Assessment of sustainable land management practices in Mediterranean rural regions

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0. Abstract

Sustainable land management practices can be suitable vehicles to simultaneously address the causes and consequences of land degradation, desertification, and climate change in land managed systems. Here, we assess the potential of a variety of sustainable land management practices that, beyond addressing specific and local issues, assist in tackling Mediterranean Basin-wide land-use challenges. With this work, we aim to highlight those options that simultaneously promote local and regional Basin-wide adaptation. To do that, we developed a novel multi-objective assessment that evaluates the effectiveness of 104 practices adopted within the Mediterranean Basin and documented in the World Overview of Conservation Approaches and Technologies global database. Results indicate that agroforestry and green covers in perennial woody crops can promote multiple ecosystem services while addressing climate change adaptation. We further argue that these two practices together with reforestation, assist in regulating the hydrological cycle of the Basin and maintaining its multifunctional landscape. Lastly, we reflect on potential biophysical and socio-economic barriers and opportunities associated with the implementation of the three practices.

Keywords: Mediterranean Basin; Desertification; Climate change adaptation; WOCAT; Sustainable land management.

1. Introduction

Changes in land-use in the Mediterranean Basin have intensified desertification and landscape degradation during the Holocene. Likely, even small changes in land-use had multiple effects on several components of the environment and hydrological system, which, subsequently, affected the regional climate (Ruiz and Sanz, 2020). Today the Basin is subject to increasing human pressure due to affluence growth and rising demand for goods and services, with subsequent negative impacts on biodiversity, the local climate, the soil's structure and health, and the carbon, nutrient, and water cycles (Plan bleu, 2016). Moreover, unsustainable land management practices and intensive agricultural systems, have been put forward to explain the region's desertification and land degradation trend (Vanwalleghem et al., 2017 and references therein), along with rural exodus and an increase in the tourism activities. According to García-Ruiz et al. (2011), future scenarios of land management in the Mediterranean Basin will promote shrublands in mountain areas together with urbanized soils and irrigated landfills in the lowlands, due to abandonment of the rural lifestyle.

Besides this, the Mediterranean Basin has witnessed more unstable weather patterns for the past few millennia, with successive reductions in mean annual precipitations, increases in mean air temperatures, and more frequent occurrences of high-intensity rainfall episodes and extreme climatic events such as floods, droughts, and heatwaves (CDC, 2018; Lionello et al., 2017; Collins et al., 2013; Combourieu-Nebout et al., 2013). Moreover, predicted climate change is expected to accentuate man-induced desertification processes, thus, endangering the resilience of the Mediterranean ecosystems and societies and compromising their adaptation capacities. Among others, but most importantly, it will critically impact the already fragile hydrological budget of the region (Pausas and Millán, 2019; Millan et al., 2005), compromising the effectiveness of efforts aimed at combating desertification, promoting rural development, and wisely managing water resources (Xoplaki et al., 2004). It becomes, therefore, more relevant to consider the land-atmosphere interactions while planning land restauration in the Basin (Millán et al., 2005) if to be successful in restoring the Mediterranean landscapes.

Reaching rural sustainable development in the Basin becomes one of the major challenges facing Mediterranean societies nowadays. Traditionally, rural sustainability has been achieved by taking specific and local actions referred to as Sustainable Land Management (SLM) practices. SLM was defined by the UN Earth Summit 1992 as "*the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions"*. Apart from the traditional use and know-how of rural peoples, scientific evidence also unveils SLM as a successful tool for increasing the resilience of socio-ecological systems and guaranteeing their capability of providing services in the long-term. Thus, SLM practices represent a holistic approach to achieving long-term productive ecosystems at low economic efforts (Sanz et al., 2017).

SLM practices should be designed and implemented at the local scale to guarantee the socio-ecological system´s capability of providing services to the local communities. Consequently, they are tightened to the specific characteristics of their site of implementation. However, if properly nested at the regional scale, SLM practices can become paramount to address regional and multifaceted environmental challenges, such as regional land degradation, biodiversity loss, food security, climate change mitigation and adaptation, water scarcity, and loss of landscape multifunctionality. In this context, and despite interdisciplinary works about integrated assessments on the ecological and social impacts of SLM (e.g. Sanz et al., 2017; Marques et al., 2016; Liniger et al., 2007), no previous studies have evaluated the upscaling of locally-designed SLM practices to enhance the sustainability of the rural areas across the Mediterranean Basin.

This study aims to provide a framework to assess the potential of a variety of SLM practices that, beyond addressing specific and local issues assist in tackling Mediterranean Basin-wide challenges. To achieve this purpose, we develop a novel multi-objective assessment that takes into account a broader-regional perspective, this way supporting the upscaling of SLM measures. It consists of: i) an up-scaling of the practices; ii) the evaluation of each practice's potential in assisting five ecological functions; iii) the examination of the possible technical, economic, cultural, institutional, and environmental barriers and opportunities related to their adoption. Our approach, which combines both local and regional spatial scales could inform policy-makers and stakeholders' decisions to address sustainability and climate change related challenges in the Mediterranean Basin.

2. Methodology

2.1. Data collection

To test our approach for the assessment of SLM practices at local scale that can be scaled up to address regional impacts in the broader Mediterranean Basin, we used the World Overview of Conservation Approaches and Technologies network (WOCAT, 1992). The WOCAT network has an openly available database of standardized and integrated assessment protocols oriented to holistically evaluate the impacts of SLM practices taking into account their ecological, socio-economic, and socio-cultural on-site effects. This network allows practitioners (i.e. project implementers, decision-makers, researchers, etc.) that they call experts, to share their SLM initiatives by providing field-tested data and documentation, fostering the mainstreaming of SLM in the financing, policy or planning frameworks. The WOCAT database is accredited and internationally standardized by the United Nations Convention to Combat Desertification (UNCCD).

We considered all SLM practices that have been implemented within the Mediterranean Basin up to the year 2018, resulting in a total of 104 practices located in Portugal (N=7), Spain (N=29), France (N=1), Italy (N=7), Greece (N=13), Turkey (N=5), Syria Arab Republic (N=5), Egypt (N=1), Tunisia (N=7), and Morocco (N=29) (Supplementary Information 1, SI-1). Among others, each SLM practice description in the WOCAT database includes information on authorship, date, location, technical specifications, and several indicators of specific impacts on the environment (called *ecological* and *off-site impacts*) and society (called *socio-economic* and *socio-cultural impacts*). From the 104 SLM practices, we collected a total of 109 impacts pooled in *ecological*, *off-site*, *socio-economic* and *socio-cultural* impacts (Section 2.2). The experts assessed each SLM practice specifically by scoring those impacts provided by the WOCAT that were related to the practice from -3 to 3, ranging from worst to best, respectively. Based on that scoring system, we evaluated the level of success of each SLM practice (Section 2.3). Additionally, each SLM practice description provides information on the geo-climatic characteristics of the implementation site, called *natural environment variables*. We used these *natural environment variables* together with information from the GAEZ v3.0–Global Agro-Ecological Zones portal (GAEZ, 2012) to identify potential areas for implementation of SLM practices within the Mediterranean Basin (Section 2.4). Figure 1 shows a diagram of the developed framework.

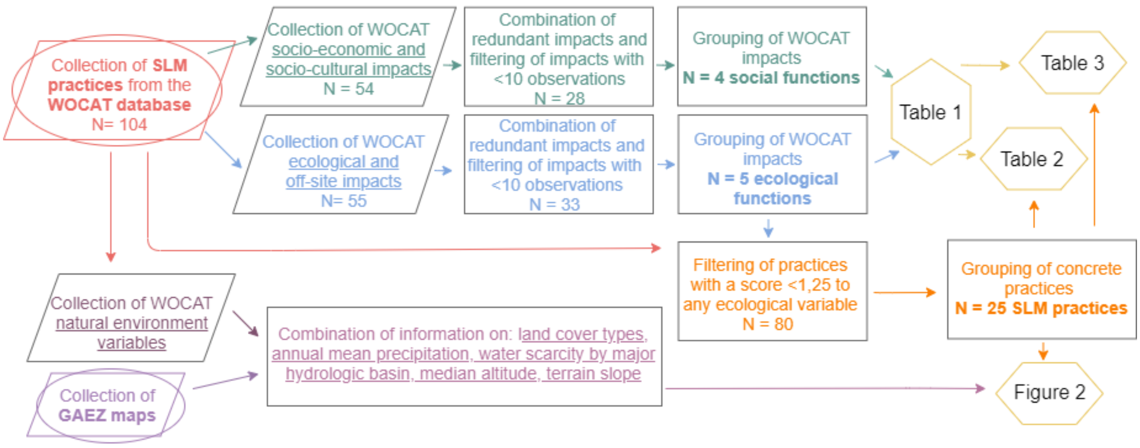


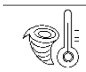
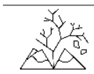
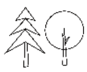
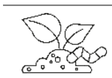
Figure 1. Diagram of the followed methodology for the construction of the multi-objective assessment of SLM practices. Oval shapes correspond to starting points, parallelograms to input data, rectangles to processes, and hexagons to results.

2.2. Selection and grouping of the WOCAT impacts

First, based on Mediterranean needs and challenges and inspired by Nature's Contributions to People (i.e. supporting, provisioning, cultural, regulating), we pooled the 109 impacts into five ecological functions and four social functions. Then, with the aim of widening the levels of SLM intervention (up-scaling), we clustered similar but concrete practices (e.g. 'afforestation with *Pinus halepensis'* and 'afforestation with *Ceratonia siliqua*' to 'afforestation', see SI-3). Both clustering of impacts and SLM practices were done following the criteria by Sanz et al. (2017) and the WOCAT database, which are under the United Nations Convention to Combat Desertification framework. A definition for each function and each group of SLM practices can be found in Table 1 and SI-2, respectively.

Following this, we inspected the possibility of filtering redundant and/or less salient data. To do so, we developed four scenarios with different filtering criteria (SI-3). The first scenario took into account all practices (N=104) and all impacts (N=109), that is, all data. The second scenario considered all practices but aggregated similar impacts, e.g. soil cover and vegetation cover, and filtered out those with less than 10 observations (N=61). The third scenario accounted for all impacts but filtered the practices that did not score 1.25 or higher to any of the five ecological functions (N=80). Score 1.25 corresponds to 75% of its potential punctuation and acts as the first filter for a SLM practice to be considered as successful. The fourth scenario combined scenarios two and three, filtering both impacts and practices. To determine which of the four scenarios best captured all the information on the assessed impacts and allowed for a robust comparison of the SLM practices, we computed their descriptive statistics (SI-4). Statistics of the four scenarios showed that the mean values and standard deviation values for each ecological function were best for the third and fourth scenarios (i.e. higher mean values and lower deviations values), with the fourth scenario as the best in terms of means in three out of the five ecological functions. Consequently, we based our discussion on the results from the fourth scenario (Table 1).

Table 1. WOCAT ecological impacts (in blue), off-site impacts (in pink), and socio-economic and socio-cultural impacts (in green) pooled under five ecological functions (top) and four social functions (bottom). A definition for each function is provided.

ECOLOGICAL FUNCTIONS	
	**Climate regulation:** includes tackling extreme events, mitigating climate change, and regulating the micro-climate
SOC/below ground carbon	Emissions of carbon and greenhouse gases
Biomass/above ground carbon	Fire risk
	Downstreaming flooding
	**Soil erosion control:** includes preventing and/or controlling soil loss by land degradation, wind and water erosion
Soil cover	Buffering/filtering capacity
Soil loss/erosion	Wind transported sediments
Surface runoff	Damage on neighbour's fields
Excess water drainage	Damage on pubic/private infrastructures
Wind velocity	
	**Biodiversity enhancement and pest/disease control:** includes protecting and preserving ecosystems and their primary functions by promoting diversity and preventing pests
Animal diversity	Habitat diversity
Plant diversity	Pest/disease control
Beneficial species	
	**Water regulation:** includes providing water quality and continuous availability by halting water overexploitation and contamination while enhancing soil moisture
Water quality	Harvesting/collection of water
Water quantity	Water availability
Groundwater table/aquifer	Downstream flow
Evaporation	Groundwater/river pollution
Soil moisture	
	**Soil quality enhancement:** includes enhancing soil fertility and soil structure by increasing its nutrient content and reducing hard-setting characteristics
Soil crusting/sealing	Salinity
Soil compaction	Downstream siltation
Nutrient cycling/recharge	

SOCIAL FUNCTIONS	
Economy and production: includes impacts related to income and expenses, and production area, amount and quality	
Crop production	Fodder production
Crop and forest quality	Animal production
Wood production	Product diversity
Risk of production failure	Expenses on agricultural inputs
Farm income	Energy generation
Production area	Fodder quality
Diversity of income sources	
Management and irrigation: includes impacts related to water demand and availability, land management and workload	
Irrigation water availability	Demand for irrigation water
Drinking water availability	Workload
Land management	
Human well-being: includes impacts related to social services such as health care, culture, education, or food that improve living conditions	
Health situation	Improved livehoods and human well-being
Cultural opportunities	Food security/Self-sufficiency
Recreational opportunities	SLM/land degradation knowledge
Conflict mitigation	Situation of disadvantaged groups
Institutions: includes impacts related to both, community, regional, and national institutions	
Community institutions	National institutions

2.3. Criteria for the evaluation of the SLM practices

On the one hand, we used the assessment of ecological and off-site- impacts to evaluate the level of on-ground success of each SLM practice, i.e. ecological functions, and provide an appraisal of their effectiveness in a comparable way (Section 3). On the other hand, we used the assessment of socio-economic and socio-cultural impacts to explore possible technical, economic, cultural, and/or institutional barriers and opportunities, i.e. social functions, for the selected SLM practices (Section 4.1).

