



Food and Agriculture
Organization of the
United Nations

VOLUME 4

RECARBONIZING GLOBAL SOILS

CASE
STUDIES

A technical manual
of recommended
management
practices



CROPLAND, GRASSLAND,
INTEGRATED SYSTEMS
AND FARMING
APPROACHES





VOLUME 4

RECARBONIZING GLOBAL SOILS

**CASE
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An illustration at the bottom of the cover shows a cross-section of soil with green grass blades growing from the top and a network of light-colored roots extending downwards into the soil. The soil is depicted in shades of brown and tan.

**CROPLAND, GRASSLAND,
INTEGRATED SYSTEMS
AND FARMING
APPROACHES**

Food and Agriculture Organization of the United Nations
Rome, 2021

Required citation:

FAO and ITPS. 2021. *Recarbonizing Global Soils – A technical manual of recommended sustainable soil management. Volume 4: Cropland, grassland, integrated systems and farming approaches – Case studies*. Rome. <https://doi.org/10.4060/cb6598en>

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ISBN 978-92-5-134897-0

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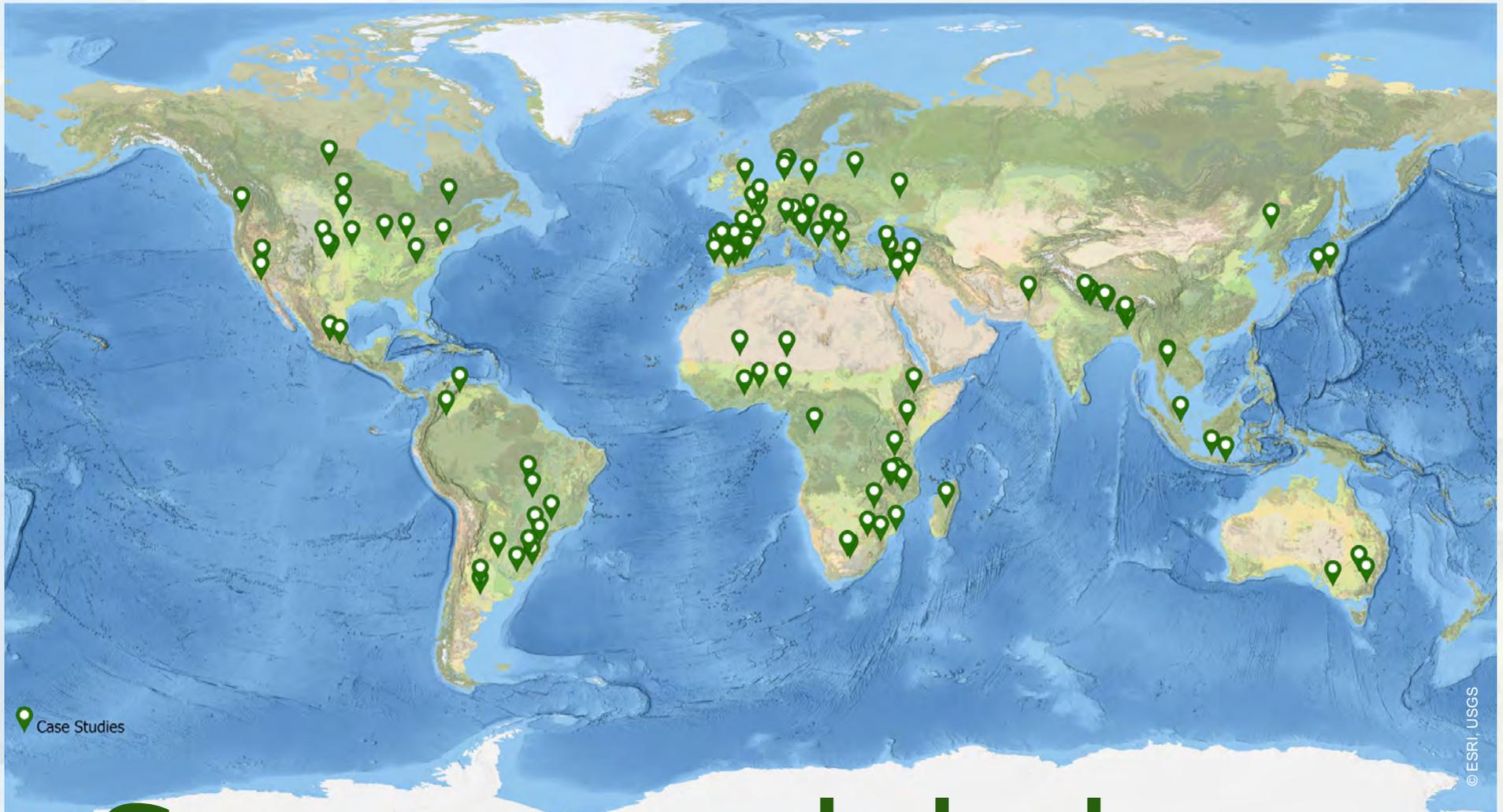
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Contents

