irrigation systems (ICID, 2014). This difference is
153 likely linked to informal (and private) groundwater irrigation and small-scale irrigation systems.
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155 Irrigated soils are prone to secondary salinization (or human-induced salinization) related to
156 imbalances in the soil salt budget. Human-induced salinization is as old as irrigation. Salinization
157 forced the early settlers of Mesopotamia, the Indus river basin and China to abandon their land
158 (Ghassemi et al., 1995). More than fifty years ago, modern states promoted the development of
159 irrigation, primarily for orchards and fruit production. The primary model of irrigation development
160 was based on large irrigation schemes using water stored in large and medium dams. These systems
161 generally faced water management problems (water supply-demand coordination issues and
162 inefficient water transport and field application), leading to a rise in groundwater levels and to the
163 so-called twin menace of “waterlogging and salinity” (Bouarfa and Kuper, 2012). Despite this well-
164 known challenge, there is still no accurate estimation of how the corresponding soils were affected
165 by secondary salinization in irrigated areas. Paranychianakis and Chartzoulakis (2005) estimated
166 that salinization in the Mediterranean basin is a serious problem with some 16 million ha out of 74
167 million ha of today irrigated lands, under the assumption that the ratio of 25% of salt affected soils
168 of irrigated areas soils in 1974 put forward by Szabolcs (1989) is still valid in spite of progresses in
169 irrigation techniques. For example, salinization occurs in most Moroccan irrigated systems. The
170 available data on salinity indicates that approximately 500.000 ha that are located primarily in the
171 command areas are threatened by salinity (Dahan et al, 2012).

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172 *Spatial soil patterns*

173 Apart from the above-evoked characteristics, Mediterranean soil cover is also remarkable for the
174 occurrence of extremely complex soil patterns with large short-scale and anisotropic variations
175 caused by the rapid successions of contrasting parent materials, erosion and re-deposition of soil
176 material within short distances and the long-term impacts of human practices. Many detailed studies
177 across this region have revealed such complex patterns (e.g., Pardini et al, 2004; Gomez et al, 2012;
178 ...).

179 It is worth noting that the existing soil data in the Mediterranean area are available at a spatial
180 resolution that is much too coarse for mapping such complex patterns. The most recent review on
181 the data available for Mediterranean soils was compiled by the European Commission (Yigini et al,
182 2013). It updates the previous assessment that was completed within the Soil Atlas of Europe
183 (European Soil Bureau Network, 2005). A large amount of additional information was collected by
184 the EU-funded project MedCoastLand (Zdruli, et al, 2007). The harmonisation of national soil
185 surveys allowed for the production of the European Soil database (EUSIS) at 1:1,000,000, further
186 extending among other countries to those of the southern part of the Mediterranean Basin. Few
187 Mediterranean countries have developed their own national database at a larger scale than
188 1:1,000,000. Some 1:250,000-scale soil databases are available in Italy
189 (<http://eussoils.jrc.ec.europa.eu/library/data/250000/Italy.htm>), Albania (Zdruli, 2005), Lebanon
190 (Darwich, T., 2008) and Mediterranean France (Bornand et al, 1994). Larger-scale soil maps cover
191 entire or at least substantial portions of Mediterranean countries. Israel (Crouvi et al, 2013),
192 southern Portugal (Goncalves et al, 1999), and the coastal part of Albania (Zdruli, 2005) are
193 covered by a 1:50,000-soil map. Complete coverage at 1:25,000 and 1:100,000 exists for Bulgaria
194 and Turkey, respectively. Badraoui and Stitou (2001) have developed a comprehensive report on
195 the availability of soil information and maps in Morocco. Finally, there have been many local
196 surveys in most countries at various scales that are hard to locate and describe, with the notable
197 exception of Tunisia, for which a database of scanned soil survey reports (BEST) has been
198 developed (Derouiche, 2011, pers. communication).

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206 **3. Analysing the future of Mediterranean soil resources under global change**

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266 The latest Global Change Model projections (Dubrovsky et al, 2013) have indicated the presence of
267 clear climate change in the Mediterranean area. The results show an increase in temperature during
268 all seasons and for all parts of the Mediterranean with good inter-model agreement. The

206 precipitation is projected, with a lower degree of model agreement, to decrease in all parts and all
207 seasons (most significantly during the summer), except for the northernmost parts in winter.
208 Furthermore, increased mean daily precipitation sums on wet days are expected for some seasons,
209 and some parts of the Mediterranean, which may imply higher daily precipitation extremes. A
210 decreased probability of wet day occurrence will imply longer drought spells all across the
211 Mediterranean. All these projections converge towards an even more aggressive climate that may
212 highly impact Mediterranean soils.

213 In addition, the demographic projections indicate a less-than-expected but still clear increase in the
214 population of the Mediterranean area with a total population of 500 million inhabitants in 2010 that
215 is expected to reach 563 million inhabitants by 2025 (Carella and Parant, 2014). This increase will
216 primarily concern urban and coastal areas, and the population of rural areas will remain stable. This
217 change will lead to reconfigurations of national spaces into a mosaic of mushroom cities and rural
218 areas (ARP Parme, 2011).

219 The two above-evoked trends will work together to substantially increase the pressure on
220 Mediterranean soil resources, i.e., producing more on less arable lands that have been depleted by
221 urbanization.

222 In the following section, the future of Mediterranean soil resources is examined by considering the
223 expected impacts of the trends evoked above and by exploring the most promising levers that
224 humans can use to counterbalance the negative impacts. For that reason, we followed the holistic
225 soil assessment approach proposed by Dominati et al. (2010) by considering the chains of “drivers
226 soil process – soil capital – Ecosystem Services/Disservices”. The central concept is soil capital,
227 which is defined as the stocks of natural and human-added assets in soils that yield a flow of
228 valuable ecosystem goods or services. This soil capital can be described through a list of
229 measurable soil properties (e.g., soil carbon stocks or available water capacity). The soil capital is
230 included in a broader chain that considers i) the upstream processes governing the soil capital
231 formation, maintenance and degradation and their associated natural and human drivers and ii) the
232 downstream soil ecosystem services, with beneficial flows arising from soil capital stocks and
233 fulfilling human needs and dis-services and adverse changes in soil capital leading to a loss of
234 ecosystem services. The processes are themselves impacted by a set of drivers among which one
235 can distinguishes the actual observable trends and the mitigation strategies that could alleviate and
236 even delete the impacts of trends.

237 We chose to select three challenging issues that deserve attention to address the future of these
238 Mediterranean resources. Our analyses are summarized in figures 2, 3 and 4. The scientific
239 background supporting these figures and the related research proposals are developed hereafter.

240 241 *Mitigating soil losses*

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243 *Insert figure 1 here*

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245 According to the trend scenario, climate change is expected to increase water erosion processes,
246 which will in turn diminish the tonnage of available soil (Figure 2). This loss of soil depth has direct
247 and obvious on-site effects relating to agricultural production including losses of plant nutrients,
248 soil water reserves, and alterations in soil properties (Lal, 1998). It also has an off-site effect related
249 to water reservoir siltation. In fact, reservoir siltation represents a major issue for water resource
250 management strategies in the Mediterranean basin, especially in North African and eastern
251 Mediterranean countries (Ayadi *et al.*, 2010). Higher sediment yields (SYs) were reported in this
252 environment than the yields for many other regions across the world (Woodward, 1995;
253 Vanmaercke *et al.*, 2011).

254 In the Mediterranean area, and especially in European Mediterranean countries, the sheet and rill
255 erosion rates that are measured at the plot scale are generally lower than the sediment yields
256 (Cerdan *et al.*, 2010; Vanmaercke *et al.*, 2012). This finding was explained by the large fraction of
257 rock fragments at the topsoil and by the importance of erosion processes that are not active at the