To evaluate both the ecological and social functions, we firstly collected the scores (from -3 to 3) that the experts who implemented and assessed each SLM practice assigned to each of the impacts. Then, we computed the average performance of each SLM practice in each of the five ecological functions and four social functions. The average performance of each SLM practice was calculated by aggregating all the impacts under each of the functions. Results can be found in Tables 2 and 3, where the standard deviations and the percentages of observations are also shown. We applied three criteria for the selection of the best practices. First, we considered a score of 1.8 (from -3 to 3) as the lowest threshold to identify a SLM practice as successful. This threshold score is higher than the average of all scores (i.e. 1.69) and allows for 40% of all SLM practices to be considered. It is thus, the second filter to consider a SLM practice successful.

Second, to ensure the robustness of the resulting scores, practices with scores higher than 1.8 had to present a standard deviation of less than 1. Third, to secure further consistency, the number of assessed impacts, here called observations, had to be higher than 40%. An observation threshold of 40% is also higher than the average of total observations (i.e. 32%) and is not too restrictive considering the data availability. Consequently, we considered as efficient on-ground SLM practices those that beyond scoring >1.8 with a <1 of standard deviation, were evaluated for at least 40% of the impacts pooled under each function.

2.4. Construction of maps

The assessed natural environment variables gathered by the WOCAT display information on the geographical and climatic characteristics of each practice's location. To explore the potential areas for the adoption of the different SLM practices (Section 4.2), we crossed this information with five map layers (i.e. land-use, average annual rainfall, available surface water, altitude, and slope) from the GAEZ v3.0–Global Agro-Ecological Zones portal (GAEZ, 2012) with a maintained scale resolution of 30 arc-seconds, i.e.~1 km^2 (Fischer et al., 2008).

For the land-use layer, we crossed the information of the six *land cover types* from the WOCAT database and the data from the five land cover types from the GAEZ portal (SI-5). To assign the different pixels of our maps to a particular land-use, we allocated pixels with an area ≥30% intended for a particular land-use, to that land-use. For instance, in a particular pixel, if the forest area was ≥30% then the pixel was considered forestland. Following this reasoning, one pixel might, therefore, be considered in more than one land-uses if these covered an area ≥30%, or to none, if each land-use occupied an area <30% of the pixel. Moreover, we created a layer called mixedland and assigned there those pixels with an area of ≥30% of a combination of cropland, forestland, and/or grassland. Thus, if, for example, both forestland and cropland covered an area ≥30% respectively, the pixel was considered as mixedland. This layer was created because multiple SLM practices can be effectively applied in a combination of two or all three types of land. For the rainfall layer, we used the *annual mean precipitation* (mm) data, which represents the average annual precipitation for the 1961−1990 time span. For the available surface water layer, we applied the water *scarcity by major hydrologic basin* map. Note, however, that while SLM practices offer on-site local information about water availability, the maps plotted here contain averaged data for a whole major basin, as defined by GAEZ. For the altitude and slope layers, we used the *median altitude* (m a.s.l.) and *terrain slope* (%) from 0 to >30% maps, respectively. In order to allocate the different pixels of the map to a particular slope range, we took into consideration the range with the highest percentage share within the pixel. Lastly, for the plotting, we generated two super-imposed maps for each practice, one in light brown with three restrictive layers for SLM practices implementation (i.e. land-use, rainfall, water availability), and a second one in green with all layers (i.e. land-use, rainfall, water availability, altitude, and slope).

3. Most efficient on-ground SLM practices

According to our multi-objective assessment criteria (i.e. mean scores >1.8 with <1 standard deviation and >40% of observations) there were two SLM practices that performed best among the whole array of SLM practices (Table 2): green covers in perennial woody crops (i.e. vineyards, olive and almond fields), which consists of growing *"perennial grasses in orchards and vineyards between rows to provide permanent soil cover"* (UNCCD Knowledge Hub); and agroforestry, which "*is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence"* (FAO Agroforestry). In the following lines, we discuss the reasons why these two SLM practices have a large potential in contributing to assist in local needs while tackling Mediterranean-wide challenges, such as its fragile hydrological cycle and the loss of landscape multi-functionality.

On the one hand, green covers in perennial woody crops prevent soil erosion by wind and surface water, enhance soil quality and water storage (Almagro et al., 2016), help promote biodiversity (Plaza-Bonilla et al., 2015), and strengthen the capacity of vegetation to address climate change mitigation and adaptation by enhancing carbon sequestration and regulating the micro-climate (Almagro et al., 2017; Vicente-Vicente et al., 2016). Caution, however, needs to be taken when choosing the species of cover crops to avoid competition for water resources with the main crop (Celette et al., 2008). Green covers in perennial woody crops, moreover, robustly contribute to all five ecological functions and have a large application potential due to the extensive geographical area of woody croplands within the Mediterranean Basin. On the other hand, agroforestry practices promote soil quality by permanent plant cover and the natural introduction of organic amendments (Cabrera et al., 2014), dampen runoff velocities and sediment transport through terracing, enhance soil stabilization and crop production (Mosquera-Losada et al., 2012), and foster animal and plant diversity together with natural management of the landscape (Enne et al., 2004; Mbow et al., 2014). Besides, if irrigation systems such as flooding terraces are used along with agroforestry, these further induce pleasant and better regulated micro-climates through tree cover and gravity irrigation systems. Agroforestry hence, also robustly contributes to all five assessed ecological functions.

Table 2. Integrated assessment of the on-ground effectiveness of SLM practices based on their ecological functions. Mean scores (in colored cells), standard deviations, and % of observations for each SLM practice and each ecological function. The symbol – is used to indicate no data.

Ecological functions → / Sustainable Land Management (SLM) practices ↓	Climate regulation	standard deviation	% observations	Biodiversity enhancement and pest/disease control	standard deviation	% observations	Soil quality	standard deviation	% observations	Soil erosion control	standard deviation	% observations	Water regulation	standard deviation	% observations	Overall	standard deviation	% observations
Afforestation	1.52	0.7	73	1.12	1.3	60	1.63	0.3	53	1.53	0.2	56	1.63	0.7	70	1.48	0.7	63
Reforestation	2.33	0.5	20	1.67	2.3	27	2.25	0.4	27	2.22	0.8	41	2.25	0.4	37	2.14	0.9	30
Control of wildfires	1.70	1.1	40	1.53	0.4	29	0.17	1.5	29	0.55	1.3	22	0.45	1.3	40	0.88	1.1	32
Eco-graze	2.00	0.0	20	1.00	0.7	33	2.00	–	–	1.92	0.1	30	2.17	0.3	26	1.82	0.3	27
Application of organic fertilizers [...]	2.13	0.3	23	2.42	0.4	23	1.83	0.8	43	2.35	0.4	20	1.44	1.1	22	2.03	0.6	27
No-till technology	2.78	0.4	27	–	–	0	2.50	0.0	20	2.33	0.3	22	2.22	0.4	37	2.46	0.3	21
Green covers in perennial woody crops	1.88	1.6	40	1.80	–	30	2.25	0.4	60	2.61	0.2	44	0.75	1.1	67	1.86	0.8	48
Vegetated earth-banked terraces	1.17	0.2	27	1.00	0.0	33	3.00	–	20	2.17	0.3	30	1.56	0.8	44	1.78	0.3	31
Water harvest with microcatchments	1.33	0.6	5	1.50	–	45	1.33	0.6	5	2.33	0.8	31	1.42	0.5	33	1.58	0.6	24
Micro-irrigation systems	1.50	2.1	7	–	–	7	1.00	1.4	13	2.50	0.7	26	2.19	0.7	26	1.80	1.2	16
Recharge of groundwater [...]	1.67	0.6	7	–	–	13	2.67	0.6	10	-0.25	1.3	17	1.83	0.7	28	1.48	0.8	15
Water harvesting [...]	1.88	1.6	15	0.25	–	35	1.44	0.5	20	2.13	1.0	31	1.44	1.2	33	1.43	1.1	27
Area closure to grazing	1.67	0.6	27	1.50	–	7	2.00	–	7	2.08	0.9	15	–	–	15	1.81	0.7	14
Establishment of protected forest areas	2.00	0.0	30	2.33	–	20	2.00	–	20	1.83	0.2	22	–	–	22	2.04	0.1	23
Agroforestry systems	1.67	0.5	50	2.19	0.6	50	1.90	0.9	40	2.15	0.8	58	1.43	0.6	64	1.87	0.7	52
Soil / stone bunds	1.33	0.9	40	1.00	–	40	1.25	0.4	30	1.54	1.1	17	1.00	0.0	50	1.23	0.6	35
Multi-specific plantation	1.67	0.0	30	1.75	0.4	60	2.00	0.0	40	2.00	0.0	22	1.33	0.5	56	1.75	0.2	42
Reduced tillage	1.33	0.6	15	1.00	0.0	25	0.88	0.3	25	1.92	0.5	25	1.00	0.0	50	1.23	0.3	28
Application of chemical fertilizers	2.00	0.0	47	1.88	0.9	40	1.25	1.1	40	1.85	1.1	44	1.72	1.3	19	1.74	0.9	38
Mulching in croplands and forestlands	1.21	0.6	30	0.75	0.4	10	2.00	0.0	20	2.19	0.3	53	1.00	0.4	69	1.43	0.3	36
Crop rotation / intercropping	2.33	0.6	7	1.33	1.5	33	1.17	0.3	40	3.00	0.0	11	1.67	0.6	22	1.90	0.6	23
Fodder crop production and mantainance	1.33	–	10	1.33	–	40	1.00	–	40	1.58	0.1	33	0.40	–	44	1.13	0.1	34
Strips and tree farming against soil erosion	2.00	–	10	2.50	0.7	20	1.50	–	10	1.25	1.1	17	2.17	1.2	44	1.88	1.0	20
Silvopastoral plantations	1.00	2.5	60	1.00	2.3	60	1.67	0.6	60	1.00	1.2	80	1.00	1.3	60	1.13	1.6	64
Range pitting and reseeding	–	–	20	2.00	0.0	40	2.00	–	40	2.22	–	40	2.00	0.5	20	2.06	0.3	32

Lastly, our approach did not select reforestation as one of the most on-ground effective SLM options due to its low number of observations (i.e. 30% in Table 2), yet this SLM practice is well known to cope with several environmental Mediterranean challenges (FAO and Plan Bleu, 2018). This fact highlights the limitation of the data in relation to the finite number of observations per SLM practice. The literature indicates that natural reforestation and wisely planned and managed reforestation practices (i.e. preserving biodiversity, including adapted native species, preferably in low productivity areas, with potential for natural water recharge) are a good choice to regulate the water cycle and strengthen the ecosystems of the Mediterranean Basin (Rey Benayas et al., 2005). Accordingly, hereafter, reforestation will be also considered as a SLM practice best assisting all ecological functions.

Other practices with highest results but a low number of observations are: No-till technology (2.46); Application of organic fertilizers (2.03); Establishment of protected forest areas (2.04); and Range pitting and reseeding (2.06). Application of organic fertilizers and no-till technology are practices only implementable in croplands, thus, we will not discuss them, as they defeat the purpose of promoting integrated solutions to the Mediterranean landscapes. Moreover, while no-till technology shows contrasting results in the literature, the application of organic fertilizers can be implicit in agroforestry systems. We will neither discuss range pitting and reseeding, as this is a non-grouped practice, and the establishment of protected forest areas because this is a practice that cannot be mainstreamed at the land-user level without the direct collaboration of governments.

Green covers in perennial woody crops, agroforestry systems, and reforestation can be implemented on their own or can be easily combined between themselves to promote synergies in all five assessed environmental functions. In particular, if we are to promote SLM practices that help mitigate climate change and better adapt to it by regulating the hydrological cycle of the Mediterranean Basin and promoting its multifunctional landscape, these three choices offer several environmental benefits. Among the three practices, reforestation offers the highest mitigation potential with an estimated global 0.5−10.12 Gt CO_2 -eq yr-1 between 2020 and 2050 (Jia et al., 2019-Figure 2.24 and references therein). In a second place, agroforestry has a calculated global mitigation potential of 0.11−5.68 Gt CO_2 -eq yr^{-1} between 2020 and 2050 (Jia et al., 2019-Figure 2.24 and references therein) in comparison to the 0.32 ± 0.08 t CO_2 ha^{-1} yr^{-1} of soils under green covers in perennial woody croplands (Poeplau and Don, 2015). Specifically, the average potential of the Mediterranean agroforestry systems to sequester C ranged between 5−20 t C ha^{-1} for the year 2010 (Zomer et al., 2016), whereas green covers in Mediterranean crops are estimated to sequester from 0.27 t C ha^{-1} yr^{-1} according to Aguilera et al. (2013) up to 1 t C ha^{-1} yr^{-1} according to Vicente-Vicente et al. (2016) and Morugán-Coronado et al. (2020) for annual cover crops. Bear in mind that these estimated potentials reflect a range of methodologies and that the estimations depend on the duration of the study periods, thus, although they might not be directly comparable, they provide an idea of the different magnitudes on their mitigation potential.