Summary global map	1
Africa and NENA	2
1. Short-time effects of no-tillage in olive orchards in Lebanon	4
2. Agricultural practices for the restoration of soil ecological functions in Madagascar	13
3. Never Ending Food (NEF) permaculture initiative in Malawi	22
4. Conservation agriculture in Mozambique	34
5. Conservation agriculture in South Africa	49
6. Intercropping grain legumes and cereals in Africa	69
Asia and Southwest Pacific	78
7. Selection and introduction of dung beetles to beetle-depauperate regions in Southern Australia	80
8. Irrigated cotton cropping systems in Australian vertisols under minimum tillage	92
9. Grazing management in rangeland grassland systems in South and East Australia	107
10. 16 years of no tillage and residue cover on continuous maize in a black soil of China	116
11. Rice straw mulching, charcoal, and no-tillage on maize in Lopburi, Thailand	126
Europe and Eurasia	137
12. Long-term experiment of manure treatments on a sandy soil, Germany	141
13. Avoidance of land use change (LUC) from grassland to arable land, Germany	150
14. The biochar challenge in viticulture: long-term experiment in Central Italy	157

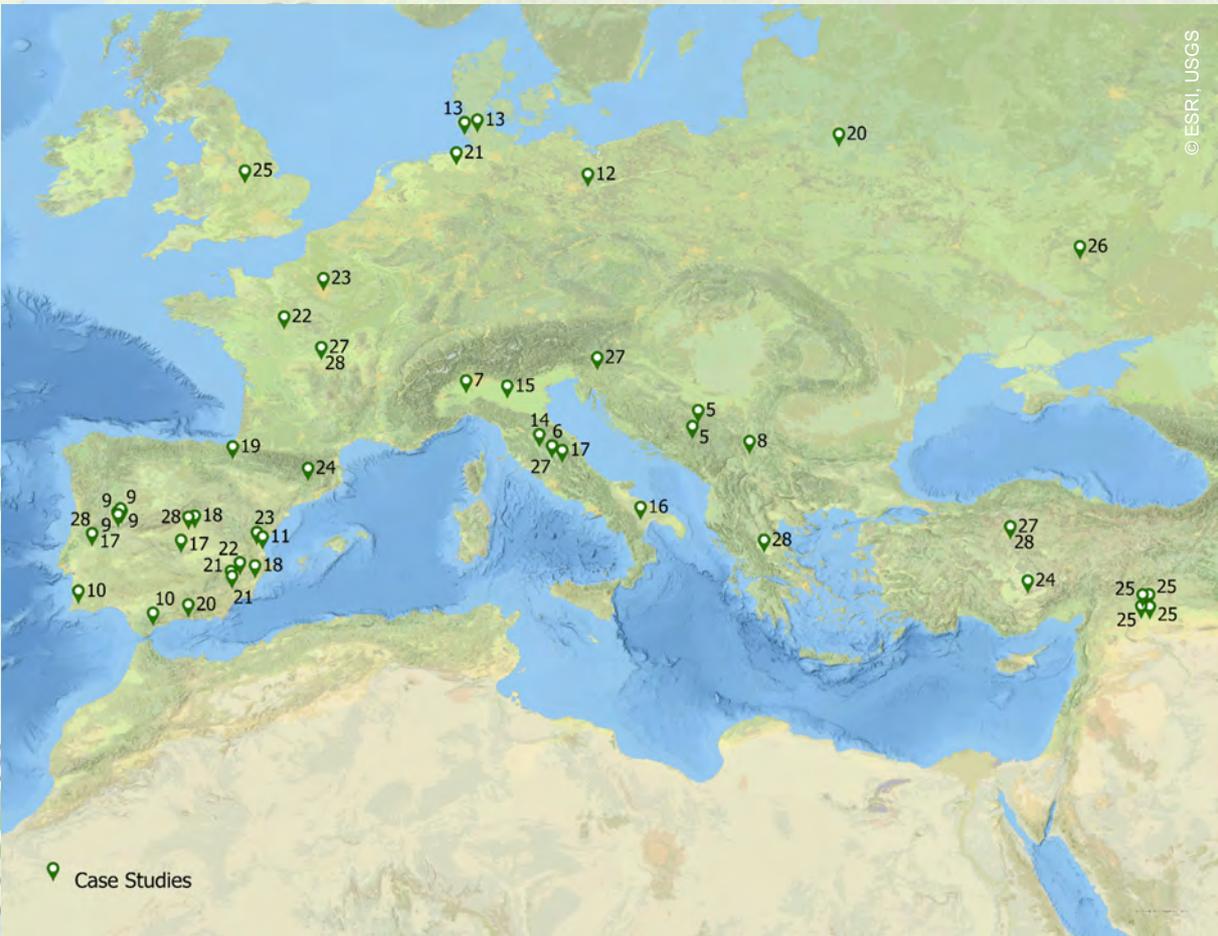
15. Conservation agriculture practices in North Italy	169
16. Mediterranean olive orchard subjected to sustainable management in Matera, Basilicata, Italy	177
17. Mediterranean savanna-like agrosilvopastoral grassland system in Spain, Italy and Portugal	187
18. Cover cropping in olive and vineyards (woody crops) in Spain	197
19. Irrigation and SOC sequestration in the region of Navarre in Spain	206
20. Application of mulching in subtropical orchards in Granada, Spain	214
21. Reduced tillage frequency and no-till to allow ground covers and seeding cover crops in rainfed almond fields, Spain	223
22. Biochar and compost application in an olive orchard, Spain	232
23. Syntropic agriculture in a Mediterranean Context	242
24. Pickle melon (<i>Cucumis melo</i>) production in Karapınar, Central Turkey	259
25. Irrigated wheat-maize-cotton in the Harran Plain, Southeast Turkey	267
26. Organo-mineral fertilization on a Ukrainian black soil	277