258 plot scale, such as gully erosion, landslides and riverbank erosion. More generally, gullies and
259 especially badlands were often identified as the primary sources of sediment responsible for
260 reservoir siltation in Mediterranean environments (Heush, 1970; De Vente *et al.*, 2006 and 2008;
261 Poesen *et al.*, 2003; Simmoneaux, 2015), even if a recent fingerprinting study showed that gully
262 erosion was the predominant sediment source for only 2 of 5 small Tunisian catchments (Ben
263 Slimane, 2015). It is noteworthy that water erosion is considered the most active process that
264 induces soil losses (Govers *et al.*, 2014), which explains why tillage or wind erosion effects are less
265 frequently measured in the Mediterranean context.
266 The expected effect of climate change is two-fold. First, by increasing the intensity of the largest
267 events, an increase in the rainfall intensities or amounts will likely increase water erosion. In this
268 specific Mediterranean context, González-Hidalgo *et al.* (2007) showed that the high dependence of
269 soil erosion with the most intense rainfall events because the three highest daily erosive events
270 represented more than 50% of the annual eroded soil. Secondly, increasing droughts may induce
271 decreased vegetation cover, which will have negative effects on soil losses and silting up because
272 vegetation cover is one of the key factors in erosion control (Wischmeier, 1975; Morgan, 2005).
273 However, mitigation strategies for counterbalancing this negative trend are possible. Mediterranean
274 civilizations successively developed or improved a large range of Soil and Water Conservation
275 (SWC) techniques to improve water conservation and management, increase agriculture production
276 and reduce soil erosion (Figure 2). These techniques are primarily based on slope correction/water
277 velocity reduction (i.e., bench terraces), increasing the ground cover (i.e., cover crop, mulching,
278 permanent cover using tree/crop associations), and/or soil quality improvement (i.e., amendments).
279 Recently, SWC has been broadened toward sustainable land management or conservation
280 agriculture, fostering less soil disturbance, the retention of crop residue, and continuous ground
281 cover, which have been shown to decrease erosion in comparison with conventional agriculture
282 based on deep tillage (Mrabet *et al.*, 2012). The efficiency of conservation agriculture at improving
283 soil water storage is well-recognized in the Mediterranean basin (Mrabet, 2011; Moreno *et al.*, 2010;
284 Ben Moussa-Machraoui *et al.*, 2010). Studies that were conducted on inter-row crops such as olive
285 groves (Francia Martínez *et al.*, 2006; Gómez *et al.*, 2009) or vineyards (Paroissien *et al.*, 2015)
286 also supported the recommendation for non-inter-row tillage and for maintaining a high inter-row
287 vegetation cover with a cover crop or grass cover. However, all these techniques have been
288 introduced so far with varying degrees of success, depending on the environmental and societal
289 contexts (García-Ruiz, 2013, De Graaf *et al.*, 2013). Maintaining a continuous land cover may for
290 instance have positive impacts on soil protection and negative impacts on production because of
291 water competition in the semi-arid context (Marques *et al.*, 2010).

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292 The primary scientific issues that are used to help define adaptation strategies for the Mediterranean
293 area are summarized below. First, there is a need to better understand the spatiotemporal variability
294 of Mediterranean catchment erosion behaviour in terms of sediment sources, active erosion
295 processes and transport efficiency from sediment sources to downstream reservoirs. Promising
296 recent methodological developments are based on the use of fingerprinting techniques or the
297 repetitive acquisition of fine digital elevation models that enable diachronic analysis. European or
298 Mediterranean networking initiatives by scientists and long-term erosion monitored catchments
299 such as the R_Osmed network (<https://sites.google.com/site/rosmedsicmed/home/introduction>) or
300 COST initiative (http://www.cost.eu/COST_Actions/essem/ES1306) will also help us better
301 understand this variability in relation to the specific role of major/extreme events in catchment
302 sediment yields or in the role of sedimentological connectivity.

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303 A second set of research actions must be dedicated to studies of the past of the Mediterranean basin
304 through a review of the large range of adaptation techniques used in this region and a comparison of
305 their evaluations in terms of soil protection efficiency and acceptability by the farmers as it will be
306 investigated in the forthcoming MASCC project (Mediterranean Agricultural Soils Conservation
307 under global Change). The implementation of these adaptation techniques within spatially explicit
308 numerical models devoted to the Mediterranean environment is also a requirement that can help

309 managers to plan the type, number and location of adaptation techniques to implement within a
310 catchment or a watershed for present and future conditions (Gumière *et al.*, 2014).
311 The last set of necessary actions consists in improving our knowledge of future conditions to
312 anticipate efficient adaptation techniques. Because of the stormy nature of major events in the
313 Mediterranean context, we still need to improve the predictions of sub-daily rainfall characteristic
314 predictions as hourly rainfall intensities. Feedback between climate change and land use change are
315 also critical for adaptation strategy planning, especially in the Mediterranean context, where
316 vegetation cover is a major lever for soil protection.

317 318 *Avoiding secondary salinization*

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320 *Insert figure 2 here*

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322 According to the trend scenario, increasing drought and sea level rise and the spread of irrigation in
323 combination with changes in irrigation techniques are expected to reinforce salinization processes
324 and to deplete soil leaching, which will in turn increase the Na and Cl contents of soils and degrade
325 soil structures (Figure 3). Crop production will be affected when the salinity exceeds the threshold
326 values that depend on each crop's sensitivity during critical stages. Most of the plants suffer yield or
327 biomass production decreases when the soil salinity exceeds 4 ds m^{-1} , which represents the limit for
328 defining soils with salinity issues. Osmotic stress is the primary process that is involved with effects
329 similar to drought and freezing; plants face difficulties when extracting water from the root zone.
330 Secondary effects are brought on by toxicity from Na and Cl and from deficiencies of other
331 elements such as Ca, K, Zn, etc. All the functions and cycles of a plant can be affected. Another
332 effect comes from the exposure of saline soil to changes in the primary ion on the adsorbed phase to
333 Na^+ . Afterwards, if the salinity decreases, for instance in the case of remediation, then clay may
334 disperse, ruining the soil structure, hampering drainage and triggering reduction. In landscapes,
335 each upstream area delivers a water supply to downstream ecosystems, and this flow is considered
336 an essential "ecoservice". When salinity increases in the soil of inland fields, leaching may provide
337 salinity to downstream and neighbouring systems through runoff, drainage or underground
338 contamination, fuelling the extension of salinity problems at the landscape scale.

339 In the near future, rising sea levels will increase the salinity pressure on coastal soils and aquifers,
340 but the primary effect is expected from the increase in droughts in Mediterranean countries, which
341 will accentuate irrigation needs. This increase may even be reinforced by the expected needs of
342 agricultural intensifications (see the introduction of this section). For the time being, only a few
343 trials have been performed to simulate increased soil salinity ahead of climatic scenarios in irrigated
344 lands. Preliminary results were obtained (De Paz Bécáres *et al.*, 2012) by modelling the fate of
345 salinity in southern Alicante (Spain), which is cultivated for citrus and legumes. Climate change is
346 creating an enlargement trend in the soil surface that is affected by salinity, from 19% to 34%.
347 Investigators indicate that this effect could be mitigated by a 20% increase in the present irrigation
348 rate. It is feared that salinization issues in the region will reinforce the direct effect of climate
349 change.

350 Furthermore, this trend will be significantly reinforced by the recent evolution of irrigated
351 agriculture techniques. First, groundwater has become increasingly important for irrigation. At
352 present, of the 300 million ha of irrigated land in the world, some 110 million now depend on
353 groundwater, which represents 25% of the total irrigation water (Siebert *et al.*, 2010). The
354 Mediterranean countries are no exception. In North African countries, groundwater has been
355 responsible for the redesign of irrigation frontiers, and it covers over 60% of the total irrigated area,
356 supplying more than 500,000 farms with irrigation water (Kuper *et al.*, 2015). After being perceived
357 as a threat, groundwater gradually became a cherished resource. Salinity issues and solutions also
358 changed in nature because they are not linked to waterlogging problems but are primarily related to
359 the water quality of groundwater. In particular, the depletion of inland groundwater has led farmers
360 to pump from deeper and older geological layers, which are sometimes affected by a natural

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361 geological salinity, and in coastal plains, the salinization of aquifers occurs through sea intrusion,
362 threatening some of the most productive irrigated soils.
363 Secondly, the water-saving policies used in several Mediterranean countries largely depend on the
364 generalization of drip irrigation technologies instead of traditional surface irrigation techniques. As
365 a result, the area in Mediterranean countries under drip irrigation has significantly increased in
366 recent years. For example, according to the Moroccan ministry of agriculture (Bennouniche, 2014),
367 the area equipped with drip irrigation has increased from less than 100,000 ha in 2000 to 360,000 ha
368 in 2013. The aim of this modernization is to “save water” by increasing the irrigation efficiency
369 according to the phrase, “more crop per drop”. However, it is important to note that drip technique
370 benefits related to efficiency will increase with the water volume and can be used at the expense of
371 the proper soil leaching fraction that is required to remove excess salts.
372 The secondary salinization process is partially linked to natural conditions but is also under the
373 control of farmer practices at the field level and water management at the irrigation scheme level,
374 which offers opportunities to undertake mitigation strategies for counterbalancing the above-evoked
375 soil degradation (Figure 3). Secondary salinization depends on the salt budget at the field level as
376 related to farmer irrigation practices, and the leaching processes that they implement depend on
377 farmer perceptions of the problem (Bouarfa et al., 2009). Salinization is also linked to water
378 management and artificial drainage facilities at a larger scale to avoid waterlogging and the
379 salinization of soils by capillary rise (FAO, 1994).
380 It is thus important to re-engage in research to address secondary salinity issues in a renewable
381 fashion. At present, research efforts in the Mediterranean basin are mostly dedicated to employing
382 effective Integrative Water Resources Management (IWRM) at regional scales (100 km² or more),
383 and they mostly consider water volume aspects. Water salinity constrains are often neglected during
384 modelling, which indicates the difficulty in assessing the complexity generated by the behaviour of
385 a particular soil interface under the influence of the individual agricultural practices of irrigation
386 and amendment. The salinity of soil and water should therefore be quantified as a primary
387 constraint to effective IWRM, and it should be considered important for resource volume
388 conservation objectives. In this sense, more research is needed to test the resilience and
389 acceptability of agrosystems with low irrigation rates as general soil salinity problems increase.
390 Another issue is that scientific studies are often solicited for situations in which severe salinity
391 problems have already been identified by the farmers (e.g., obvious soil salinity crusting, and/or
392 dramatic yield decreases). Therefore, because most past studies focused on severe salinization
393 situations, they are likely to present rough representations of the processes that may be inadequate
394 for modelling large time scales with good accuracy. Therefore, the research should focus on ways to
395 identify discrete evidence of early salinization that would allow for under-threshold management
396 and/or accurate modelling of the long-term soil fate with respect to salinity.