To assist in regulating the hydrological cycle of the Mediterranean Basin as a climate change adaptation strategy, by themselves, the three SLM practices have the potential to naturally store water and evapotranspirate it, making it available again. With this process, the hydrological cycle of the region is impacted in two main ways. First, it is impacted by increased soil water infiltration. This relates to the concept of blue and green water that refers to the reduction of direct soil evaporation (blue water or freshwater stored in the surface or underground) whereby increased plant transpiration (green water) without reducing the amount of blue water. Indeed, soil water storage has been found to be higher under tree cover than outside the canopy, (Rey Benayas et al., 2005; Joffre and Rambal, 1993), although this situation might reverse during extended droughts (Moreno and Rolo, 2011). Moreover, agroforestry and green covers in perennial woody crops have the potential to further improve the water-use efficiency by distributing the vegetation in a heterogeneous way and promoting rooting and associated infiltration, retention, and water access at different depths (i.e. shallow-lateral rooting plants and shrubs with deep rooting trees), minimizing water stress while maximizing biomass. The combination of both SLM practices would, moreover, boost the Mediterranean mosaic-like landscape (Cubera and Moreno, 2007). Second, the hydrological cycle of the region is impacted by raised atmospheric moisture through enhanced evapotranspiration. Increased evapotranspiration decreases temperature (Mueller et al., 2016) and heatwave duration (Thiery et al., 2017), and has the potential to enhance topographic rainfall. The potential of temperate forests to increase topographic rainfall through evapotranspiration is nonetheless discussed (Bonan, 2008; Layton and Ellison, 2016). Taking into account the crop coefficient approach from FAO (1998) to calculate crop evapotranspiration (ET_c), it can be approximated without calculations, that only by comparing the crop coefficient (K_c) of different Mediterranean fruit trees (K_c = ~0.4−0.7) with those of vegetables (K_c = ~0.7−1.05) and cereals (K_c = ~0.3−1.15), and knowing that the reference crop evapotranspiration (ET_o) is independent of crop type and management practice, ET_c is higher for croplands than for fruit-trees alone (Allen et al., 1998 chapter 6). In agroforestry systems, however, both the evapotranspiration rates of (fruit)-trees and crops might be added up. At the same time, irrigation in croplands further raises evapotranspiration (e.g. Alter et al., 2015) and, thus, if more efficiently managed (see Jägermeyr et al., 2016), irrigated croplands can contribute to climate change adaptation and mitigation in the Mediterranean through the rise of atmospheric moisture. Crop coefficients for fruit trees with- and without-ground cover (i.e. green covers in perennial woody crops) have also been calculated (Allen et al., 1998 chapter 6). In this case, the evapotranspiration of ground-covered orchards (K_c = ~0.5−0.9) is higher than those without one (K_c = ~0.4−0.7). Nevertheless, both in croplands and agroforestry systems, soil water content is presumably higher than in open pasture due to larger infiltration and reduced evaporation, out-weighing water uptake by plants and canopy

4. Conditioning and enabling factors for SLM application

Despite the scientific advances in understanding land degradation (e.g. Geist and Lambin, 2004; Mortimore et al., 2009; Reynolds et al., 2010) and the increasing promotion of SLM practices at the policy and cooperation level (Sanz et al., 2017; World Bank, 2006), land degradation further expands within the Mediterranean Basin, threatening its adaptation and mitigation capacities. This situation evidences the existing gap between the acknowledgment of the need to effectively adopt SLM practices and their actual implementation. Exploring the creation of enabling environments for the implementation of SLM practices is key to overcome potential barriers that slow down their adoption (e.g. Schooven and Runhaar, 2018). Thus, to complete the evaluation of the most on-ground efficient SLM practices with a more comprehensive and multi-objective assessment, we assessed potential barriers and opportunities associated with their implementation. In the remainder of this section, we discuss five conditioning and enabling factors for SLM implementation: technical and economic (economy and production, management and irrigation), cultural (human well-being), institutional (institutions), and environmental (land-use, rainfall, water availability, altitude, and slope).

4.1. Technical, economic, cultural, and institutional factors

Technical factors refer to the potential access to appropriate technologies, equipment or knowledge; economic and cultural factors refer to the expansion or limit of public capability, acceptance, and effective adoption of SLM practices; and institutional factors refer to governance structures that facilitate or inhibit decision-making. We evaluated these, by inspecting the socio-economic and socio-cultural impacts provided by WOCAT. As a result, we produced Table 3, which helps to understand the social framework whereby the different SLM choices might be implemented.

Table 3. Integrated assessment of SLM practices based on their social functions. Mean scores (in colored cells) for each SLM practice and each social function. The symbol – is used to indicate no data.

Social functions → / Sustainable Land Management (SLM) practices ↓	Economy and production	Management and irrigation	Human well-being	Institutions	Overall
Afforestation	1.43	-0.33	1.33	0.00	0.61
Reforestation	1.63	-1.00	2.00	2.00	1.16
Control of wildfires	1.07	-0.25	1.11	2.00	0.98
Eco-graze	1.83	-2.00	1.58	1.50	0.73
Application of organic fertilizers [...]	1.31	0.92	1.68	3.00	1.73
No-till technology	2.25	0.67	1.33	2.00	1.56
Green covers in perennial woody crops	0.58	1.00	1.65	–	1.08
Vegetated earth-banked terraces	0.72	1.33	1.56	–	1.20
Water harvest with microcatchments	1.60	0.00	1.50	–	1.03
Micro-irrigation systems	1.17	1.11	0.94	–	1.07
Recharge of groundwater [...]	1.15	1.08	1.29	2.00	1.38
Water harvesting [...]	1.50	-0.67	0.81	0.00	0.41
Area closure to grazing	1.17	1.75	2.06	–	1.66
Establishment of protected forest areas	1.30	1.00	0.75	–	1.02
Agroforestry systems	2.23	0.02	1.48	2.33	1.52
Soil / stone bunds	1.00	-0.50	2.17	0.00	0.67
Multi-specific plantation	–	–	1.00	–	1.00
Reduced tillage	0.44	1.33	1.33	–	1.04
Application of chemical fertilizers	0.56	0.00	0.58	2.50	0.91
Mulching in croplands and forestlands	-0.33	1.25	1.33	–	0.75
Crop rotation / intercropping	1.22	-0.25	1.33	–	0.77
Fodder crop production and mantainance	1.20	-2.00	0.50	–	-0.10
Strips and tree farming against soil erosion	1.90	2.00	2.00	1.00	1.73
Silviopastoral plantations	1.13	0.00	0.25	1.00	0.59
Range pitting and reseeding	2.00	–	2.00	–	2.00

Table 3 shows that to effectively implement SLM practices, on-ground proved efficiency is a necessary but incomplete condition. Together with this, coordinated environmental policies (i.e. institutions), the recognition of socio-cultural characteristics (i.e. human well-being), and appropriate knowledge and access to markets and management tools (i.e. economy and production, management and irrigation) need to be taken into account. In this regard, reforestation and agroforestry can provide high benefits to the economy and human well-being, as these two SLM practices provide a wide array of market products (e.g. timber, mushrooms, honey, and cork) and have the capacity to increase profitability through the diversification of their outputs (i.e. agroforestry), while also improving health and food security (Schooven and Runhaar, 2018; Mosquera-Losada et al., 2012). However, in the first stage of their implementation, these practices may need of economic investment due to the delay between tree plantation and economic return. Similarly, they may challenge management and irrigation at the beginning, due to substantial water requirements and workload (Mbow et al., 2014; Rey Benayas et al., 2005). Implementing these two SLM practices more effectively may, thus, require water harvesting systems and/or adaptation of irrigated systems.

Green covers in perennial woody crops likewise positively impact all four assessed social functions, although this practice does not directly increase crop or fodder production. Nevertheless, it contributes to soil conservation and fertility maintenance sustaining productivity in the long-term and returning its cost of implementation, i.e. positive cost-benefit analysis (SI-1 links for practices 2 and 6). Moreover, like agroforestry systems, these two practices establish key nodes across multiple sectors (i.e. climate change, food production, biodiversity, land degradation, etc.), facilitating the development of a coordinated framework for their implementation (Sanz et al., 2017).

All three SLM practices benefit from land-users' traditional knowledge (Marques et al., 2016) and are supported at the local level by practitioners and rural development programs (World Bank, 2006), especially agroforestry systems and green covers in perennial woody crops (Plan bleu, 2016). They prevent perpetuating vulnerabilities encountered in the different regions of the Mediterranean Basin as they are inexpensive and the spatial scale at which their success is demonstrated is broad. The three SLM practices, moreover, integrate biodiversity and autochthonous species conservation, are flexible to accommodate new weather regimes, and thus, can adapt to climate change.

4.2. Environmental factors

Environmental factors refer to the specific geo-climatic conditions wherein a practice might be implemented and to the availability of land and water resources to adopt it, recognizing that these need to be balanced in the short and long terms. We evaluated this factor seeking for by taking into account five of the natural environment variables that the experts from the WOCAT network provided to characterize each SLM practice in its geographic context: land-use, average annual rainfall, available surface water, altitude, and slope. With this information, we generated a map for each practice (SI-6), highlighting all regions within the Mediterranean Basin that met the baseline conditions wherein each practice had been previously implemented, seeking geographic replication, and thus, out-scaling. In the following lines and with the use of Figure 2, we discuss the potential area for implementing reforestation, agroforestry, and green covers in perennial woody crops across the Basin.

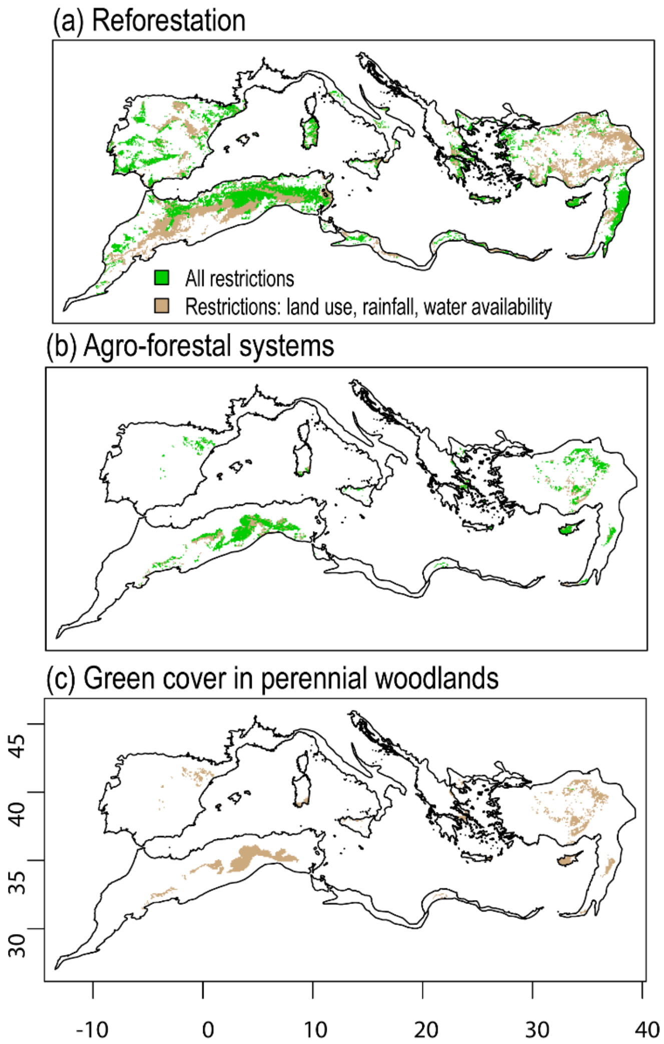


Figure 2. Regions within the Mediterranean Basin that meet the environmental conditions wherein the different SLM practices (a–c) have been implemented according to the WOCAT framework. Light brown regions correspond to geographical areas where the following conditions are met: land-use, rainfall, and water availability. Green regions meet all conditions considered: land-use, rainfall, water availability, altitude, and slope.

Maps show that the SLM practice most widely applicable in terms of environmental conditions is reforestation (Fig. 2a), followed by agroforestry systems (Fig. 2b) and green covers in perennial woody crops (Fig. 2c). Reforestation practices have been successfully adopted in arid to sub-humid environments with mean annual rainfalls ranging from less than 250 to750 mm/yr, with none-to-medium availability of surface water, from flat to steep slopes (3–60%), and between 100–1000 m a.s.l. Agroforestry systems and green covers in perennial woody crops have been previously adopted in arid and semi-arid environments with mean annual rainfall ranging from less than 250 to 500 mm/yr, with medium to limited surface water availability, from plains to steep slopes (3–60%), and between 100–2000 m a.s.l. However, beyond these defined environmental conditions, the three SLM practices have been historically applied in a wider range of environments, evidencing their further implementation potential. Reforestation, for example, has been successfully adopted in many Northern Mediterranean areas as a means to restore degraded lands (e.g. Bautista et al., 2010 and references therein; Valdecantos and et al., 2019), while green covers in perennial woody crops have been widely implemented across the whole Mediterranean Basin (Palese et al., 2014). Similarly, agroforestry systems have been extensively implemented in Northern Mediterranean areas (e.g. Enne et al., 2004; Rota and Sperrandini, 2009; Valdecantos and et al., 2019) and in North Africa and West Asia areas (e.g. Ben Salem and Nefzaoui, 1999; Enne et al., 2004), as well as around three Mha of dehesas and montados in south-western Spain and southern Portugal (García de Jalón et al., 2018). These examples evidence that the representation of the potential area of implementation of the SLM practices is limited. Such limitation is due to the five considered functions and to the environmental conditions where the different practices have been previously implemented under the WOCAT network. Therefore, the here provided maps estimate the geographical potential of the different SLM practices within the Mediterranean Basin.