27. Interrow organic management to restore soil functionality of vineyards	286
28. Cover crops, organic amendments and combined management practices in Mediterranean woody crops	296
Latin America and the Caribbean	305
29. Increasing carbon inputs in agricultural lands in Argentina: fertilizer use, inclusion of cover crops and integration of perennial pastures in crop rotations	308
30. Application of swine and cattle manure through injection and broadcast systems in a black soil of the Pampas, Argentina	328
31. No tillage and cover crops in the Pampas, Argentina	342
32. Increasing yield and carbon sequestration in a signalgrass pasture by liming and fertilization in São Carlos, São Paulo, Brazil	353
33. Conservation agriculture in lowlands – an experience from South America	365
34. Integrated farming in tropical agroecosystems of Brazil	374
35. Integrated crop-livestock systems on SOC sequestration in subtropical Brazil	385

36. Agroforestry, silvopastoral systems and water funds initiatives contribute to improve soil capacity to remove and store carbon in Colombia	404
37. 30 years of conservation agriculture practices on Vertisols in central Mexico	416
38. Rehabilitation of hardened neo-volcanic soils in Mexico	429
39. Crop-pasture rotation on Black Soils of Uruguay and Argentine	442
40. Mitigation of SOC losses due to the conversion of dry forests to pastures in the plains of Venezuela	453
North America	461
41. Biochar as a soil amendment for carbon sequestration in Canada	463
42. Willow riparian buffer systems for biomass production in the black soils of Elie, Manitoba, Canada	475
43. Response of soil carbon to various combinations of management practices (annual-perennial rotation system, animal manure application, reduced tillage) in Quebec, Canada	486
44. Zone tillage of a clay loam in Southwestern Ontario, Canada	495
45. Long-term no-tillage maize in Kentucky, the United States of America	501
46. Deficit irrigation scenarios using sprinkle irrigation system in western Kansas, the United States of America	508
47. Whole orchard recycling as a practice to build soil organic carbon in the San Joaquin Valley, California, the United States of America	515