397 398 *Maintaining Soil Carbon stocks*

399
400 *Insert figure 3 here*

401
402 According to the trend scenario, climate change may further diminish the soil organic carbon
403 content of the Mediterranean area (Figure 4). As SOC is also the primary constituent of soil organic
404 matter (SOM), representing approximately 50% of its weight (Pribyl, 2010). Thus, SOC is also
405 often an indicator of soil fertility in environmental services. The loss of SOM and therefore of SOC
406 especially when initial levels are low, as in dryland regions, results in the degradation of soils and
407 their associated agronomic and environmental functions and services (Lal, 2004). Figure 4
408 represents global reported tendencies encountered in the literature, however it should be highlighted
409 that some models and studies predict increasing SOC under certain management practices and
410 predicted climate change conditions, as in Álvaro-Fuentes et al. (2012). Moreover, mineralization
411 depends not only on temperature but also on moisture regime, and, whereas the behaviour of the
412 temperature driver is well established toward an increase, it is less consensual concerning the

413 precipitation regime both in quantity and distribution annually. Therefore, uncertainties are still
414 high as illustrated in the example below

415
416 Few studies have addressed the impact of future climate change in Mediterranean regions. Hamdi et
417 al. (2011) designed a study to examine an agricultural soil from northern Tunisia to investigate the
418 effects of temperature variations of up to 50°C on soil respiration and (ii) to test the effect of further
419 organic carbon additions. The results do not support an important increase in soil respiration
420 sensitivity to temperatures ranging from 20-40°C. Only at 50°C, such as during a heat wave, was
421 there a significant increase in the water-soluble carbon, which was likely related to either dead
422 microbial cells or SOC solubilization. Overall, the results indicate a moderate response in the soil
423 respiration to high temperatures, as shown by the Q_{10} value that was close to 1.7, even from 40°C-
424 50°C, illustrating the need to be cautious when using a mechanistic model such as Roth C based on
425 a Q_{10} higher than 2. Indeed, a review analysis by Hamdi et al. (2013) collected and calculated Q_{10}
426 values from incubations of 253 unique soils from 63 published studies. The authors encountered a
427 large variability of observed temperature sensitivities of SOC dynamics, with a mean value of 2.04 ,
428 but with a standard deviation of 1.09 and a median of 1.85. Moreover, the authors showed that this
429 variability is still largely unexplained.

430 Another important aspect of CC is related to water availability. The drying and wetting of
431 Mediterranean soils was shown to stimulate SOM decomposition and carbon dioxide emission. This
432 effect is known as the “Birch effect” (Birch, 1958). Yemadje et al. (2016) recently employed a
433 Soudano-sahelian context that was in some ways comparable to Mediterranean climate conditions
434 (annual rainfall from 900-950 mm, but with a long dry period). Soil wetting and mulching were
435 shown to increase soil carbon mineralization, but frequent wetting-drying cycles did not increase
436 the total soil C mineralization (Yemadje et al., 2017). But, these last authors also reported that
437 conflicting results for the effect of wetting-drying cycles on C and N mineralization can be found in
438 the literature, with higher or lower, or similar values for C and N mineralization in soils subjected to
439 wetting-drying cycles.

440
441 In terms of adaptation strategies in combination with the need to fight agricultural soil degradation
442 and organic C depletion, several approaches were proposed and tested in a Mediterranean context,
443 and some of them were widely adopted by stakeholders at the plot or watershed level.

444 The change of land use in a semi-arid area is a strategy in which the major patterns are related to the
445 reduction in long-term fallowing (FAO, 2014). Annual soil cultivation that employs appropriate
446 nutrient management increases the soil C-return (root, stubble,...) because the above and
447 belowground biomass production was increased in comparison with that of the fallow system. The
448 choice of crop species and cultivars is an important key to maximizing the production of crop
449 residues, which are a major resource for organic inputs in Mediterranean croplands. In the cereal-
450 livestock system, straw is largely exported out of the plot instead of being incorporated back into
451 the soil. In addition, stubble is intensively grazed primarily to the south of the Mediterranean Sea
452 (Ryan et al, 2006). The implementation of crop rotations with plants that allocate more carbon to
453 top and subsoil through a deep root system is an adaptation measure for sinking C. The
454 improvement of rangeland productivity by legume sowing, shrub plantation and integrated livestock
455 are widely used strategies to boost the soil fertility in the arid part of the Mediterranean region.

456 Field studies that were undertaken in Morocco and Tunisia by Mrabet et al. (2001) and Jemai et al.
457 (2012) showed 14% and 28% increases in the SOC from the 0-20 cm soil layer after 11 and 7 years
458 of switching from conventional tillage to conservation agriculture practices, respectively. In Spain,
459 Alvaro-Fuentes et al. (2012) observed a 23% SOC increase in the top 30 cm layer of soil after it was
460 converted to conservation agriculture for 13 years. More generally, the concentrations of organic
461 matter in top-soils of Mediterranean regions were found to increase routinely under no-tillage
462 systems because of the favourable shift in the accumulation and decomposition balance (Kassam et
463 al, 2012; Friedrich et al, 2014).

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464 However, the wide adoption of conservation agriculture among farmers in the Mediterranean
465 regions is still limited. According to Kassam et al. (2012), the total Mediterranean cultivated land
466 under conservation agriculture is 1.53 million hectares.

467 Research questions are still focused on refining the expected level of C sequestration attained in the
468 different bioclimatic zones, and also by considering the deeper soil layers from which C losses have
469 been registered under other climatic conditions. However, one of the most important points
470 concerns the adoption and mainstreaming of conservation agriculture, which will have a strong
471 impact on the management of the residues at the landscape and even sub-national level. Residues
472 are also an important source of biomass resources that are made available for livestock. Synergies
473 (other services in the fight against erosion) and trade-offs (biomass competition should then be
474 addressed as well) to find the most appropriate technical solutions for farmers and smallholders
475 whose objectives are yield and income increases.

476 By contrast, the concentrations of organic matter in topsoils from Mediterranean regions routinely
477 increase under no-tillage systems because of the favourable shift in the balance of accumulation
478 and decomposition (Kassam et al, 2012; Friedrich et al, 2014).

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481 **4. Challenging transversal issues for the future of Mediterranean soil resources**

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483 Apart from the above-evoked ongoing research on each driver-process-soil capital-ecosystem
484 service chain upon separation, the management of soil resources under global change raises some
485 transversal issues that are detailed here.

486

487 *Towards a reliable change in soil management practices within viable agrosystems*

488 Many of the mitigation strategies evoked in the next sections are based on deep changes in
489 agricultural practices. Beyond the successful results obtained on experimental farms, the massive
490 introduction of such strategies within actual Mediterranean agrosystems is still a challenge. For
491 example, the broad adoption of conservation agriculture among farmers in the Mediterranean region
492 is still limited because of possible negative impacts such as the decrease in grazing resources for
493 livestock through the introduction of mulching, or water-stress on agricultural production from the
494 introduction of a permanent vegetation cover. Another aspect is the need for local and national
495 policies that should support actions for, e.g., building up and raising the status of SOC using the
496 adapted programmes and mechanisms with national-wide agricultural strategies such as those
497 within the framework of NAMA. It is now recognized that policies that support sustainable land
498 management practices are focused on both maintaining (preventing loss) and increasing (storing
499 even more) soil organic carbon production for far greater economic, social and environmental
500 impact than the absolute amount of sequestered carbon (Banwart et al., 2014).

501 The introduction of mitigation strategies should be applied in a wider context that considers the
502 whole agrosystem explicitly and its socio-economic environment. An integrated assessment of
503 agricultural systems is therefore required (Van Ittersum et al, 2008).

504

505 *Towards site-specific adaptations for preserving the soil resource*

506 Beyond the field and farm levels, IAASTD (2009) recommended that the landscape level be
507 considered and that “new cropping patterns adapted to site-specific conditions” be introduced. This
508 approach accounts for the diversity of local contexts (see the first issue in this section) and to admit
509 that “the search for universal truths about causes and remedies for desertification and the
510 appropriate actions to be taken are as diverse as the mosaic of landscape itself” (Thornes, 2002).
511 This interpretation is particularly relevant in Mediterranean areas where the complexity of soil
512 patterns (see above) involves a significant diversity of soil properties and soil processes, starting
513 from very small areas such as parcels, farm territories and small watersheds.