4.3. Opportunities

On the one hand, opportunities may stem from the fact that the different practices can be implemented in a set of wide environmental conditions, with multiple benefits to the landscape, climate, and society. For this reason, SLM practices assist in restoring degraded lands, combating climate change, and alleviating poverty, contributing simultaneously to several Sustainable Development Goals (SDG), in particular zero hunger (SDG2), clean water and sanitation (SDG6), climate action (SDG13), and life on land (SDG15). The adoption of such practices within the Mediterranean Basin can, hence, promote the recognition of the synergies these provide, boosting their acceptance while raising awareness about the different environmental issues among the public. On the other hand, many opportunities can arise from the fact that implementing SLM needs from cross-sectoral collaboration. First, for the correct implementation and monitoring of SLM practices, policy-makers and land-users, potentially also scientists, need to work together. Through the establishment of platforms that enable collaboration among the groups, the views of each can be gathered from the first involvement stage of SLM design and implementation, enhancing the capacity building of the different actors and bridging existing gaps between them. Moreover, with this approach, the valuable yet often overlooked traditional know-how and experience of the land-users is highlighted. Second, with the involvement of different actors, attention is paid to the social system where the practice will be implemented. This will provide information and tools on how to overcome technical, socio-economic, and cultural barriers by exposing different capacity-building measures and resources. Third, because SLM impacts multiple adaptation and mitigation sectors (i.e. water, land planning, energy, etc.), new funding sources for their promotion and implementation might arise.

5. Conclusions

Three outcomes might be extracted from this study. First, we need to promote those SLM practices that more effectively assist in regulating the hydrological cycle of the Mediterranean Basin since overall, water is the primary limiting factor for the provision of ecological functions. Second, although SLM practices can be easily combined to promote synergies, agroforestry systems represent their own a holistic approach to strengthen climate change mitigation and adaptation capacities, to combat desertification, to promote the traditional multifunctionality of the Mediterranean landscape, and to achieve healthier, more productive, and more diverse ecosystems. Third, Basin-wide assessments with up-and out-scaled SLM options are necessary for developing coordinated and successful strategies across the Mediterranean region that steer efforts in the same direction.

The main limitation of this work is that it is restricted to the availability of already implemented SLM choices and subject to the finite number of observations that ensure consistency for SLM scalability at the regional level. We addressed these two issues by pooling impacts and grouping similar yet very concrete practices, which, at the same time, allowed us to upscale the 104 local SLM practices. By approaching these constrains in such a manner, we are able to provide a Basin-wide integrated view that can be useful in articulating the scientific knowledge, translating it into policy-relevant language, and promoting the adoption of more coherent practices at the Basin-scale.

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Supplementary Information 1

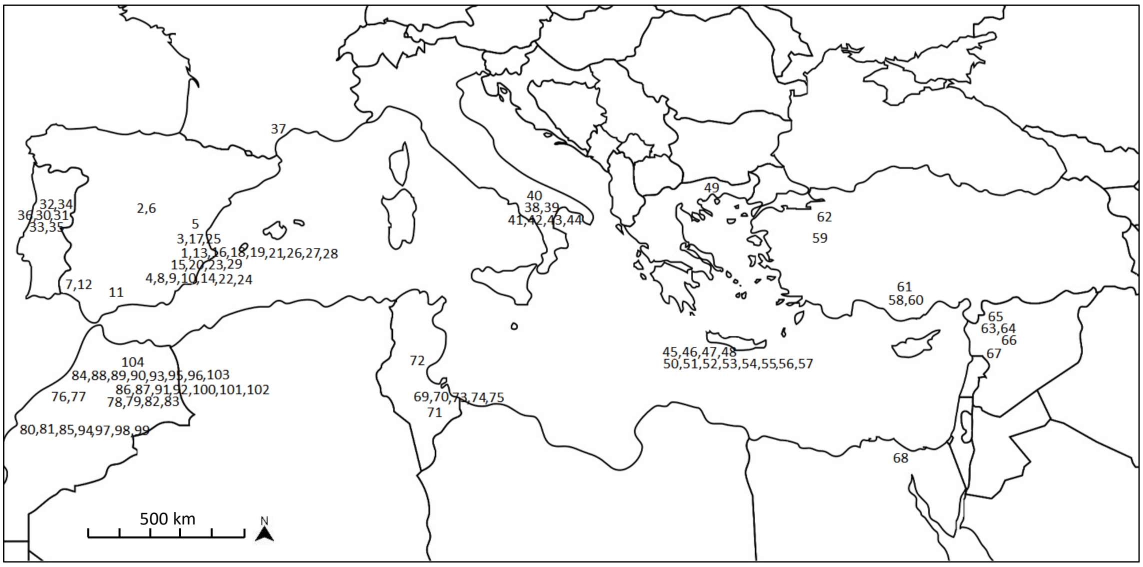
List and geographical location of the 104 considered Sustainable Land Management (SLM) practices and list of the 109 impacts

ID	SLM practice	Reference
1	Non tillage	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1264/
2	Cover crops in organic vineyard	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1162/
3	Selective forest clearing to prevent large forest fires	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1586/
4	Reduced contour tillage of cereals in semi-arid environments	https://qcat.wocat.net/en/wocat/technologies/view/technologies_939/
5	Seedling	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1266/
6	Cover crops on olive orchards	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1173/
7	Adición de enmiendas a suelos contaminados	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1273/
8	Vegetated earth-banked terraces	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1516/
9	Reduced tillage of almonds and olives	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1711/
10	Organic amendment located in dripper point in organic citrus production	https://qcat.wocat.net/en/wocat/technologies/view/technologies_2010/
11	Aserpiado	https://qcat.wocat.net/en/wocat/technologies/view/technologies_907/
12	Fitoestabilización de suelos contaminados	https://qcat.wocat.net/es/wocat/technologies/view/technologies_1272/
13	Afforestation with Pinus Halepensis after the fire of 1979	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1584/
14	Water harvesting from concentrated runoff for irrigation purposes	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1517/
15	Application of 'Preparation 500' in agricultural soils under a biodynamic management	https://qcat.wocat.net/en/wocat/technologies/view/technologies_2690/
16	Contour-felled log barriers	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1681/
17	Prescribed fire	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1679/
18	Reforestation	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1267/
19	Straw mulching to improve soil quality	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1255/
20	Multi-specific plantation	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1649/
21	Selective clearing and planting to promote shrubland fire resilience	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1579/
22	Ecological production of almonds and olives using green manure	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1019/
23	Annual green manure with Phacelia tanacetifolia in southern Spain	https://qcat.wocat.net/en/wocat/technologies/view/technologies_3219/
24	Organic mulch under almond trees	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1109/
25	Cleared strip network for fire prevention (firebreaks)	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1592/
26	Chipped branches	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1269/
27	Catch crop	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1268/
28	Natural revegetation	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1265/
29	Multi-specific plantation of semiarid woody species on slopes	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1618/

30	Minimum tillage in Mediterranean vineyards	https://qcat.wocat.net/en/wocat/technologies/view/technologies_2879/
31	Hydromulching for reducing runoff and soil erosion	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1299/
32	Post-fire salvage logging; post-fire traditional logging	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1713/
33	Prescribed fire	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1534/
34	Post-fire Forest Residue Mulch	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1186/
35	Primary strip network system for fuel management	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1361/
36	Post-fire Natural Mulching	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1298/
37	Construction en pierres sèches	https://qcat.wocat.net/fr/wocat/technologies/view/technologies_1124/
38	Selective cutting	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1610/
39	Ploughing and seeding of fodder species to recover degraded grazing areas	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1210/
40	Controlled grazing in deciduous woods as an alternative to grazing on rangeland	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1463/
41	Unvegetated strips to reduce fire expansion	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1606/
42	Pasture manuring (application of manure from shelter)	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1209/
43	Cutting of Ferns in degraded pastures to use as litter and fodder	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1214/
44	Metallic fences to prevent damages to pastures from wild boars	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1608/
45	Establishment of intensive grazing areas on low productive slopes	https://qcat.wocat.net/en/wocat/technologies/view/technologies_2900/
46	Application of biological agents to increase crop resistance to salinity	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1281/
47	Integrated water-harvesting and livestock water-point system	https://qcat.wcat.net/en/wocat/technologies/view/technologies_1206/
48	Water and soil conservation by using rock fragments	https://qcat.wocat.net/en/wocat/technologies/view/technologies_2911/
49	Transport of freshwater from local streams	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1042/
50	Olive groves under no-tillage operations	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1035/
51	Soil erosion control by ridges	https://qcat.wocat.net/en/wocat/technologies/view/technologies_2922/
52	Application of water by drip irrigation	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1456/
53	Land terracing in olive groves	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1512/
54	Crop rotation for green manuring in greenhouse	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1246/
55	No tillage operations, plastic nets permanently on the soil surface	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1087/
56	Grazing land afforestation with Ceratonia siliqua (carob trees) in the Mediterranean	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1600/
57	Rainwater harvesting for greenhouse irrigation	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1658/
58	Rotational Grazing	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1398/
59	Fodder Crop Production	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1015/
60	Strip farming	https://qcat.wocat.net/en/wocat/technologies/view/technologies_995/
61	Drip irrigation	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1014/

62	Woven Wood Fences	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1535/
63	Semi-circle bunds	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1549/
64	Furrow-enhanced runoff harvesting for olives	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1005/
65	Stone Wall Bench Terraces	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1411/
66	Range Pitting and Reseeding	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1410/
67	Adding Soil	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1004/
68	Calcareous soils management	https://qcat.wocat.net/en/wocat/technologies/view/technologies_716/
69	Rangelands resting	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1399/
70	Gabion check dam	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1400/
71	Jessour	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1013/
72	Area closure and reforestation with Acacia	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1568/
73	Recharge well	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1412/
74	Tabia	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1420/
75	Cistern	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1413/
76	No-till technology	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1253/
77	Réhabilitation par mise en défens	https://qcat.wocat.net/en/wocat/technologies/view/technologies_3210/
78	Gestion des parcours sans coupe ni ébranchage des arbres	https://qcat.wocat.net/en/wocat/technologies/view/technologies_3177/
79	Stabilisation de terrasses en bordure d'oued avec des peupliers	https://qcat.wocat.net/en/wocat/technologies/view/technologies_2807/
80	Fumier	https://qcat.wocat.net/fr/wocat/technologies/view/technologies_3207/
81	Citerne	https://qcat.wocat.net/fr/wocat/technologies/view/technologies_3205/
82	Parcelle agro-forestière à base de plantation d'arbres fruitiers et forestièrs	https://qcat.wocat.net/en/wocat/technologies/view/technologies_2897/
83	Récupération d'eau de pluie dans les plantations arboricoles avec irrigation en goutte à goutte par des buttes en terre	https://qcat.wocat.net/en/wocat/technologies/view/technologies_2842/
84	Gully control by plantation of Atriplex	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1110/
85	Interdiction provisoire d'accès du cheptel aux peuplements d'arganier	https://qcat.wocat.net/en/wocat/technologies/view/technologies_3209/
86	Taille du romarin avec trois ans de repos	https://qcat.wocat.net/en/wocat/technologies/view/technologies_3117/
87	Période de fermeture du pâturage de l'almou collectif servant aux équins	https://qcat.wocat.net/en/wocat/technologies/view/technologies_3157/
88	Plantation d’arbres fruitiers avec mesures de contrôle de l’érosion	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1195/
89	Assisted cork oak regeneration	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1428/
90	Crop rotation: cereals / fodder legumes (lupin)	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1031/
91	Mur de soutènement en gabion avec contreforts pour protéger des berges	https://qcat.wocat.net/en/wocat/technologies/view/technologies_2993/
92	Khtarat	https://qcat.wocat.net/fr/wocat/technologies/view/technologies_3206/
93	Plantation Sylvo pastorales	https://qcat.wocat.net/fr/wocat/technologies/view/technologies_1196/
94	Jardins en agroforesterie irrigués par des seguia	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1707/
95	Labour minimum couplé à la mise en défens partielle des chaumes	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1039/

96	Olive tree plantations with intercropping	https://qcat.wocat.net/en/wocat/technologies/view/technologies_1112/
97	Terrasse	https://qcat.wocat.net/fr/wocat/technologies/view/technologies_3208/
98	Plantation forestière	https://qcat.wocat.net/en/wocat/technologies/view/technologies_3232/
99	Mare d'eau	https://qcat.wocat.net/fr/wocat/technologies/view/technologies_3204/
100	Banquettes en terre combinées avec de l'Agroforesterie	https://qcat.wocat.net/fr/wocat/technologies/view/technologies_2165/
101	Elevage de lapins sous terre	https://qcat.wocat.net/en/wocat/technologies/view/technologies_2835/
102	Taille de frêne dimorphe (Fraxinus dimorpha) en têtard pour l'utilisation comme fourrage	https://qcat.wocat.net/en/wocat/technologies/view/technologies_2167/
103	Seuils en gabion	https://qcat.wocat.net/fr/wocat/technologies/view/technologies_1734/
104	Reboisement	https://qcat.wocat.net/fr/wocat/technologies/view/technologies_1733/



Geographical location of the 104 SLM practices implemented within the Mediterranean Basin under the WOCAT framework up to the year 2018. Each number corresponds to one of the SLM practices identified in the table (ID). Portugal (N=7), Spain (N=29), France (N=1), Italy (N=7), Greece (N=13), Turkey (N=5), Syria Arab Republic (N=5), Egypt (N=1), Tunisia (N=7), and Morocco (N=29)