Summary global map

Europe and Eurasia



Case Study ID	Region	Title	Practice 1	Practice 2	Practice 3	Duration
12	Europe	Long-term experiment of manure treatments on a sandy soil, Germany	Manure	Organic fertilization	Mineral fertilization	29
13	Europe	Avoidance of land use change (LUC) from grassland to arable land, Germany	Avoided conversion of LU			1 to 7
14	Europe	The biochar challenge in viticulture: long-term experiment in Central Italy	Biochar			1 to 10
15	Europe	Conservation agriculture practices in North Italy	Conservation agriculture	Adapted irrigation		5 to 20
16	Europe	Mediterranean olive orchard subjected to sustainable management in Matera, Basilicata, Italy	Soil cover	No-till	Adapted irrigation	20
17	Europe	Mediterranean savanna-like agrosilvopastoral grassland system in Spain, Italy, and Portugal	Grassland diversification	Agrosilvopastoralism		4 to 37



Case Study ID	Region	Title	Practice 1	Practice 2	Practice 3	Duration
18	Europe	Cover cropping in olive and vineyards (woody crops) in Spain	Cover crops	Intercropping	Strip cropping	2 to 4
19	Europe	Irrigation and SOC sequestration in the region of Navarre in Spain	Organic farming	Irrigation	Crop rotation	6 to 20
20	Europe	Application of mulching in subtropical orchards in Granada, Spain	No-till	Mulching	Terracing	5
21	Europe	Reduced tillage frequency and no-till to allow ground covers and seeding cover crops in rain fed almond fields, Spain	No-till; Reduced tillage	Cover crops	Organic Agriculture	10
22	Europe	Biochar and compost application in an olive orchard, Spain	Biochar	Compost	Organic farming	4
23	Europe	Syntropic agriculture in a Mediterranean context	Syntropic agriculture			3

Case Study ID	Region	Title	Practice 1	Practice 2	Practice 3	Duration
24	Eurasia	Pickle melon (<i>Cucumis melo</i>) production in Karapınar, Central Turkey	Manure	Mixed-farming		60
25	Eurasia	Irrigated wheat-maize-cotton in the Harran Plain, Southeast Turkey	Crop rotation	Adapted irrigation		30
26	Europe	Organo-mineral fertilization on a Ukrainian black soil	Integrated soil fertility management	Mulching		5
27	Europe	Interrow organic management to restore soil functionality of vineyards	Composting	Intercropping	Cover crops	2
28	Eurasia	Cover crops, organic amendments and combined management practices in Mediterranean woody crops	Cover crops	Organic amendments		Various (<30)



16. Mediterranean olive orchard subjected to sustainable management in Matera, Basilicata, Italy

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1. Related practices

Cover cropping, organic mulch, no-till, fertigation, mineral fertilization, adequate irrigation practices

2. Description of the case study

A case study was set up in 2000 within a typical Mediterranean context to compare the effects of long-term olive orchard management - based on sustainable practices - with the agronomically ordinary management, which is widespread in the study area. Specifically, sustainable techniques have been adopted for 20 years in a mature olive orchard (1-ha wide, 156 plants/ha; plants > 70-year-old) to conserve and improve soil organic matter content, taking care to maintain olive tree productivity. The sustainable grove (S_{mng}) was drip-irrigated (on average, 2850 m³/ha/yr) from March to October with urban wastewater treated by a pilot unit according to simplified schemes, aimed to recover organic matter and nitrogen as fertilizing substances (Palese *et al.*, 2009). A light pruning was carried out every year during winter in order to reach vegetative-reproductive balance of the trees. The soil was permanently covered by spontaneously self-seeding weeds that were mowed at least twice a year. Weeds and pruning residues were shredded and left along the row as mulch. Fertigation was applied following the nutrient balance approach, which took into account nutrient input (by wastewater), output (by yield), and recycling/immobilization in the olive grove system (by pruned material, senescent leaves, cover crops). An integrative amount of about 40 kg/ha/yr of N-NO₃⁻ was distributed in the early spring to entirely satisfy plant nutrient needs. An adjacent orchard (1 ha) with the same characteristics was kept as 'control' (C_{mng}). It was rainfed and managed by tillage (harrowing up to 10 cm soil depth) performed 2-3 times per year in order to control weeds. Intensive pruning was carried out every two years. Pruning residues were removed from the olive orchard. Mineral fertilization was carried out empirically once per year in early spring by using granular product. The statistical analysis of the data here presented was performed using Sigmastat 3.1 software (SPSS