514 Significant advances are expected from employing spatial organizations of land uses and soil
515 management practices. These choices will ensure the optimal exploitation of local soil

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516 characteristics while providing the best pooled result in terms of soil cover protection at the scale of
517 resource watersheds or irrigation perimeters in which collective management is possible (10-100
518 km²).

519 An example of current research that is being performed in the Mediterranean area to address these
520 opportunities is the ALMIRA project (Adaptating Landscape Mosaics of rainfed Mediterranean
521 Agrosystems for a sustainable management of crop production, water and soil resources). ALMIRA
522 aims to explore the modulation of landscape mosaics to adapt to the Mediterranean Rainfed
523 Agrosystems to Climate Change. For that purpose, ALMIRA proposes to design, implement and
524 test a new Integrated Assessment Modelling approach that explicitly i) includes innovations and
525 actions in prospective scenarios for landscape evolutions, and ii) addresses landscape mosaics and
526 processes of interest from the agricultural field to the resource governance catchment.

527 *Towards a high resolution for mapping Mediterranean soil properties*

528 A systematic soil survey of the Mediterranean basin using the most updated technology and
529 scientific knowledge is still lacking for a site-specific adaptation of local mitigation strategies and
530 should be one of the priority actions in the near future. The specifications of this survey may follow
531 those of the new Digital Soil Map of the world as targeted by the GlobalSoilMap project (Sanchez
532 et al, 2009; Arrouays et al, 2014a). This targeted global soil map is expected to provide quantitative
533 estimates of major soil properties with associated uncertainties at the nodes of a 90 m x 90 m grid
534 covering the planet and for a set of fixed soil depth intervals ranging from 0 to 2 metres. This new
535 soil map is expected to be largely available through free-access web portals. Researchers (Arrouays
536 et al, 2014b) have suggested the rapid production of a first version of the global soil map by
537 applying largely tested Digital Soil Mapping (DSM) techniques (McBratney et al., 2003,
538 Lagacherie et al., 2007) to existing spatial datasets. These datasets include the input of globally
539 available landscape parameters (e.g., DTM, digital maps of land use, and multispectral remote
540 sensing) and legacy soil data (measured soil profiles, soil maps) that are available in existing soil
541 databases. Interest in the above-evoked Digital Soil Mapping approach for producing the new soil
542 map of the world was tested in various parts of the world including Mediterranean areas such as the
543 Cap Bon Region in northern Tunisia (Ciampalini et al, 2012) and the Languedoc-Roussillon Region
544 in southern France (Vaysse et Lagacherie, 2015). In this latter experiment, successful predictions
545 captured more than 50% of the variability in the mapped soil properties and provided realistic
546 estimates of the prediction uncertainty where possible (for the pH and OC in Languedoc-
547 Roussillon). However, the sparseness of the legacy soil data that were available in current soil
548 databases hampered the capture of the short-scale soil variations of soil properties within the
549 complex Mediterranean Soil patterns. A priority should be made for the densification of these soil
550 data by i) increasing the retrieval of legacy-measured soil profiles, ii) using soil sensing techniques
551 such as Vis-NIR hyperspectral imagery (Lagacherie & Gomez, 2013) or iii) reviving the field
552 collection of soil data following optimized sampling (Brus et al, 2011). These required efforts for
553 collecting soil data will likely not fully remove the uncertainty on the soil property predictions,
554 considering the short scale of variations of Mediterranean soils. However the expected progresses
555 brought by GlobalSoilMap – i.e. increasing the spatial resolution of soil predictions, providing
556 quantitative estimations and providing explicit values of expected uncertainty - may greatly help for
557 site-specific decision making.

559 **Conclusions**

560 The Mediterranean soil resource is a highly specific research object with regards to i) its remarkable
561 characteristics as caused by a unique combination of natural and anthropogenic soil-forming factors
562 and ii) the extent of the expected climate and societal changes that are expected to affect this
563 resource in this region of the world.

564 In this context, the preservation of Mediterranean soil resources encompasses three crucial
565 challenges: mitigating soil losses, avoiding soil salinization and maintaining carbon stocks. For
566 each of these challenges, there are specific studies to continue or initiate to try to gain a better
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568 understanding of the soil processes driving the trend evolutions in Mediterranean soil resources and
569 the mitigation strategies that should be applied to preserve these resources.
570 The effective application of these mitigation strategies also implies progress in the integrated
571 assessment of the Mediterranean agrosystems and in the design of site-specific adaptations to global
572 change. A significant contribution of soil scientists to this task will be to provide improved
573 information on fine-scale Mediterranean soil patterns through advanced Digital Soil mapping
574 techniques.
575 Finally, this paper has underscored the urgent need to deepen Mediterranean cooperation
576 with regards to soil research and to enrich the exchange and sharing of technologies,
577 resources, experiences and knowledge.

578 579 **Bibliography**

- 580
581 Alvaro-Fuentes J, Joaquin Morell F, Plaza-Bonilla D, Luis Arrue J, Cantero-Martinez C 2012.
582 Modelling tillage and nitrogen fertilization effects on soil organic carbon dynamics. *Soil &*
583 *Tillage Research* 120 : 32–39. doi: 10.1016/j.still.2012.01.009.
- 584
585 Arrouays, D., McBratney, A.B., Minasny, B., Hempel, J.W., Heuvelink, G.B.M., MacMillan, R.A.,
586 Hartemink, A.E., Lagacherie, P., McKenzie, N.J., 2014a. The GlobalSoilMap project
587 specifications, in: Arrouays, D., McKenzie, N.J., Hempel, J.W., Richer-de-Forges, A.C.,
588 McBratney, A.B. (Eds.), *GlobalSoilMap : Basis of the Global Spatial Soil Information*
589 *System.. CRC Press-Taylor & Francis Group, Boca Raton, USA, pp. 9–12.*
- 590
591 Arrouays, D., Grundy, M.G., Hartemink, A.E., Hempel, J.W., Heuvelink, G.B.M., Hong, S.Y.,
592 Lagacherie, P., Lelyk, G., McBratney, A.B., McKenzie, N.J., Mendonca Santos, M.L.,
593 Minasny, B., Montanarella, L., Odeh, I.O., Sanchez, P.A., Thompson, J.A., Zhang, G.-L.,
594 2014b. *GlobalSoilMap: Toward a Fine-Resolution Global Grid of Soil Properties*, in:
595 *Advances in Agronomy*. Chapter 3, pp. 93–134. doi : 10.1016/B978-0-12-800137-0.00003-0
- 596
597 ARP Parme, 2011 *Quelles recherches pour quel partenariat en Méditerranée, Atelier de reflexion*
598 *prospective PARME. ANR AGROPOLIS International Rapport Final. 191 pp*
- 599
600 Ayadi I, Abida H, Djebbar Y, Mahjoub R. 2010. Sediment yield variability in central Tunisia: a
601 quantitative analysis of its controlling factors. *Hydrological Sciences Journal* 55, 446–458. doi:
602 10.1080/02626661003741526
- 603
604 Amundson, R, Berhe, A A, Hopmans, J W, Olson, C, Sztein, A E, Sparks, D.L. 2015. Soil and
605 human security in the 21st century. *Science*, 348, 6235. doi: 10.1126/science.1261071.
- 606
607 Badraoui M, Stitou M. 2001. Status of soil survey and soil information system in Morocco. In :
608 Zdruli P et al, eds. *Soil resources of Southern and Eastern Mediterranean countries*. Bari : Centre
609 international de Hautes Etudes Agronomiques Méditerranéennes-Instituto Agronomico
610 Mediterraneo di Bari (Ciheam-IAMB).
- 611
612 Banwart S, Black H, Cai Z, Gicheru P, Joosten H, Victoria R, Milne E, Noellemeyer E, Pascual U,
613 Nziguheba G, Vargas R, Bationo A, Buschiazzi D, de-Brogniez D, Melillo J, Richter D,
614 Termansen M, van Noordwijk M, Goverse T, Ballabio C, Bhattacharyya T, Goldhaber M,
615 Nikolaidis N, Zhao Y, Funk R, Duffy C, Pan G, la Scala N, Gottschalk P, Batjes N, Six J, van
616 Wesemael B, Stocking M, Bampa F, Bernoux M, Feller C, Lemanceau P, Montanarella L 2014.
617 Benefits of soil carbon: report on the outcomes of an international scientific committee on
618 problems of the environment rapid assessment workshop. *Carbon Management*. 5, 2, 185-192.
619 doi : 10.1080/17583004.2014.913380