List of impacts associated to the 104 SLM practices

WOCAT ecological impacts (in blue), off-site impacts (in pink), and socio-economic and socio-cultural impacts (in green)

Water quality
Water quantity
Surface runoff
Excess water drainage
Groundwater table/aquifer
Evaporation
Soil moisture
Soil cover
Soil loss
Soil crusting/sealing
Soil compaction
Nutrient cycling/recharge
Salinity
SOC/below ground C
Biomass/above ground C
Emissions of C and GHG
Fire risk
Animal diversity
Pest/disease control
Plant diversity
Harvesting/collection of water
Landslides/debris flows
Wind velocity
Acidity
Soil surface temperature
Invasive alien species
Beneficial species
Hazards towards adverse events
Soil erosion
Risk of overgrazing in the woodland
Waste
Wind erosion
Soil livings
Habitat diversity
Risk of contamination of aquifers
Soil fertility
Vegetation cover
Soil accumulation
Micro-climate
Flood impact
Drought impact
Impacts of cyclones/rain storms

Downstream siltation
Buffering/filtering capacity
Wind transported sediments
Water availability
Downstreaming flooding
Groundwater/river pollution
Impact of GHG
Rel. Stable dry season
Damage on neighbour's fields
Natural seed multip. and supply
Damage on p/p infrastructure
Runoff
Surf. water to reach downstream

Expenses on agricultural inputs
Workload
Crop production
Fodder production
Irrigation water availability
Irrigation water quality
Demand for irrigation water
Farm income
Fodder quality
Animal production
Wood production
Product diversity
Production area
Energy generation
Fuelwood
Job uncertainty
Crop quality
Forest/woodland quality
Drinking water availability
Risk of production failure
Land management
Economic disparities
Increase in fertility
Decrease in pollution
Diversity of income sources
Drinking water quality
Costs of implementation
Maintenance costs
Water quality for livestock
Water availability for livestock
Demand for groundwater
Tree growth
Grazing land
Dependency on tractor
Flexible labour inputs
Timeliness
Costs
Non-wood forest production
Initial costs
SLM/land degradation knowledge
Landusers perception of the landscape
Improved livehoods and human well-being
Food security/Self-suffiency
Health situation
Cultural opportunities
Recreational opportunities
Conflict mitigation
Situation of disadvantaged groups
Contribution to human well-being
Land use/water rights
Community institutions
National institutions
Usage of abandoned vineyards
Landscape and environmental quality

<u>Supplementary Information 2</u>

Description of the resulting 25 SLM practices after the grouping of the originally gathered 104 practices (IDs are included as in SI-1).

<u>Practices grouped under the UNCCD report's classification</u>

Afforestation / 'Land reclamation by introducing native forest species' in the UNCCD report: Native trees, shrubs and grasses planted through participatory action

13 Afforestation with Pinus Halepensis after the fire of 1979
56 Grazing land afforestation with Ceratonia siliqua (carob trees) in the Mediterranean
104 Reboisement

Reforestation / 'Reforestation in former forest lands' in the UNCCD report : Establishment of new forest areas in formerly (less than 50 years according to UNFCCC, 2002) deforested lands

28 Natural revegetation
72 Area closure and reforestation with Acacia
89 Assisted cork oak regeneration

Control of wildfires: Forest fire control comprises three activity components: prevent forest fire from occurring; extinguish forest fires rapidly while they are still small; use fire only for certain purposes and on a limited scale

17 Prescribed fire
33 Prescribed fire
38 Selective cutting
3 Selective forest clearing to prevent large forest fires
41 Unvegetated strips to reduce fire expansion
21 Selective clearing and planting to promote shrubland fire resilience
32 Post-fire salvage logging; post-fire traditional logging

Eco-graze: An ecologically sound and practical grazing management system, based on rotation, wet season resting and getting the right balance between stock numbers and the forage resource

40 Controlled grazing in deciduous woods as an alternative to grazing on rangeland
58 Rotational Grazing
69 Rangelands resting: Stopping grazing for pre-established periods of time

Application of organic fertilizers and biological agents: Organic fertilizers (compost; straw pen manure with litter or household waste) or green manure to enhance productivity by improving the structure and fertility of the soil, as well as its capacity for infiltration and water retention. It stimulates biological activity in the soil and increases yields and production

10 Organic amendment located in dripper point in organic citrus production
23 Annual green manure with Phacelia tanacetifolia in southern Spain
22 Ecological production of almonds and olives using green manure
15 Application of 'Preparation 500' in agricultural soils under a biodynamic management
80 Fumier
46 Application of biological agents to increase crop resistance to salinity

No-till technology: Growing crops (or pastures) without disturbing the soil through tillage, direct seeding/planting

50 Olive groves under no-tillage operations
55 No tillage operations, plastic nets permanently on the soil surface
76 No-till technology

Green covers in perennial woody crops: Growing perennial grasses in the strips between the main crop to provide permanent soil cover

2 Cover crops in organic vineyard
6 Cover crops on olive orchards

Vegetated earth-banked terraces: Earth-banked terraces are constructed by carefully removing a superficial soil layer from one part of a field, concentrating it on the lower end of that field in order to reduce slope gradient and length. Another terrace is created directly downslope to form a cascade of terraces

8 Vegetated earth-banked terraces
53 Land terracing in olive groves
97 Terrasse

Water harvest with microcatchments: Water harvesting system collecting the runoff from hillslopes and the rainfall through micro-depressions within a field

11 Aserpiado
71 Jessour
74 Tabia
64 Furrow-enhanced runoff harvesting for olives

Micro-irrigation systems: Drip irrigation - delivering small amounts of water directly to the plants through pipes.

52 Application of water by drip irrigation

61 Drip irrigation
83 Récupération d'eau de pluie dans les plantations arboricoles avec irrigation en goutte à goutte par des buttes en terre

Recharge of groundwater; water collection to enable off-season irrigation: Storage efficiency in off-seasons a water management practice in which water is applied in advance of the growing season

47 Integrated water-harvesting and livestock water-point system
57 Rainwater harvesting for greenhouse irrigation
49 Transport of freshwater from local streams
73 Recharge well
75 Cistern
81 Citerne

Water harvesting from concentrated runoff for irrigation purposes: Water harvesting systems, collecting the runoff from hillslopes, can be found at regular distances to supply water points

37 Construction en pierres sèches
70 Gabion check dam
62 Woven Wood Fences
103 Seuils en gabion

Area closure to grazing: Area closure is a land management practice aiming to address severe soil degradation, loss of vegetation cover and low water holding capacity of degraded lands by rehabilitating and restoring the natural resource bases (soil, vegetation and soil water) and enhancing the productive and environmental functions through community consultation and collective actions

44 Metallic fences to prevent damages to pastures from wild boars
85 Interdiction provisoire d'accès du cheptel aux peuplements d'arganier
87 Période de fermeture du pâturage de l'almou collectif servant aux équins

Establishment of protected forest areas: Establishment of protected forest areas, such as natural and national parks. Protecting forest in reserves, and controlling other anthropogenic disturbances.

77 Réhabilitation par mise en défens
78 Gestion des parcours sans coupe ni ébranchage des arbres

Agroforestry systems / 'Plantation crop combinations, multipurpose trees on crop lands' in the UNCCD report: Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence

82 Parcelle agro-forestière à base de plantation d'arbres fruitiers et forestièrs
94 Jardins en agroforesterie irrigués par des seguia
100 Banquettes en terre combinées avec de l'Agroforesterie
88 Plantation d'arbres fruitiers avec mesures de contrôle de l'érosion

Soil / stone bunds: Soil / stone bund is an embankment of soil/stone constructed across the slope following the contour

63 Semi-circle bunds
65 Stone Wall Bench Terraces

<u>Extended classification following UNCCD's classification style</u>

Multi-specific plantation: Plantation of native woody species on degraded ravines and gullies to control erosion, mitigate landscape degradation, prevent flooding and restoring the diversity and cover of vegetation

29 Multi-specific plantation of semiarid woody species on slopes
20 Multi-specific plantation

Reduced tillage: Reducing tillage intensity to allow the establishment of a native plant cover in annual and perennial woody crops under semiarid conditions

4 Reduced contour tillage of cereals in semi-arid environments
9 Reduced tillage of almonds and olives
30 Minimum tillage in Mediterranean vineyards
95 Labour minimum couplé à la mise en défens partielle des chaumes

Application of chemical fertilizers: Application of chemicals to the soil to increase yields and production

12 Fitoestabilización de suelos contaminados
7 Adición de enmiendas a suelos contaminados
68 Calcareous soils management

Mulching in croplands and forestlands: In croplands, mulching involves spreading waste crop after harvesting. Covering the soil with mulch protects it against wind and water erosion and provides nutrients which has a positive effect on yields and food security. In forestlands, and after forest fires, slash mulch is spread immediately after a wildfire in order to prevent soil erosion and reduce overland flow

34 Post-fire Forest Residue Mulch

36 Post-fire Natural Mulching
24 Organic mulch under almond trees
31 Hydromulching for reducing runoff and soil erosion

Crop rotation / intercropping: Crop rotation is an agronomic practice that consists in the successive cultivation of different crops in a specified order on the same fields, in contrast to a one-crop system or to haphazard crop successions. Intercropping consists on growing two or more crops on the same land simultaneously in a given growing season

54 Crop rotation for green manuring in greenhouse
90 Crop rotation: cereals / fodder legumes (lupin)
96 Olive tree plantations with intercropping

Fodder crop production and maintenance: Production of fodder crops every year both for feeding livestock and increasing soil fertility, including pruning forage trees to allow their regeneration

102 Taille de frêne dimorphe (Fraxinus dimorpha) en têtard pour l'utilisation comme fourrage
59 Fodder Crop Production

Strips and tree farming against soil erosion: Plantation of strips and trees to prevent from wind and surface runoff erosion

60 Strip farming
84 Gully control by plantation of Atriplex

<u>No grupped practices</u>

93 **Silviopastoral plantations: Fodder shrubs are planted on the same land-management units as animals, in some form of spatial arragament or temporal sequence**

66 **Range Pitting and Reseeding: This technique is used to restore degraded rangelands (steppe areas) and it is based on the pitting technique that uses the 'Camel Pitter' implement**

Supplementary Information 3

Results on the performance of each SLM practice for each of the four considered scenarios (i.e. from -3 to +3)

(1) No filtering of practices and/or impacts

All selected 104 practices and all resulting 109 assessed impacts (i.e. N=55+54) are considered. The rationale behind this consideration is that although a specific practice might not give information about many impacts, the ones being assessed might be very highly scored. Therefore, a very specifically aimed practice might be implemented together with other very specifically aimed practices. Likewise, impacts with few observations are considered in this scenario, as these observations might be highly scored.

SLM practice	Climate regulation	Biodiversity enhancement and pest/disease control	Soil quality	Soil erosion control	Water regulation
1	0.33	N/A	0.20	0.83	0.50
2	3.00	N/A	2.50	2.71	0.00
3	1.20	1.50	1.00	1.00	1.50
4	1.00	N/A	1.00	1.83	1.00
5	N/A	N/A	1.00	1.00	1.00
6	0.75	1.80	2.00	2.50	1.50
7	2.00	2.50	0.50	1.80	1.67
8	1.33	1.00	3.00	2.00	0.67
9	2.00	1.00	1.00	2.50	1.00
10	1.80	3.00	3.00	3.00	1.00
11	N/A	N/A	N/A	3.00	1.67
12	2.00	1.25	2.00	0.75	0.50
13	0.75	0.00	1.50	1.67	1.50
14	1.00	N/A	N/A	1.00	1.00
15	2.50	2.33	2.00	2.00	0.67
16	0.00	N/A	N/A	1.00	N/A
17	1.50	1.00	N/A	-1.00	N/A
18	1.00	N/A	N/A	0.00	N/A
19	1.00	0.00	0.00	0.00	0.13
20	1.67	2.00	2.00	2.00	1.00
21	1.60	1.67	1.00	0.67	1.50
22	2.00	2.25	1.00	2.25	3.00
23	2.00	2.00	2.00	2.50	2.00
24	1.33	1.00	2.00	1.71	1.00
25	0.75	N/A	1.00	0.00	0.00
26	0.00	N/A	0.00	1.00	1.00
27	0.00	N/A	0.67	1.00	0.25
28	N/A	-1.00	N/A	1.33	N/A
29	1.67	1.50	2.00	2.00	1.67
30	1.00	1.00	1.00	1.33	1.00
31	2.00	N/A	2.00	2.40	0.50
32	-0.33	2.00	-2.00	-1.40	-1.20
33	3.00	1.50	0.67	0.57	0.00
34	1.00	0.50	2.00	2.43	1.50
35	1.20	0.00	0.00	0.50	0.00
36	0.50	N/A	2.00	2.20	1.00
37	N/A	N/A	N/A	3.00	1.00
38	2.33	N/A	N/A	2.00	N/A
39	0.33	0.33	0.00	0.25	1.00
40	2.00	N/A	2.00	1.00	N/A
41	3.00	N/A	N/A	2.00	N/A
42	1.00	0.75	0.67	0.33	1.00
43	N/A	1.00	N/A	1.00	N/A
44	1.00	1.50	2.00	1.25	N/A
45	0.00	-1.00	N/A	0.00	N/A
46	N/A	2.50	1.00	N/A	0.00
47	N/A	N/A	N/A	N/A	2.33
48	N/A	N/A	N/A	1.00	1.00