60
61
62
63
64
65

- 613 Ben Moussa-Machraoui S, Errouissi F, Ben-Hammouda M. and Noura S. 2010. Comparative
614 effects of conventional and no-tillage management on some soil properties under Mediterranean
615 semi-arid conditions in north-western Tunisia. *Soil & Tillage Research* 106 247–253. doi: 1
616 0.1016/j.still.2009.10.009
- 617 Bennouniche, M. 2014. Une innovation technique en train de se faire : le goutte à goutte en pratique
618 au Maroc : acteurs, bricolages et efficacités. Thèse en sciences agronomiques à l'université
619 Montpellier II. 139p. <https://hal.archives-ouvertes.fr/tel-01130810>
- 620 Ben Slimane A, Raclot D, Evrard O, Sanaa M, Lefèvre I, Le Bissonnais Y 2015. Relative
621 contribution of surface and subsurface erosion to reservoir siltation in Tunisia. *Land degradation
622 and Development*. doi: 10.1002/ldr.2387
- 623 Bernoux M, Chevallier T 2014. Carbon in dryland soils : Multiple essential functions. Les dossiers
624 thématiques du CSFD. N°10, juin 2014. CSFD/Agropolis International, Montpellier, France. 44
625 pp.
- 626 Birch H 1958. The effect of soil drying on humus decomposition and nitrogen availability. *Plant
627 and soil* 10, 9-31. doi: 10.1007/BF01343734
- 628 Bornand M, Legros J P, Rouzet C, 1994. Les banques régionales de données-sols. Exemple du
629 Languedoc-Roussillon. *Etude et Gestion des Sols* 1, 67–82.
- 630 Bouarfa S, Marlet, S, Douaoui A, Hartani T, Mekki I, Ghazouani W G, Ben Aissa I, Vincent B,
631 Hassani F, and Kuper M. Salinity patterns in irrigation systems, a threat to be demystified, a
632 constraint to be managed: Field evidence from Algeria and Tunisia, *Irrigation and Drainage*, vol.
633 58, no. S3, pp. S273–S284, Jul. 2009.
- 634 Brahim N, Bernoux M, Gallali T. 2012. Pedotransfer functions to estimate soil bulk density for
635 Northern Africa: Tunisia case. *Journal of Arid Environments*. 81, 77-83. doi:
636 10.1016/j.jaridenv.2012.01.012
- 637 Brus, D.J., Kempen B., Heuvelink G.B.M. 2011. Sampling for validation of digital soil mapping.
638 *European Journal of Soil Science*. 62, 394-407. doi: 10.1111/j.1365-2389.2011
- 639 Carella, M. , A. Parant. 2014. Demographic trends and challenges in the Mediterranean. *South East
640 European Journal of Political Science (SEEJPS)*, Vol. II, No. 3. 10-21.
- 641 Cerdà A, Giménez-Morera A, Bodí MB. 2009. Soil and water losses from new citrus orchards
642 growing on sloped soils in the western Mediterranean basin. *Earth Surface Processes and
643 Landforms* 34, 1822–1830. doi: 10.1002/esp.1
- 644 Cerdan O, Govers G, Le Bissonnais Y, Van Oost K, Poesen J, Saby N, Gobin A, Vacca A, Quinton
645 J, Auerswald K, Klik A, Kwaad FJPM, Raclot D, Ionita I, Rejman J, Rouseva S, Muxart T,
646 Roxo MJ, Dostal T. 2010. Rates and spatial variations of soil erosion in Europe: a study based on
647 erosion plot data. *Geomorphology* 122, 167–177. doi : 10.1016/j.geomorph.2010.06.011
- 648 Ciampalini R., Lagacherie P., Hamrouni H., 2012. Documenting GlobalSoilMap.net grid cells from
649 legacy measured soil profile and global available covariates in Northern Tunisia, in: Minasny,
650 B., Malone, B.P., McBratney, A.B. (Eds.), *Digital Soil Assessments and Beyond*. CRC Press,
651 pp. 439–444.
- 652 Crouvi O., Zaidenberg, R., Shapiro, M., 2013. Soil Resources of Israel, in *Soil Resources of
653 Mediterranean and Caucasus countries*, Ed. Yigini, Y., Panagos, P. and Montanarella, L.. JRC
654 Ispra. 113-132
- 655 Dahan R, Boughlala M, Mrabet R, Laamari A, Balaghi, R, Lajouad, L. 2012. A review of available
656 knowledge on land degradation in Morocco. ISBN: 92-9127-265-5. ICARDA publication. 38p.

- 657 Darwish T, 2013. Soil Resources of Lebanon, in Soil Resources of Mediterranean and Caucasus
658 countries, Ed. Yigini, Y., Panagos, P. and Montanarella, L.. JRC Ispra 149-174
- 659 De Franchis L, Ibanez L, 2003. Threats to Soils in Mediterranean Countries. Document review.
660 Plan Bleu papers 2. Plan Bleu UNEP Sophia Antipolis. 67 pp.
661 <http://www.prosodol.gr/sites/prosodol.gr/files/Threats%20of%20soils%20Med.pdf>
- 662 De Graaff J, Aklilu A, Ouessar, M, Asins-Velis S, Kessler A, 2013 The development of soil and
663 water conservation policies and practices in five selected countries from 1960 to 2010. Land Use
664 Policy, 32: 165– 174. doi: 10.1016/j.landusepol.2012.10.018
- 665 De Paz Bécares J M, Visconti Reluy F, Molina M J, Sánchez J, Martínez D, and Ingelmo Sánchez
666 F, 2012. Prediction of the effects of climate change on the soil salinity of an irrigated area under
667 Mediterranean conditions, in European Confederation of Soil Science Societies (Poster).
- 668 De Vente J, Poesen J, Bazzofi P, Van Rompaey A, Verstraeten G. 2006. Predicting catchment
669 sediment yield in Mediterranean environments: the importance of sediment sources and
670 connectivity in Italian drainage basins. Earth Surface Processes and Landforms 31: 1017–1034.
671 10.1002/esp.1305
- 672 De Vente J, Poesen J, Verstraeten G, Van Rompaey A, Govers G. 2008. Spatially distributed
673 modelling of soil erosion and sediment yield at regional scales in Spain. Global and Planetary
674 Change 60, 393–415. doi: 10.1016/j.gloplacha.2007.05.002
- 675 Dominati E, Patterson M, Mackay A, 2010. A framework for classifying and quantifying the natural
676 capital and ecosystem services of soils. Ecological Economics 69(9), 1858–1868.
677 doi:10.1016/j.ecolecon.2010.05.002
- 678 Dubrovský M, Hayes M, Duce P, Trnka M, Svoboda M, Zara P 2013. Multi-GCM projections of
679 future drought and climate variability indicators for the Mediterranean region. *Regional
680 Environmental Change*, 1–13. doi:10.1007/s10113-013-0562-z
- 681 European Soil Bureau Network, Soil Atlas of Europe, European Commission, 2005, 128 pp Office
682 for Official Publications of the European Communities, L-2995 Luxembourg
- 683 FAO. 1994. Water quality for agriculture. R.S. Ayers and D.W. Westcot (Eds). FAO Irrigation And
684 Drainage Paper 29. ISBN 92-5-102263-1.
- 685 FAO. 2012. World agriculture towards 2030/2050 The 2012 Revision. Nikos Alexandratos and
686 Jelle Bruinsma Eds. ESA Working Paper No. 12-03.
- 687 Francia Martínez J R, Durán Zuazo V H, Martínez Raya A, 2006. Environmental impact from
688 mountainous olive orchards under different soil-management systems (SE Spain). Science of the
689 Total Environment 358 (1–3), 46–60. doi : 10.1016/j.scitotenv.2005.05.036
- 690 Friedrich T, Kassam A, Corsi S. 2014. Conservation agriculture in Europe. In. R.A. Jat, K.L.
691 Sahrawat and A.H. Kassam (Eds). Conservation agriculture: Global prospects and
692 challenges. CABI –International, ISBN 978-1-78064-259-8. p 127-179.
- 693 Gabriel J L, Almendros P, Hontoria C, and Quemada M, The role of cover crops in irrigated
694 systems: Soil salinity and salt leaching, Agriculture. Ecosystems & Environment, vol. 158, pp.
695 200–207, 2012. doi: 10.1016/j.agee.2012.06.012
- 696 García-Ruiz J.M, Lana-Renault N. 2011. Hydrological and erosive consequences of farmland
697 abandonment in Europe, with special reference to the Mediterranean region – A review.
698 Agriculture, Ecosystems and Environment, 140, 317–338. doi: 10.1016/j.agee.2011.01.003
- 699 García-Ruiz JM, Nadal-Romero E, Lana-Renault N, Beguería S. 2013. Erosion in Mediterranean
700 landscapes: changes and future challenges. Geomorphology 198, 20–36.
701 doi:10.1016/j.geomorph.2013.05.023

- 702 Ghassemi F, Jakeman A J, Nix H A 1995. Salinisation of land and water resources: human causes,
703 extent, management and case studies 544 pp. ISBN 0-85198-906-3
- 704 Gómez J A., Sobrinho T A, Girálde, J , Fereres E, 2009. Soil management effects on runoff, erosion
705 and soil properties in an olive grove of Southern Spain. *Soil and Tillage Research*, 102(1), 5-13.
706 doi: 10.1016/j.still.2008.05.005
- 707 Gomez C, Lagacherie P, Bacha S, 2012. Using Vis-NIR hyperspectral data to map topsoil
708 properties over bare soils in the Cap-Bon Region, Tunisia, in: Minasny, B., Malone, B.,
709 McBratney, A.B. (Eds.), *Digital Soil Assessment and Beyond*. Taylor & Francis, London, pp.
710 387–392.
- 711 Goncalves M C, Reiss L C L, Paz, J G, 1999. Progress of soil survey in Portugal. in. Bullock, P.,
712 Jones, : R.J.A, and Montanarella, L. *Soil Resources of Europe*, European Soil Bureau research
713 report n°6, 129-133.
- 714 González-Hidalgo J C , Pëna-Monné J L, de Luis, M, 2007. A review of daily soil erosion in
715 Western Mediterranean areas. *Catena* 71, 193–199. doi: 10.1016/j.catena.2007.03.005
- 716 Govers G, Van Oost K, Wang Z 2014. Scratching the critical zone: the global footprint of
717 agricultural soil erosion. *Procedia Earth and Planetary Science* 10, 313-318. doi:
718 10.1016/j.proeps.2014.08.023
- 719 Gumiere S., Bailly J S, Cheviron B, Raclot D, Le Bissonnais Y, Rousseau A, 2014. Evaluating the
720 Impact of the Spatial Distribution of Land Management Practices on Water Erosion: Case Study
721 of a Mediterranean Catchment. *Journal of Hydrologic Engineering*. 20 (6)
722 doi:10.1061/(asce)he.1943-5584.0001076
- 723 Hamdi S, Chevallier T, Ben Aïssa N, Ben Hammouda M, Gallali T, Chotte J L , Bernoux M. 2011.
724 Short-term temperature dependence of heterotrophic soil respiration after one-month of pre-
725 incubation at different temperatures. *Soil Biology and Biochemistry*, 43, 1752-1758.
726 doi:10.1016/j.soilbio.2010.05.025
- 727 Hamdi S, Moyano F, Sall S, Bernoux M, Chevallier T 2013. Synthesis analysis of the temperature
728 sensitivity of soil respiration from laboratory studies in relation to incubation methods and soil
729 conditions. *Soil Biology and Biochemistry*, 58, 115-126. doi: 10.1016/j.soilbio.2012.11.012
- 730 Henry M., Valentini R, Bernoux M 2009. Soil carbon stocks in ecoregions of Africa.
731 *Biogeosciences Discuss*, 6, 797-823. doi:10.5194/bgd-6-797-2009
- 732 IAASTD, 2009; *Agriculture at the crossroad*. Vol. 1 Central & West Asia & North Africa. Report.
733 Ed Mc Intyre, B.D., Herren, H.R., Wakhungu, J., Watson, R.T. <http://www.agassessment.org/>
734 179 pp
- 735 ICID, 2014. Annual report 2014-15. www.icid.org/world%20irrigated%20area.pdf
- 736 IPCC, 2014: *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III
737 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing
738 Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
- 739 IUSS (International Union of Soil Scientists) Working Group WRB. 2006. *World Reference Base*
740 *for Soil Resources 2006*, World Soil Resources Report No. 103. Food and Agriculture
741 Organization of the United Nations, Rome, Italy.
- 742 van der Kooij, Zwarteveen M, Boesveld H, Kuper M 2013. The efficiency of drip irrigation
743 unpacked. *Agricultural Water Management*, Volume 123, Pages 103–110. doi:
744 10.1016/j.agwat.2013.06.012.

- 745 Jemai I, Ben Aissa N, Ben Guirat S, Ben Hammouda M, Gallali T 2012. On-farm assessment of
746 tillage impact on the vertical distribution of soil organic carbon and structural soil properties in a
747 semiarid region in Tunisia. *Journal of Environmental Management* 113 : 488-494. doi:
748 10.1016/j.jenvman.2012.05.029
- 749 Jones A, Breuning-Madsen H, Brossard M, Dampha A, Deckers J, Dewitte O, Gallali T, Hallett S,
750 Jones R, Kilasara M, Le Roux P, Michéli E, Montanarella L, Spaargaren O, Thiombiano L, Van
751 Ranst E, Yemefack, M, Zougmore R, (eds.), 2013. *Soil Atlas of Africa*. European Commission,
752 Publications Office of the European Union, Luxembourg. 176 pp. ISBN 978-92-79-26715-4, doi
753 10.2788/52319
- 754 van Ittersum, M K, Ewert F, Heckelei T, Wery J, Alkan Olsson J, Andersen E, Bezlepkina I,
755 Brouwer F, Donatelli M, Flichman G, Olsson ., Rizzoli A E, van der Wal, T, Wien J E, Wolf J,
756 2008. Integrated assessment of agricultural systems – A component-based framework for the
757 European Union (SEAMLESS). *Agricultural Systems* 96, 150–165. doi:10.1016/j.agsy.2007.07.009
- 758 Jacobsen S E., Jensen C R, and Liu F. 2012. Improving crop production in the arid Mediterranean
759 climate, *F. Crop. Res.*, vol. 128, pp. 34–47, 2012. doi: 10.1016/j.fcr.2011.12.001
- 760 Jones R J A, Hiederer R, Rusco E et al. (2005) Estimating organic carbon in the soils of Europe for
761 policy support. *European Journal of Soil Science*, 56, 655–671. doi: 10.1111/j.1365-
762 2389.2005.00728.x
- 763 Kassam A., Friedrich T., Derpsch R, Lahmar R, Mrabet R, Basch G, González-Sánchez E J , Serraj
764 R 2012. Conservation agriculture in the dry Mediterranean climate. *Field Crops Research* 132, 7–17
765 . doi:10.1016/j.fcr.2012.02.023
- 766 Lagacherie, P., McBratney, A.B., Voltz, M. (Eds.), 2007. *Digital Soil Mapping - An Introductory
767 perspective*. Elsevier, Amsterdam.
- 768 Lagacherie, P., Gomez, C., 2012. What can GlobalSoilMap expect from Vis-NIR HyperSpectral
769 Imagery in the near future? in: Arrouays, D., McKenzie, N.J., Hempel, J.W., Richer-de-Forges,
770 A.C., McBratney, A.B. (Eds.), *GlobalSoilMap : Basis of the Global Spatial Soil Information
771 System..* CRC Press-Taylor & Francis Group, Boca Raton, USA, pp387–392.
- 772 Lahmar R Ruellan. A, 2007. Dégradation des sols et stratégies coopératives en Méditerranée : la
773 pression sur les ressources naturelles et les stratégies de développement durable. *Cahiers
774 Agricultures* 16(4) : 318-323.
- 775 Lal R. 1998. Soil Erosion Impact on Agronomic Productivity and Environment Quality. *Critical
776 Reviews in Plant Sciences*, 17(4), 319-464 . 10.1080/07352689891304249
- 777 Lal R 2004. Soil carbon sequestration impacts on global climate change and food security. *Science*.
778 304 (5677), 1623-1627. doi: 10.1126/science.1097396
- 779 Laudicina V A, Novara A, Barbera V, Egli M, Badalucco L 2014. Long term tillage and cropping
780 system effects on chemical and biochemical characteristics of soil organic matter in a
781 Mediterranean semiarid environment. *Land Degradation & Development*. doi: 10.1002/ldr.2293
- 782 Lionello P, Abrantes F, Gacic M, Planton S, Trigo R, Ulbrich U, 2014. The climate of the
783 Mediterranean region: research progress and climate change impacts. *Reg. Environ. Chang.* 14,
784 1679–1684. doi 10.1007/s10113-014-0666-0
- 785 McBratney A B, Mendonca Santos M L, Minasny B, 2003. On digital soil mapping. *Geoderma* 117,
786 3–52. doi:10.1016/S0016-7061(03)00223-4