49	1.00	N/A	3.00	0.00	0.80
50	3.00	N/A	2.50	2.50	2.00
51	N/A	N/A	N/A	N/A	0.00
52	3.00	N/A	0.50	N/A	3.00
53	N/A	N/A	N/A	2.50	2.00
54	2.00	1.00	1.50	N/A	1.00
55	3.00	N/A	2.50	2.00	2.00
56	2.00	2.60	2.00	1.25	1.00
57	2.00	N/A	3.00	0.00	2.25
58	2.00	0.50	N/A	2.00	N/A
59	1.33	1.33	1.00	1.67	0.40
60	N/A	2.00	N/A	0.50	1.33
61	0.00	N/A	0.00	2.00	1.83
62	N/A	N/A	2.00	3.00	2.00
63	0.67	N/A	1.00	2.33	1.00
64	1.00	1.50	1.00	3.00	2.00
65	2.00	1.00	1.50	0.75	1.00
66	N/A	2.00	2.50	2.25	2.00
67	0.00	-1.00	-0.50	0.00	0.33
68	2.00	N/A	N/A	3.00	3.00
69	2.00	1.50	N/A	1.75	N/A
70	3.00	N/A	1.00	1.50	2.75
71	2.00	N/A	2.00	1.67	0.40
72	2.67	3.00	2.50	2.33	2.00
73	2.00	N/A	2.00	1.00	1.40
74	1.00	N/A	1.00	1.67	1.00
75	N/A	N/A	N/A	-2.00	2.50
76	2.33	N/A	3.00	2.50	2.50
77	2.00	N/A	N/A	2.00	N/A
78	2.00	2.33	2.00	1.75	N/A
79	-1.00	-1.00	N/A	1.00	-1.00
80	2.00	N/A	2.00	2.00	2.00
81	2.00	N/A	N/A	N/A	1.67
82	2.50	3.00	2.33	2.67	1.00
83	N/A	N/A	N/A	3.00	1.75
84	2.00	3.00	1.50	2.00	3.00
85	2.00	N/A	N/A	2.00	N/A
86	N/A	N/A	N/A	1.00	1.00
87	2.00	N/A	N/A	3.00	N/A
88	1.00	1.50	1.00	1.00	1.00
89	2.00	3.00	2.00	3.00	2.50
90	3.00	3.00	1.00	3.00	2.00
91	N/A	N/A	N/A	N/A	N/A
92	N/A	1.00	N/A	1.00	-1.00
93	1.00	1.00	1.67	1.00	1.00
94	2.00	2.25	3.00	2.75	2.33
95	N/A	N/A	0.50	2.00	1.00
96	2.00	0.00	1.67	3.00	2.00
97	1.50	1.00	N/A	2.00	2.00
98	0.86	1.00	0.33	1.20	0.00
99	1.00	N/A	N/A	N/A	N/A
100	1.80	2.00	1.25	2.40	1.40
101	N/A	N/A	N/A	N/A	N/A
102	1.00	N/A	N/A	1.50	N/A
103	0.75	0.25	1.33	1.00	0.00
104	1.80	0.75	1.40	1.67	2.38

(2) No filtering of practices and filtering of impacts

All the selected 104 practices are considered, while some ecological and off-site impacts are aggregated to avoid redundancies (e.g. soil loss/erosion: soil loss; soil erosion; wind erosion). Results of the aggregated impacts are averaged throughout the aggregation process. After the combination of the impacts, we further filter those that have less than 10 observations to ensure more robustness of the results. With this process, we reduce the number of impacts from 109 to 61 (i.e. N=33+28).

SLM practice	Climate regulation	Biodiversity enhancement and pest/disease control	Soil quality	Soil erosion control	Water regulation
1	0.33	N/A	0.20	0.83	0.50
2	3.00	N/A	2.50	2.71	0.00
3	1.20	1.50	1.00	1.00	1.50
4	1.00	N/A	1.00	1.83	1.00
5	N/A	N/A	1.00	1.00	1.00
6	0.75	1.80	2.00	2.50	1.50
7	2.00	2.50	0.50	1.80	1.67
8	1.33	1.00	3.00	2.00	0.67
9	2.00	1.00	1.00	2.50	1.00
10	2.00	3.00	3.00	3.00	1.00
11	N/A	N/A	N/A	3.00	1.67
12	2.00	1.25	2.00	0.75	0.50
13	0.75	0.00	1.50	1.67	1.50
14	1.00	N/A	N/A	1.00	1.00
15	2.50	2.33	2.00	2.00	0.67
16	0.00	N/A	N/A	1.00	N/A
17	1.50	1.00	N/A	-1.00	N/A
18	1.00	N/A	N/A	0.00	N/A
19	1.00	0.00	0.00	0.00	0.13
20	1.67	2.00	2.00	2.00	1.00
21	1.50	1.67	1.00	0.67	1.50
22	2.00	2.25	1.00	2.25	3.00
23	N/A	2.00	2.00	2.50	2.00
24	1.33	1.00	2.00	1.71	1.00
25	0.75	N/A	1.00	0.00	0.00
26	0.00	N/A	0.00	1.00	1.00
27	0.00	N/A	0.67	1.00	0.25
28	N/A	-1.00	N/A	1.33	N/A
29	1.67	1.50	2.00	2.00	1.67
30	1.00	1.00	1.00	1.33	1.00
31	2.00	N/A	2.00	2.40	0.50
32	-0.33	2.00	-2.00	-1.40	-1.20
33	3.00	1.50	0.67	0.57	0.00
34	1.00	0.50	2.00	2.43	1.50
35	0.75	0.00	0.00	0.56	0.00
36	0.50	N/A	2.00	2.20	1.00
37	N/A	N/A	N/A	3.00	1.00
38	2.00	N/A	N/A	2.00	N/A
39	0.33	0.33	0.00	0.25	1.00
40	2.00	N/A	2.00	2.00	N/A
41	3.00	N/A	N/A	2.00	N/A
42	1.00	0.75	0.67	0.33	1.00
43	N/A	1.00	N/A	1.00	N/A
44	1.00	1.50	2.00	1.25	N/A
45	0.00	-1.00	N/A	0.00	N/A
46	N/A	2.50	1.00	N/A	0.00
47	N/A	N/A	N/A	N/A	2.33
48	N/A	N/A	N/A	1.00	1.00
49	1.00	N/A	3.00	0.00	0.80
50	3.00	N/A	2.50	2.50	2.00
51	N/A	N/A	N/A	N/A	0.00

52	3.00	N/A	2.00	N/A	3.00
53	N/A	N/A	N/A	2.50	2.00
54	2.00	1.00	1.50	N/A	1.00
55	3.00	N/A	2.50	2.00	2.00
56	2.00	2.60	2.00	1.25	1.00
57	2.00	N/A	3.00	0.00	2.25
58	2.00	0.50	N/A	2.00	N/A
59	1.33	1.33	1.00	1.67	0.40
60	N/A	2.00	N/A	0.50	1.33
61	0.00	N/A	0.00	2.00	1.83
62	N/A	N/A	2.00	3.00	2.00
63	0.67	N/A	1.00	2.33	1.00
64	1.00	1.50	1.00	3.00	2.00
65	2.00	1.00	1.50	0.75	1.00
66	N/A	2.00	2.00	2.25	2.00
67	0.00	-1.00	-0.50	0.00	0.33
68	2.00	N/A	N/A	3.00	3.00
69	2.00	1.50	N/A	1.75	N/A
70	3.00	N/A	1.00	1.50	2.75
71	2.00	N/A	2.00	1.67	1.00
72	2.67	3.00	2.50	2.33	2.00
73	2.00	N/A	2.00	1.00	1.40
74	1.00	N/A	1.00	1.67	1.00
75	N/A	N/A	N/A	-2.00	2.50
76	2.33	N/A	N/A	2.50	2.67
77	2.00	N/A	N/A	2.00	N/A
78	2.00	2.33	2.00	1.67	N/A
79	-1.00	-1.00	N/A	-1.00	-1.00
80	2.00	N/A	2.00	2.00	2.00
81	N/A	N/A	N/A	N/A	1.67
82	2.00	3.00	2.33	2.50	1.00
83	N/A	N/A	N/A	3.00	1.75
84	2.00	3.00	1.50	2.00	3.00
85	2.00	N/A	N/A	2.00	N/A
86	N/A	N/A	N/A	1.00	1.00
87	2.00	N/A	N/A	3.00	N/A
88	1.00	1.50	1.00	1.00	1.00
89	2.00	3.00	2.00	3.00	2.50
90	3.00	3.00	1.00	3.00	2.00
91	N/A	N/A	N/A	N/A	N/A
92	N/A	1.00	N/A	1.00	-1.00
93	1.00	1.00	1.67	1.00	1.00
94	2.00	2.25	3.00	2.75	2.33
95	N/A	N/A	0.50	2.00	1.00
96	2.00	0.00	1.00	3.00	2.00
97	1.00	1.00	N/A	2.00	2.00
98	0.75	1.00	0.33	1.03	0.00
99	N/A	N/A	N/A	N/A	N/A
100	1.67	2.00	1.25	2.34	1.40
101	N/A	N/A	N/A	N/A	N/A
102	N/A	N/A	N/A	1.50	N/A
103	0.75	0.25	1.33	1.00	0.00
104	1.80	0.75	1.40	1.67	2.38

List of aggregated impacts. In bold the renewed assessed impacts, in black the ecological impacts, and in grey the off-site impacts. N refers to the number of practices that have assessed each impact. Note that we have not combined on-site with off-site impacts.

Impact of extreme weather event (total n=12)
Hazards towards adverse events (n=4)
Flood impact (n=5)
Drought impact (n=6)
Impacts of cyclons/rain storms (n=2)
Soil loss/erosion (total n=70)
Soil loss (n=69)
Soil erosion (n=1)
Wind erosion (n=1)
Downstream flow (total n=17)
Reliable and stable stream flow in the dry season (n=16)
Runoff (n=1)
Surface water to reach downstream (n=1)
Soil cover (total n=54)
Soil cover (n=52)
Vegentation cover (n=8)
Animal diversity (total n=27)
Animal diversity (n=26)
Soil livings (n=1)
Peast/disease control (total n=27)
Peast/disease control (n=25)
Invasive alien species(n=2)

The obtained filtered impacts are: Landslides/debris flows; Acidity; Soil surface temperature; Risk of overgrazing in the woodland; Waste; Risk of contamination of aquifers; Soil fertility; Soil accumulation; Micro-climate; Impact of extreme weather event; Impact of GHG; Natural seed multiply and supply.

(3) Filtering of practices and no filtering of impacts

All original impacts are considered. Instead, those SLM practices that do not assist with an averaged >1.25 (from the -3 to 3 expert evaluation) to each ecological variable, are excluded. Through this process, we reduce the number of practices from 104 to 80.

SLM practice	Climate regulation	Biodiversity enhancement and pest/disease control	Soil quality	Soil erosion control	Water regulation
2	3.00	N/A	2.50	2.71	0.00
3	1.20	1.50	1.00	1.00	1.50
4	1.00	N/A	1.00	1.83	1.00
6	0.75	1.80	2.00	2.50	1.50
7	2.00	2.50	0.50	1.80	1.67
8	1.33	1.00	3.00	2.00	0.67
9	2.00	1.00	1.00	2.50	1.00
10	1.80	3.00	3.00	3.00	1.00
11	N/A	N/A	N/A	3.00	1.67
12	2.00	1.25	2.00	0.75	0.50
13	0.75	0.00	1.50	1.67	1.50
15	2.50	2.33	2.00	2.00	0.67
17	1.50	1.00	N/A	-1.00	N/A
20	1.67	2.00	2.00	2.00	1.00
21	1.60	1.67	1.00	0.67	1.50
22	2.00	2.25	1.00	2.25	3.00
23	2.00	2.00	2.00	2.50	2.00
24	1.33	1.00	2.00	1.71	1.00
28	N/A	-1.00	N/A	1.33	N/A
29	1.67	1.50	2.00	2.00	1.67
30	1.00	1.00	1.00	1.33	1.00
31	2.00	N/A	2.00	2.40	0.50
32	-0.33	2.00	-2.00	-1.40	-1.20
33	3.00	1.50	0.67	0.57	0.00
34	1.00	0.50	2.00	2.43	1.50
36	0.50	N/A	2.00	2.20	1.00
37	N/A	N/A	N/A	3.00	1.00
38	2.33	N/A	N/A	2.00	N/A
40	2.00	N/A	2.00	1.00	N/A
41	3.00	N/A	N/A	2.00	N/A
44	1.00	1.50	2.00	1.25	N/A
46	N/A	2.50	1.00	N/A	0.00
47	N/A	N/A	N/A	N/A	2.33
49	1.00	N/A	3.00	0.00	0.80
50	3.00	N/A	2.50	2.50	2.00
52	3.00	N/A	0.50	N/A	3.00
53	N/A	N/A	N/A	2.50	2.00
54	2.00	1.00	1.50	N/A	1.00
55	3.00	N/A	2.50	2.00	2.00
56	2.00	2.60	2.00	1.25	1.00
57	2.00	N/A	3.00	0.00	2.25
58	2.00	0.50	N/A	2.00	N/A
59	1.33	1.33	1.00	1.67	0.40
60	N/A	2.00	N/A	0.50	1.33
61	0.00	N/A	0.00	2.00	1.83
62	N/A	N/A	2.00	3.00	2.00
63	0.67	N/A	1.00	2.33	1.00
64	1.00	1.50	1.00	3.00	2.00
65	2.00	1.00	1.50	0.75	1.00
66	N/A	2.00	2.50	2.25	2.00
68	2.00	N/A	N/A	3.00	3.00
69	2.00	1.50	N/A	1.75	N/A
70	3.00	N/A	1.00	1.50	2.75