- 787 Marques M J, García-Muñoz S, Muñoz-Organero G and Bienes R . 2010, Soil conservation beneath
788 grass cover in hillside vineyards under Mediterranean Climatic conditions (Madrid, Spain). *Land*
789 *Degrad. Dev.*, 21: 122–131. doi: 10.1002/ldr.915
- 790 Mrabet R, Saber N, El Brahli A, Lahlou S, Bessam F 2001. Total, particulate organic matter, and
791 structural stability of a Calcixeroll soil under different wheat rotations and tillage systems in a
792 semiarid area of Morocco. *Soil Tillage Research* 57, 225-235. doi.org/10.1016/S0167-
793 1987(00)00180-X
- 794 Mrabet R 2011. No-tillage agriculture in West Asia & North Africa. In. *Rainfed farming systems.*
795 *Tow, P.G., Cooper, I.M., Partridge, I, & Birch. C.J. (Eds). Springer, Dordrecht Netherlands, pp.*
796 *1015-1042. ISBN: 978-1-4020-9131-5.*
- 797 Mrabet R, Moussadek R, Fadlaoui A, van Ranst E 2012. Conservation agriculture in dry areas of
798 Morocco. *Field Crops Research*, 132, 84–94. doi:10.1016/j.fcr.2011.11.017
- 799 Moreno F Arrúe J L, Cantero-Martínez C, López M V, Murillo J M, Sombrero A, López-Garrido
800 R, Madejón E, Moret D, Álvaro-Fuentes J. 2010. Conservation Agriculture Under Mediterranean
801 Conditions in Spain. *Sustainable Agriculture Reviews*. 5 :175-193. doi: 10.1007/978-90-481-
802 9513-8_6
- 803 Morgan R P C. 2005 *Soil Erosion and Conservation*, 3rd edition. Blackwell Publishing, Oxford,
804 304 pp.
- 805 Nieto O M, Castro J, Fernández E, Smith P 2010. Simulation of soil organic carbon stocks in a
806 Mediterranean olive grove under different soil-management systems using the RothC model.
807 *Soil Use and Management* 26, 118–125. doi: 10.1111/j.1475-2743.2010.00265.x
- 808 Paranychianakis N V, Chartzoulakis K S 2005. Irrigation of Mediterranean crops with saline water:
809 from physiology to management practices. *Agriculture, Ecosystems & Environment* Volume 106,
810 Issues 2–3, 2 April 2005, Pages 171–187. doi: 10.1016/j.agee. 2004.10.006.
- 811 Pardini, G, Gispert M, Dunjo G, 2004. Distribution Patterns of Soil Properties in a Rural
812 Mediterranean Area in Northeastern Spain. *Mountain Research and Development* 24, 44–51.
813 [http://dx.doi.org/10.1659/02764741\(2004\)024\[0044:DPOSPI\]2.0.CO;2](http://dx.doi.org/10.1659/02764741(2004)024[0044:DPOSPI]2.0.CO;2)
- 814 Paroissien J B, Lagacherie P, Le Bissonnais Y 2010. A regional-scale study of multi-decennial
815 erosion of vineyard fields using vine-stock unearthing–burying measurements. *Catena*, 82, 159-
816 168. doi: 10.1016/j.catena.2010.06.002
- 817 Paroissien J B, Darboux F, Couturier A, Devillers B, Mouillot F, Raclot D, Le Bissonnais Y 2015.
818 A method for modeling the effects of climate and land use changes on erosion and sustainability
819 of soil in a Mediterranean watershed (Languedoc, France). *Journal of Environmental*
820 *Management*, 150, 57-68. doi: 10.1016/j.jenvman.2014.10.034.
- 821 Poesen J, Nachtergaele J, Verstraeten G, Valentin C. 2003. Gully erosion and environmental
822 change: importance and research needs. *Catena* 50, 91–133. doi: 10.1016/S0341-8162(02)00143-
823 1
- 824 Pribyl D W, 2010. A critical review of the conventional SOC to SOM conversion factor. *Geoderma.*
825 156: 75-83. doi: 10.1016/j.geoderma.2010.02.003
- 826 Qadir M, Quilléro, E, Nangia V, Murtaza G, Singh M, Thomas R J, Drechsel P, and Noble A D,
827 Economics of salt-induced land degradation and restoration, *Nat. Resour. Forum*, vol. 38, no. 4,
828 pp. 282–295, 2014. doi: 10.1111/1477-8947.12054

- 829 Raclot D, Le Bissonnais Y, Louchart X, Andrieux P, Moussa R, Voltz M. 2009. Soil tillage and
830 scale effects on erosion from fields to catchment in a Mediterranean vineyard area. *Agriculture,*
831 *Ecosystems and Environment*, 134, 201–210. doi:10.1016/j.agee.2009.06.019
- 832 Ryan J, de Pauw E, Gomez H & Mrabet R 2006. Drylands of the Mediterranean Zone: Biophysical
833 Resources and Cropping Systems. G.A. Peterson et al. (Eds). *Dryland Agriculture* (2nd edition).
834 American Society of Agronomy Monograph N° 23. Pp: 577-624. LCCCN: 2006922050
- 835 Sanchez P A, Ahamed S, Carré F, Hartemink, A E, Hempel J, Huising J, Lagacherie P, McBratney
836 A B, McKenzie N J, Mendonca-Santos M L. Minasny B, Montanarella L, Okoth, P, Palm C A ,
837 Sachs J D, Shepherd K D, Vagen T ,G, Vanlauwe B, Walsh M G, Winowiecki L A, Zhang G L,
838 2009. Digital Soil Map of the World. *Science* (80-.). 325, 680–681. doi: 10.1126/science.1175084
- 839 Simmoneaux V, Cheggour A, Deschamps C, Mouillot F, Cerdan O, Le Bissonnais Y 2015 Land use
840 and climate change effects on soil erosion in a semi-arid mountainous watershed (High Atlas,
841 Morocco). *Journal of Arid Environments* 122, 64:75. doi:10.1016/j.jaridenv.2015.06.002
- 842 Sluiter R, Jong S M, 2006. Spatial patterns of Mediterranean land abandonment and related land
843 cover transitions. *Landscape Ecology* 22, 559–576. doi: 10.1007/s10980-006-9049-3
- 844 Smedema L K, Abdel-dayem S, Ochs WJ. 2000. Drainage and agricultural development. *Irrigation*
845 *and Drainage Systems* 14: 223–235. doi:10.1023/A:1026570823692
- 846 Sommer R, Ryan J, Masri S, Singh M, Diekmann J 2011. Effect of shallow tillage, moldboard
847 plowing, straw management and compost addition on soil organic matter and nitrogen in a
848 dryland barley/wheat-vetch rotation. *Soil & Tillage Research* 115-116, doi:
849 10.1016/j.still.2011.06.003
- 850 Szabolcs I. 1989. Salt-affected soils. CRC Press, Boca Raton, 274 pp
- 851
- 852 Tarolli P, Preti F, Romano N. 2014. Terraced landscapes: From an old best practice to a potential
853 hazard for soil degradation due to land abandonment. *Anthropocene*, 6, 10–25. doi:
854 10.12691/jgg-4-4-1
- 855 Thornes J B. 2002 Emerging Mosaics. In Geeson N.A ., Brandt C.J., Thornes J.B. (Eds)
856 *Mediterranean Desertification – A Mosaic of processes and responses*. John Wiley and Sons,
857 LTD. 419-427
- 858 Vanmaercke M, Poesen J, Verstraeten G, de Vente J, Ocakoglu F. 2011. Sediment yield in Europe:
859 spatial patterns and scale dependency. *Geomorphology* 130, 142–161.
860 doi:10.1016/j.geomorph.2011.03.010
- 861 Vanmaercke M, Maetens W, Poesen J, Jankauskas B, Jankauskiene G, Verstraeten G, de Vente J
862 2012. A comparison of measured catchment sediment yields with measured and predicted
863 hillslope erosion rates in Europe. *Journal of Soils and Sediments* 12, 586–602.
864 doi:10.1007/s11368-012-0479-z
- 865 Vaysse K, Lagacherie P, 2015. Evaluating Digital Soil Mapping approaches for mapping
866 GlobalSoilMap soil properties from legacy data in Languedoc-Roussillon (France). *Geoderma*
867 *Regional*. 4, 20–30. doi: 10.1016/j.geodrs.2014.11.003
- 868 Visconti F , de Paz J M, Rubio J L, and Sánchez, J. 2011 SALTIRSOIL: A simulation model for the
869 mid to long-term prediction of soil salinity in irrigated agriculture. *Soil Use & Management*, vol.
870 27, no. 4, pp. 523–537. doi: 10.1111/j.1475-2743.2011.00356.x