71	2.00	N/A	2.00	1.67	0.40
72	2.67	3.00	2.50	2.33	2.00
73	2.00	N/A	2.00	1.00	1.40
74	1.00	N/A	1.00	1.67	1.00
75	N/A	N/A	N/A	-2.00	2.50
76	2.33	N/A	3.00	2.50	2.50
77	2.00	N/A	N/A	2.00	N/A
78	2.00	2.33	2.00	1.75	N/A
80	2.00	N/A	2.00	2.00	2.00
81	2.00	N/A	N/A	N/A	1.67
82	2.50	3.00	2.33	2.67	1.00
83	N/A	N/A	N/A	3.00	1.75
84	2.00	3.00	1.50	2.00	3.00
85	2.00	N/A	N/A	2.00	N/A
87	2.00	N/A	N/A	3.00	N/A
88	1.00	1.50	1.00	1.00	1.00
89	2.00	3.00	2.00	3.00	2.50
90	3.00	3.00	1.00	3.00	2.00
93	1.00	1.00	1.67	1.00	1.00
94	2.00	2.25	3.00	2.75	2.33
95	N/A	N/A	0.50	2.00	1.00
96	2.00	0.00	1.67	3.00	2.00
97	1.50	1.00	N/A	2.00	2.00
100	1.80	2.00	1.25	2.40	1.40
102	1.00	N/A	N/A	1.50	N/A
103	0.75	0.25	1.33	1.00	0.00
104	1.80	0.75	1.40	1.67	2.38

The obtained filtered practices are:
1, 5, 14, 16, 18, 19, 25, 26, 27, 35, 39, 42, 43, 45, 48, 51, 67, 79, 86, 91, 92, 98, 99, 101

(4) Filtering of practices and of impacts

This scenario takes into account both the reduction in number of SLM practices and the aggregation and filtering of the ecological and off-site- impacts.

SLM	Clim. Reg.	*N max 6*	Biodiv. […]	*N max 5*	Soil quality	*N max 5*	Soil erosion […]	*N max 9*	Water reg.	*N max 9*	Avg.	*N max 34*
2	3.00	*2*	N/A	*0*	2.50	*2*	2.71	*7*	0.00	*3*	2.05	*14*
3	1.20	*5*	1.50	*2*	1.00	*3*	1.00	*2*	1.50	*2*	1.24	*14*
4	1.00	*2*	N/A	*0*	1.00	*3*	1.83	*6*	1.00	*2*	1.21	*13*
6	0.75	*4*	1.80	*5*	2.00	*3*	2.50	*4*	1.50	*4*	1.71	*20*
7	2.00	*4*	2.50	*4*	0.50	*4*	1.80	*5*	1.67	*3*	1.69	*20*
8	1.33	*3*	1.00	*4*	3.00	*1*	2.00	*6*	0.67	*3*	1.60	*17*
9	2.00	*2*	1.00	*1*	1.00	*2*	2.50	*4*	1.00	*1*	1.50	*10*
10	2.00	*2*	3.00	*2*	3.00	*2*	3.00	*2*	1.00	*1*	2.40	*9*
11	N/A	*0*	N/A	*0*	N/A	*0*	3.00	*2*	1.67	*3*	2.33	*5*
12	2.00	*2*	1.25	*4*	2.00	*1*	0.75	*4*	0.50	*2*	1.30	*13*
13	0.75	*4*	0.00	*3*	1.50	*2*	1.67	*6*	1.50	*4*	1.08	*19*
15	2.50	*2*	2.33	*3*	2.00	*3*	2.00	*1*	0.67	*3*	1.90	*12*
17	1.50	*2*	1.00	*1*	N/A	*0*	-1.00	*1*	N/A	*0*	0.50	*4*
20	1.67	*3*	2.00	*3*	2.00	*1*	2.00	*3*	1.00	*3*	1.73	*13*
21	1.50	*4*	1.67	*3*	1.00	*2*	0.67	*3*	1.50	*2*	1.27	*14*
22	2.00	*2*	2.25	*4*	1.00	*3*	2.25	*4*	3.00	*1*	2.10	*14*
23	N/A	*0*	2.00	*2*	2.00	*2*	2.50	*2*	2.00	*1*	2.13	*7*
24	1.33	*3*	1.00	*2*	2.00	*2*	1.71	*7*	1.00	*4*	1.41	*18*
28	N/A	*0*	-1.00	*1*	N/A	*0*	1.33	*3*	N/A	*0*	0.17	*4*
29	1.67	*3*	1.50	*4*	2.00	*1*	2.00	*3*	1.67	*3*	1.77	*14*
30	1.00	*2*	1.00	*1*	1.00	*2*	1.33	*3*	1.00	*4*	1.07	*12*
31	2.00	*1*	N/A	*0*	2.00	*1*	2.40	*5*	0.50	*4*	1.73	*11*
32	-0.33	*3*	2.00	*1*	-2.00	*3*	-1.40	*6*	-1.20	*5*	-0.59	*18*
33	3.00	*1*	1.50	*4*	0.67	*3*	0.57	*7*	0.00	*3*	1.15	*18*
34	1.00	*2*	0.50	*2*	2.00	*1*	2.43	*7*	1.50	*6*	1.49	*18*
36	0.50	*2*	N/A	*0*	2.00	*2*	2.20	*5*	1.00	*2*	1.43	*11*
37	N/A	*0*	N/A	*0*	N/A	*0*	3.00	*2*	1.00	*1*	2.00	*3*
38	2.00	*2*	N/A	*0*	N/A	*0*	2.00	*2*	N/A	*0*	2.00	*4*
40	2.00	*2*	N/A	*0*	2.00	*1*	2.00	*3*	N/A	*0*	2.00	*6*
41	3.00	*1*	N/A	*0*	N/A	*0*	2.00	*2*	N/A	*0*	2.50	*3*
44	1.00	*1*	1.50	*2*	2.00	*1*	1.25	*4*	N/A	*0*	1.44	*8*
46	N/A	*0*	2.50	*2*	1.00	*1*	N/A	*0*	0.00	*1*	1.17	*4*
47	N/A	*0*	N/A	*0*	N/A	*0*	N/A	*0*	2.33	*3*	2.33	*3*
49	1.00	*1*	N/A	*0*	3.00	*2*	0.00	*1*	0.80	*5*	1.20	*9*
50	3.00	*1*	N/A	*0*	2.50	*2*	2.50	*2*	2.00	*3*	2.50	*8*
52	3.00	*1*	N/A	*0*	2.00	*1*	N/A	*0*	3.00	*2*	2.67	*4*
53	N/A	*0*	N/A	*0*	N/A	*0*	2.50	*2*	2.00	*2*	2.25	*4*
54	2.00	*2*	1.00	*1*	1.50	*2*	N/A	*0*	1.00	*1*	1.38	*6*
55	3.00	*1*	N/A	*0*	2.50	*2*	2.00	*2*	2.00	*3*	2.38	*8*
56	2.00	*2*	2.60	*5*	2.00	*1*	1.25	*4*	1.00	*1*	1.77	*13*
57	2.00	*1*	N/A	*0*	3.00	*1*	0.00	*2*	2.25	*4*	1.81	*8*
58	2.00	*3*	0.50	*2*	N/A	*0*	2.00	*5*	N/A	*0*	1.50	*10*
59	1.33	*3*	1.33	*3*	1.00	*4*	1.67	*6*	0.40	*5*	1.15	*21*
60	N/A	*0*	2.00	*1*	N/A	*0*	0.50	*4*	1.33	*3*	1.28	*8*
61	0.00	*1*	N/A	*0*	0.00	*2*	2.00	*1*	1.83	*6*	0.96	*10*
62	N/A	*0*	N/A	*0*	2.00	*1*	3.00	*1*	2.00	*1*	2.33	*3*
63	0.67	*3*	N/A	*0*	1.00	*1*	2.33	*3*	1.00	*4*	1.25	*11*
64	1.00	*1*	1.50	*4*	1.00	*2*	3.00	*2*	2.00	*1*	1.70	*10*
65	2.00	*1*	1.00	*3*	1.50	*2*	0.75	*4*	1.00	*2*	1.25	*12*
66	N/A	*0*	2.00	*3*	2.00	*1*	2.25	*4*	2.00	*1*	2.06	*9*
68	2.00	*1*	N/A	*0*	N/A	*0*	3.00	*1*	3.00	*1*	2.67	*3*
69	2.00	*3*	1.50	*2*	N/A	*0*	1.75	*4*	N/A	*0*	1.75	*9*
70	3.00	*1*	N/A	*0*	1.00	*1*	1.50	*2*	2.75	*4*	2.06	*8*

71	2.00	1	N/A	0	2.00	1	1.67	3	1.00	4	1.67	9
72	2.67	3	3.00	1	2.50	2	2.33	6	2.00	4	2.50	16
73	2.00	1	N/A	0	2.00	1	1.00	1	1.40	5	1.60	8
74	1.00	1	N/A	0	1.00	1	1.67	3	1.00	5	1.17	10
75	N/A	0	N/A	0	N/A	0	-2.00	3	2.50	2	0.25	5
76	2.33	3	N/A	0	N/A	0	2.50	2	2.67	3	2.50	8
77	2.00	2	N/A	0	N/A	0	2.00	3	N/A	0	2.00	5
78	2.00	2	2.33	3	2.00	2	1.67	3	N/A	0	2.00	10
80	2.00	1	N/A	0	2.00	2	2.00	1	2.00	1	2.00	5
81	N/A	0	N/A	0	N/A	0	N/A	0	1.67	3	1.67	3
82	2.00	2	3.00	3	2.33	3	2.50	4	1.00	6	2.17	18
83	N/A	0	N/A	0	N/A	0	3.00	1	1.75	4	2.38	5
84	2.00	1	3.00	1	1.50	2	2.00	2	3.00	1	2.30	7
85	2.00	2	N/A	0	N/A	0	2.00	2	N/A	0	2.00	4
87	2.00	1	N/A	0	N/A	0	3.00	1	N/A	0	2.50	2
88	1.00	3	1.50	4	1.00	1	1.00	5	1.00	3	1.10	16
89	2.00	2	3.00	1	2.00	2	3.00	5	2.50	2	2.50	12
90	3.00	1	3.00	1	1.00	2	3.00	1	2.00	1	2.40	6
93	1.00	3	1.00	5	1.67	3	1.00	5	1.00	5	1.13	21
94	2.00	2	2.25	4	3.00	1	2.75	4	2.33	5	2.47	16
95	N/A	0	N/A	0	0.50	2	2.00	2	1.00	2	1.17	6
96	2.00	2	0.00	1	1.00	2	3.00	3	2.00	1	1.60	9
97	1.00	3	1.00	3	N/A	0	2.00	3	2.00	2	1.50	11
100	1.67	3	2.00	2	1.25	4	2.34	9	1.40	5	1.73	23
102	N/A	0	N/A	0	N/A	0	1.50	2	N/A	0	1.50	2
103	0.75	4	0.25	4	1.33	3	1.00	7	0.00	7	0.67	25
104	1.80	5	0.75	4	1.40	5	1.67	9	2.38	8	1.60	31

Supplementary Information 4

Summary of all extracted descriptive statistic of each scenario

Scenario 1

Climate regulation	Biodiversity enhancement a pest/disease control	Soil quality	Soil erosion control	Water regulation
Min. :-1.000	Min. :-1.0000	Min. :-2.000	Min. :-2.000	Min. :-1.2000
1st Qu.: 1.000	1st Qu.: 0.9375	1st Qu.: 1.000	1st Qu.: 1.000	1st Qu.: 0.7667
Median : 1.733	Median : 1.4167	Median : 1.500	Median : 1.714	Median : 1.0000
Mean : 1.517	Mean : 1.3286	Mean : 1.432	Mean : 1.558	Mean : 1.2306
3rd Qu.: 2.000	3rd Qu.: 2.0000	3rd Qu.: 2.000	3rd Qu.: 2.333	3rd Qu.: 2.0000
Max. : 3.000	Max. : 3.0000	Max. : 3.000	Max. : 3.000	Max. : 3.0000
NA's :20	NA's :48	NA's :33	NA's :9	NA's :20
Sd: 0.8765059	Sd: 1.064594	Sd: 0.95175	Sd: 1.029117	Sd: 0.9145195

Scenario 2

Climate regulation	Biodiversity enhancement a pest/disease control	Soil quality	Soil erosion control	Water regulation
Min. :-1.000	Min. :-1.0000	Min. :-2.000	Min. :-2.000	Min. :-1.20
1st Qu.: 1.000	1st Qu.: 0.9375	1st Qu.: 1.000	1st Qu.: 1.000	1st Qu.: 0.95
Median : 1.667	Median : 1.4167	Median : 1.500	Median : 1.714	Median : 1.00
Mean : 1.494	Mean : 1.3286	Mean : 1.415	Mean : 1.543	Mean : 1.24
3rd Qu.: 2.000	3rd Qu.: 2.0000	3rd Qu.: 2.000	3rd Qu.: 2.333	3rd Qu.: 2.00
Max. : 3.000	Max. : 3.0000	Max. : 3.000	Max. : 3.000	Max. : 3.00
NA's :24	NA's :48	NA's :34	NA's :9	NA's :20
Sd: 0.8898291	Sd: 1.064594	Sd: 0.9301357	Sd: 1.058049	Sd: 0.913249