- 871 Visconti F, de Paz J M, Molina M J, and Sánchez J. 2012 Advances in validating SALTIRSOIL at
872 plot scale: First results. *J. Environ. Manage.*, vol. 95, no. suppl., pp. S31–S36,
873 doi:10.1016/j.jenvman.2011.03.020
2
- 874 Wischmeier W H 1975. Estimating the soil loss equation's cover and management factor for
875 undisturbed area. In *Present and prospective technology for predicting sediment yields and*
876 *sources*. USDA ARS Publication ARS-S-40: 118–24.
- 877 Woodward J C 1995. Patterns of erosion and suspended sediment yield in Mediterranean river
878 basins, in: Foster, I. D. L., Gurnell, A. M., Webb, B.W. (Eds.), *Sediment and Water Quality in*
879 *River Catchments*. Wiley, Chichester, 365–389.
- 880 World Bank 2010. *The cost of environmental degradation: Case studies from the Middle East and*
881 *North Africa*. Edited by Leila Croitrou and Maria Sarraf. *Directions in Development*; ISBN: 978-
882 0-8213-8318-6; SKU: 18318
15
- 883 Yaalon D H, 1997. Soils in the Mediterranean region: what makes them different? . *CATENA* 28,
884 157–169. doi: 10.1016/S0341-8162(96)00035-5
16
- 885 Yemadje P L, Guibert H, Chevallier T, Deleporte P, Bernoux M 2016. Effect of biomass
886 management regimes and wetting-drying cycles on soil carbon mineralization in a Sudano-
887 Sahelian region. *Journal of Arid Environments*. 127, 1-6.
888 <http://dx.doi.org/10.1016/j.jaridenv.2015.10.017>
25
- 889 Yemadje P L, Chevallier T, Guibert H, Bertrand I, Bernoux M 2017. Wetting-drying cycles do not
890 increase organic carbon and nitrogen mineralization in soils with straw amendment. *Geoderma.*, in
891 press. doi:10.1016/j.geoderma.2016.06.023
30
- 892 Yigini, Y. ; Panagos, P., Montanarella, L., 2013. Soil resources of Mediterranean and Caucasian
893 countries. Extension of European Soil Database. JRC Technical Report. European Commission.
894 225 pp
32
- 895 Zdruli P., Jones R J A, Montanarella L 2004. *Organic Matter in the Soils of Southern Europe*.
896 *European Soil Bureau Research Report No. 15*. Office for Official Publications of the European
897 Communities, Luxembourg. EUR 21083 EN, 17pp.
35
- 898 Zdruli P. 2005 *Soil surveys in Albania*. European Soil Bureau, research report n°9
41
- 899 Zdruli P, Lacirignola C, Lamaddalena N, and Trisorio Liuzzi G. 2007. The EU-funded
900 MEDCOASTLAND Thematic Network and its Findings in Combating Land Degradation in the
901 Mediterranean region. In: M.V.K. Sivakumar and N. Ndiang'ui (eds). *Climate and Land*
902 *Degradation*. Environmental Science and Engineering. Proceedings of the International Workshop
903 on Climate and Land Degradation, held in Arusha, Tanzania 11-15 December 2006 sponsored by
904 the World Meteorological Organisation and United Nations Convention to Combat Desertification.
905 Springer-Verlag Berlin Heidelberg 2007. pp 422-434.
49
- 906 Zdruli, P., Kapur, S., Çelik, I., 2011. Soils of the Mediterranean Region, Their Characteristics,
907 Management and Sustainable Use, in: Kapur, S., Eswaran, H., Blum, W. (Eds.), *Sustainable Land*
908 *Management*. Springer-Verlag, Berlin/Heidelberg, pp. 125–142.
54
- 909 Zdruli P. 2014. Land resources of the Mediterranean: Status, pressures, trends and impacts on
910 future regional development, *L. Degrad. Dev.*, vol. 25, no. 4, pp. 373–384. doi; 10.1002/ldr.2150
59
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1 thank you for the revision. Our Guest Editor Wolfgang Ludwig now recommends
2 acceptance of the paper and I agree about the scientific content.

3 **Thank you both for acknowledging that the scientific content is OK.**

4
5
6 However, you seem to have ignored my advice from the previous decision letter
7 which was "In addition, I suggest to delete the abstract and write a fresh one.
8 Remember that an abstract should not be part of the introduction - it should rather
9 deliver as many of the findings and conclusions as possible."

10
11
12 Indeed, I am quite serious about this. An abstract, and also the title, are the parts of
13 any publication that are read by most people, and their information content is very
14 important. To say that some authors did this or that does not belong into an abstract.
15 So I would like to repeat this request, and also expand it to provide me with a more
16 specific title that precisely speaks to the content of your paper. Note there is also no
17 such thing in English as "Global Changes".

18
19
20 **The abstract has been deeply reworked for matching your advice. There is no more**
21 **direct reference to authors and we provide a more precise description of our finding.**
22 **The title of the paper was modified too for giving more precise details on the paper.**

23
24
25 Going through the paper, I also notice that there are minor changes needed: you
26 cannot use "GC" as an acronym, spell out global change if you mean that, but not in
27 plural.

28 **GC were replaced by « global change » and the 's' were deleted**

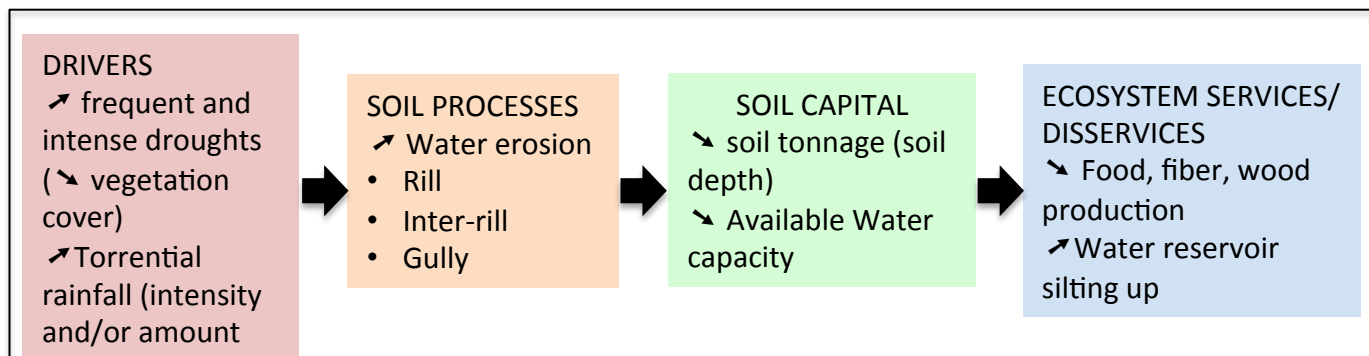
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31 Some references still lack doi-numbers.

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34 **We added 6 more doi to our reference list. 57% of our reference are now**
35 **documented with a doi. In spite of our efforts, we did not find any doi for the**
36 **remaining references. Looking at the five most recent REEC papers published as**
37 **open access papers (on 2017 May18th), we observed that the ratio of documented**
38 **doi was between 5% and 72% (between 56% and 72% if we only consider « non**
39 **social science » papers). Our paper match therefore what has been achieved in**
40 **REEC recent papers.**

41
42
43 Finally, I did not earlier pay much attention to the figures. They definitely need to be
44 designed properly. At the moment they are rather tables with some arrows and it is
45 not at all clear to me what they are supposed to represent. Please use an appropriate
46 drawing software to prepare these figures - the publisher has now facilities to offer for
47 doing this in your place.

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50 **The figures have been modified for not looking like tables. This allowed to better**
51 **represent the status of the « mitigation strategies » that have been discussed by the**
52 **reviewers in earlier versions.**

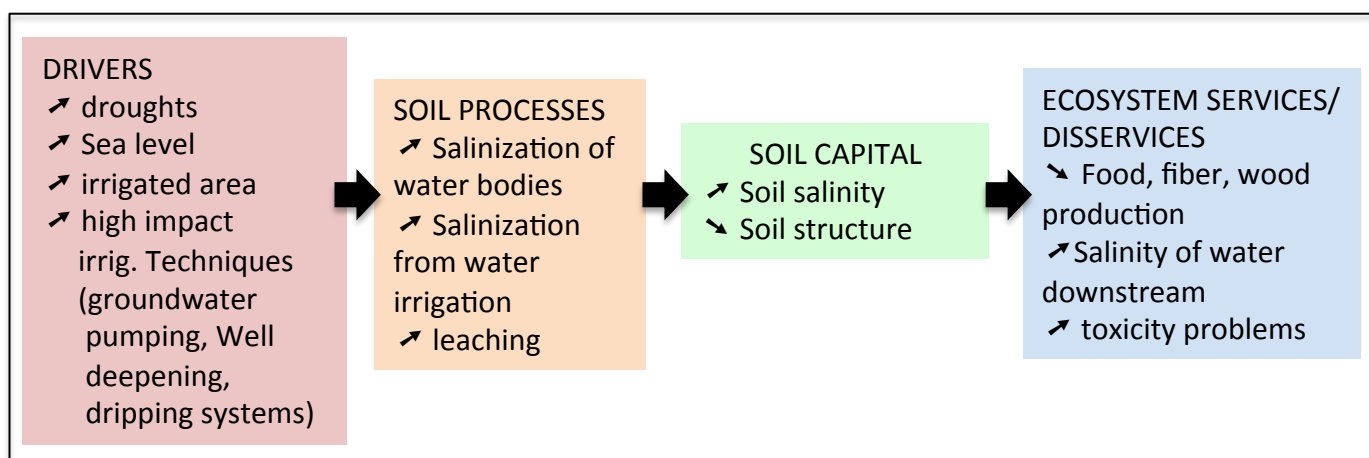
Figure



RECOMMENDED MITIGATION STRATEGIES

- ↗ Soil and Water Conservation techniques,
- ↗ vegetation regeneration, forestry plantations and agroforestry
- ↗ Rangeland restoration (forage trees, grass-legume mixtures etc..)

Figure



RECOMMENDED MITIGATION STRATEGIES

- ↗ artificial drainage,
- ↗ Irrigation practices for controlling the salt budget
- ↗ Salt-tolerant crops and plants.

Figure