Scenario 3

Climate regulation	Biodiversity enhancement a pest/disease control	Soil quality	Soil erosion control	Water regulation
Min. :-0.3333	Min. :-1.000	Min. :-2.000	Min. :-2.000	Min. :-1.20
1st Qu.: 1.1500	1st Qu.: 1.000	1st Qu.: 1.000	1st Qu.: 1.333	1st Qu.: 1.00
Median : 2.0000	Median : 1.500	Median : 2.000	Median : 2.000	Median : 1.50
Mean : 1.7640	Mean : 1.594	Mean : 1.639	Mean : 1.799	Mean : 1.45
3rd Qu.: 2.0000	3rd Qu.: 2.250	3rd Qu.: 2.000	3rd Qu.: 2.500	3rd Qu.: 2.00
Max. : 3.0000	Max. : 3.000	Max. : 3.000	Max. : 3.000	Max. : 3.00
NA's :12	NA's :34	NA's :20	NA's :5	NA's :13
Sd: 0.738227	Sd: 0.9147175	Sd: 0.8698523	Sd: 1.006534	Sd: 0.8374224

Scenario 4

Climate regulation	Biodiversity enhancement a pest/disease control	Soil quality	Soil erosion control	Water regulation
Min. :-0.3333	Min. :-1.000	Min. :-2.000	Min. :-2.000	Min. :-1.200
1st Qu.: 1.0000	1st Qu.: 1.000	1st Qu.: 1.000	1st Qu.: 1.417	1st Qu.: 1.000
Median : 2.0000	Median : 1.500	Median : 2.000	Median : 2.000	Median : 1.500
Mean : 1.7474	Mean : 1.594	Mean : 1.621	Mean : 1.808	Mean : 1.462
3rd Qu.: 2.0000	3rd Qu.: 2.250	3rd Qu.: 2.000	3rd Qu.: 2.500	3rd Qu.: 2.000
Max. : 3.0000	Max. : 3.000	Max. : 3.000	Max. : 3.000	Max. : 3.000
NA's :15	NA's :34	NA's :21	NA's :5	NA's :13
Sd: 0.7465094	Sd: 0.9147175	Sd: 0.8448675	Sd: 1.000378	Sd: 0.8326032

Supplementary Information 5

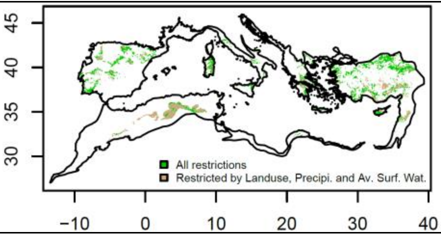
Relation between the GAEZ maps, the WOCAT data, and the resulting classification used in this study

Restriction 1: Land-use type		
GAEZ classification	WOCAT classification	This study
Total cultivated land	Woody; herbaceous cropland Rain-fed/irrigated	Cropland
Forestland	Forestland	Forestland
Grassland & woodland	Grazingland	Grazingland
Barrenland sparsely vegetated land	-	
Built-up land	Settlement	Built-up land
-	Mixedland	Mixedland
Restriction 2: Rainfall (mm/yr)		
no relation has been needed		
Restriction 3: Available surface water layer		
GAEZ classification	WOCAT classification	This study
Very high	Excess	Very high
High	Good	High
Moderate	Medium	Moderate
Low	Poor/none	Low
Restriction 4: Altitude (m a.s.l.)		
no relation has been needed		
Restriction 5: Slope (%)		
GAEZ classification	WOCAT classification	This study
0-2%	Flat (0-2%)	0-2%
2-5%	Gentle (3-5%)	3-5%
5-8%	Moderate (6-10%)	6-10%
8-16%	Rolling (11-15%)	11-15%
16-30%	Hilly (16-30%)	16-30%
30-45% >45%	Steep (31-60%) Very steep (>60%)	>31%

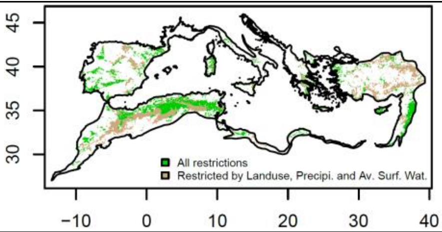
Supplementary Information 6

Map for each of the 25 practices, in where it is highlighted all regions within the Mediterranean Basin that meet the geo-climatic conditions wherein each practice has been implemented under the WOCAT framework. Light brown regions correspond to geographical areas where the following conditions are met: land-use, rainfall, water availability. Green regions meet all five considered conditions: land-use, rainfall, water availability, altitude, slope.

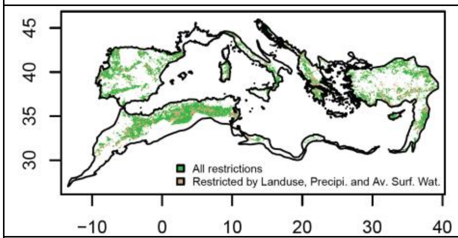
Afforestation



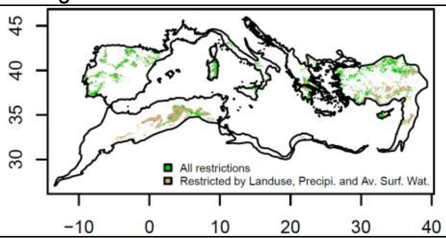
Reforestation



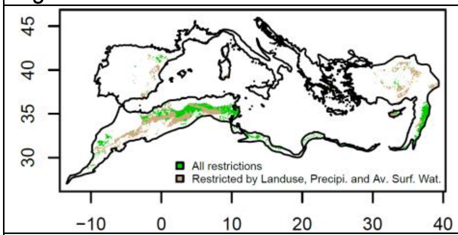
Control of wildfires



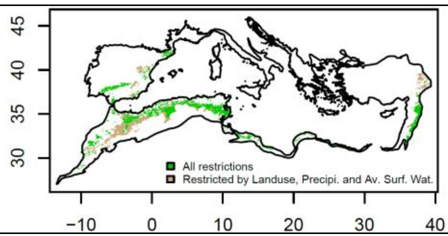
Eco-graze



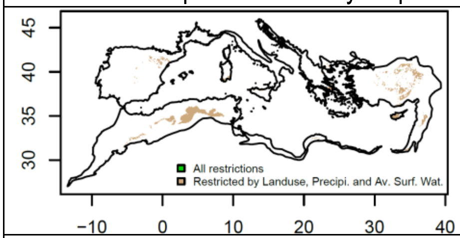
Application of organic fertilizers and biological agents



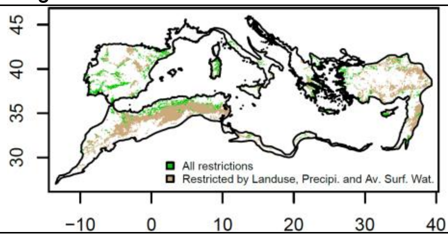
No-till technology



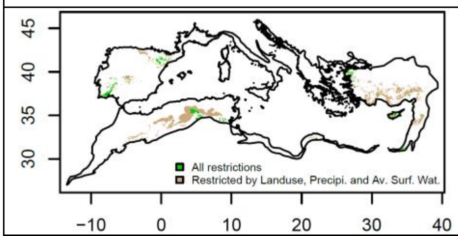
Green cover in perennial woody crops



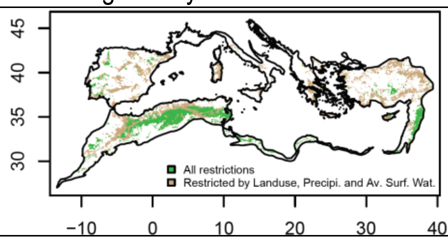
Vegetated earth-banked terraces



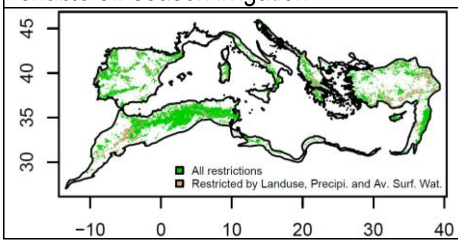
Water harvest with microcatchments



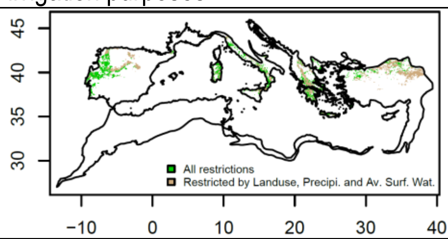
Micro-irrigation systems



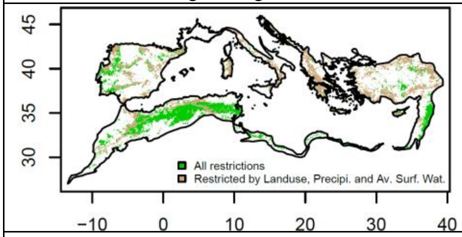
Recharge of groundwater; water collection to enable off-season irrigation



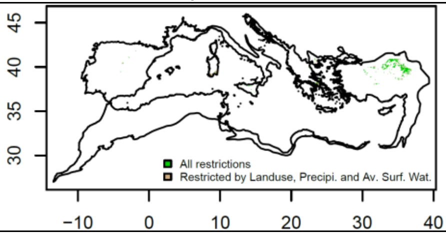
Water harvesting from concentrated runoff for irrigation purposes



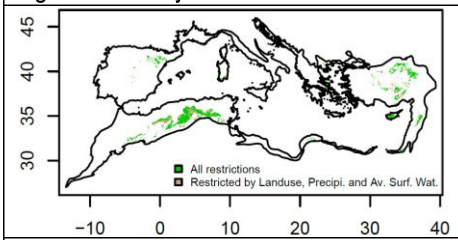
Area closure to grazing



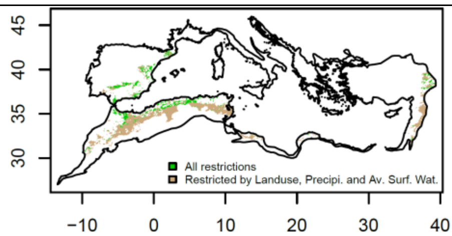
Establishment of protected forest areas



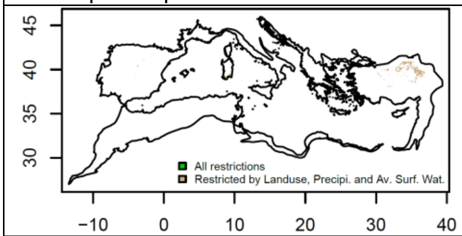
Agro-forestal systems



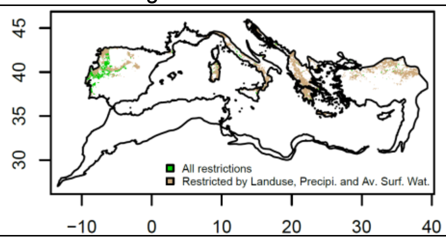
Soil / stone bunds



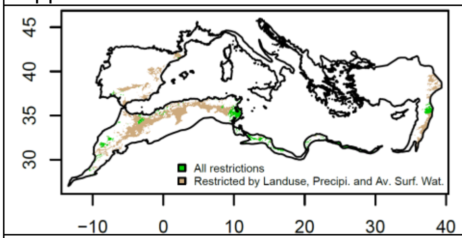
Multi-specific plantation



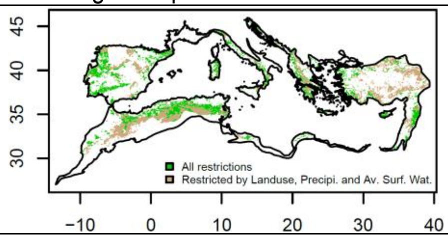
Reduced tillage



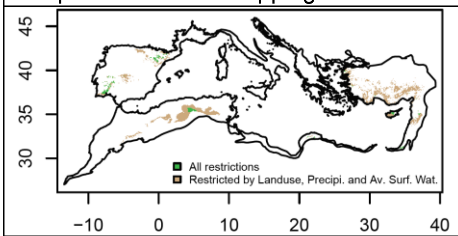
Application of chemical fertilizers



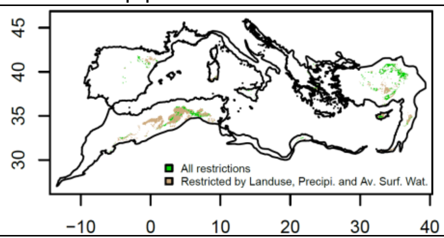
Mulching in croplands and forestlands



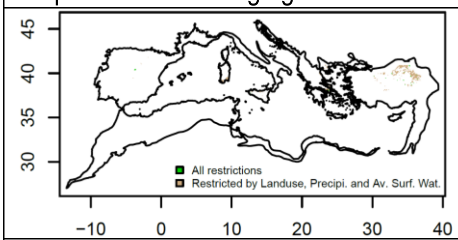
Crop rotation / intercropping



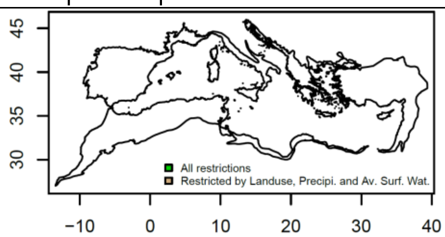
Fodder crop production and mantainance



Strips and tree farming against soil erosion



Silviopastoral plantations



Range Pitting and Reseeding