Inc., Quarry Bay, Hong Kong). The means of all the measured parameters were treated by one-way analysis of variance (ANOVA) with the orchard management type (S_{mng} and C_{mng}) as a factor. Means were separated according to Fisher's LSD test at $p \leq 0.05$. Five analytical replicates for each treatment from five independent composite soil samples ($n = 5$) were considered.

3. Context of the case study

Olive is a widespread crop within Mediterranean area and Italy is one of the biggest producer of olives and oil in the world (IOC, 2020). Italian olive growing is characterized by wide pedoclimatic conditions and topography combinations, many varieties and olive orchard management typologies, all making it a multifunctional rural activity with the most disparate objectives: economic/productive, social, landscaping, environmental, recreational, of territory protection and gastronomic tourism.

In detail, the case study was located in Southern Italy, Basilicata region, in a village named Ferrandina within Matera Province (40°29' N; 16°28' E). The autochthonous cultivar "Maiatica di Ferrandina", widespread in that geographical location, is a dual-purpose cultivar producing good oil and tasty table olives. These last are harvested at black maturity stage and then processed according to a typical local method in order to obtain oven dried drupes, an excellent specialty of Ferrandina (Brighigna, 1998).

The area is characterized by a warm temperate dry climate, with an annual rainfall of 558 mm (mean 1995-2017) and a mean annual temperature of 16.0 °C. The soil is a sandy loam, Haplic Calcisol with sediment as parental material (Lal, 2017). The coverage of the case-study can be defined as local.

4. Possibility of scaling up

Given the importance of the olive growing and the area covered by this crop, the study can be adapted for scaling up for the whole Mediterranean area (9,800,000 ha covered by olive, with 1,200,000,000 plants).

5. Impact on soil organic carbon stocks

Table 62. SOC stocks changes after 20 years of implementation of SSM on the olive grove plantation

Soil depth (cm)	Baseline SOC stock (t SOC/ha) ^a	Additional SOC storage potential (t SOC/ha/yr)	SOC stock after 20 years of sustainable management (t SOC/ha)	References ^b
0-5	7.20 ± 1.49 b	0.61 ± 0.07	19.39 ± 0.13 a	Sofo, Mininni and Ricciuti (2020); Sofo <i>et al.</i> (2019a, 2019b); Palese <i>et al.</i> (2014)
5-10	8.26 ± 1.04 a	0.02 ± 0.04	8.58 ± 0.21 a	
10-20	4.76 ± 0.27 b	0.14 ± 0.01	7.56 ± 0.17 a	
20-30	5.27 ± 0.64 b	0.09 ± 0.03	7.08 ± 0.08 a	
30-50	3.19 ± 1.15 b	0.08 ± 0.04	4.80 ± 0.26 a	
60-80	2.94 ± 1.37 a	0.05 ± 0.06	3.95 ± 0.26 a	
80-100	1.93 ± 0.48 b	0.05 ± 0.01	2.89 ± 0.33 a	

^aThe baseline SOC stock corresponds to C_{mng} after 20 years, that remains statistically unchanged during the whole experimental period

^bEach value represents the mean (± standard deviation) from five independent composite soil samples (n = 5)

Means were separated according to Fisher's LSD test at $p \leq 0.05$

The values of SOC stock followed by different letters are statistically different ($p \leq 0.05$) between the two treatments (S_{mng} and C_{mng})

6. Other benefits of the practice

6.1. Improvement of soil properties

Physical properties:

S_{mng} system showed higher values of soil macroporosity (9.4 vs 5.6 percent v/v in the 0-30 cm soil layer), lower soil bulk density (1.25 vs 1.38 g/cm³), and a better soil structure, characterized by macropores of smaller size (50-500 mm), interconnected and homogeneously distributed along the profile, which positively affected soil water movement (160 vs 13 mm/day water vertical infiltration). This made S_{mng} system more efficient to intercept and store water, compared to the C_{mng} soil (4.250 vs 2.935 m³/ha water holding capacity) (Celano *et al.*, 2011; Palese *et al.*, 2014). Also, water stable aggregates (WSA) values were higher in the S_{mng} system conferring to the soil a greater structure stability (Lombardo *et al.*, 2019).

The pedological soil profiles of the 0-90 cm layer were different in the two systems because of the higher presence of grass roots and soil macrofauna in the S_{mng} system, that caused a higher soil macroporosity and a reduction in bulk density (Sofa *et al.*, 2019b).

Chemical properties:

The soil of the S_{mng} system had significantly lower pH (7.23 vs 7.91 in the 0-30 cm soil layer), higher soil organic carbon (SOC) (13.18 vs 10.59 g/kg soil in the 0-30 cm soil layer) and soil total N (1.56 vs 1.13 in the 0-30 cm soil layer), lower C/N ratio (7.69 vs 9.33 in the 0-30 cm soil layer), higher cation-exchange capacity (CEC), and higher content in macronutrients (particularly N, P, K, but also Ca and Mg) and micronutrients (particularly Fe, Zn and Cu), compared to the C_{mng} soil (Sofa *et al.*, 2019b).

Biological properties:

The soil of the S_{mng} system had higher diversity (genetic, functional and metabolic), abundance and activity of bacteria, fungi and soil fauna (in the S_{mng} system: 35.6 bacterial CFU $\times 10^6$ g⁻¹ soil and 21.4 fungal CFU $\times 10^4$ /g soil in the 0-30 cm soil layer, and 4.011 g of earthworms and 0.552 g of other macrofauna in a 25 \times 25 \times 25-cm deep soil block; in the C_{mng} system: 10.0 bacterial CFU $\times 10^6$ g⁻¹ soil and 2.9 fungal CFU $\times 10^4$ /g soil in the 0-30 cm soil layer, and 1.397 g of earthworms and 0.252 g of other macrofauna in a 25 \times 25 \times 25-cm deep soil block) (Sofa *et al.*, 2014; Sofa, Mininni and Ricciuti, 2020). Soil microorganisms and macrofauna responded positively to a sustainable orchard management characterized by periodic applications of locally derived organic matter (Sofa *et al.*, 2010, 2014).

6.2 Minimization of threats to soil functions

Table 63. Soil threats

Soil threats	
Soil erosion	<p>In comparative trials performed by means of a rainfall simulator on small plots, the S_{mgn} system reduced surface runoff to approximately one-third and soil losses to zero compared with the C_{mgn} system (Palese <i>et al.</i>, 2015).</p> <p>The amount of Water Stable Aggregation was significantly higher in S_{mgn} system, thanks to the greater stability of the soil structure conferred by cover crops and no-tillage (Lombardo <i>et al.</i>, 2019). This decreases soil erosion risk caused by the beating action of the rain and by surface runoff and avoids the break of soil aggregates into smaller particles and the formation of the surface crust.</p>
Nutrient imbalance and cycles	<p>In the S_{mgn} system:</p> <p>the average values of organic N, P and K distributed by means of the treated wastewater were 54, 3 and 50 kg/ha/yr, respectively (Sofa <i>et al.</i>, 2019a);</p> <p>higher N fixation and enhanced N-cycle were found (Pascazio <i>et al.</i>, 2018; Sofa <i>et al.</i>, 2010, 2019b)</p>

Soil threats	
	soil reserves of the main macronutrients (N, P and K) generally increased, with both low or none input of external chemical fertilizers (Sofo <i>et al.</i> , 2019b).
Soil contamination / pollution	The irrigation with treated urban wastewater in the S_{mng} system did not cause contamination with potential human pathogenic bacteria or other contaminants/pollutants (Palese <i>et al.</i> , 2009; Sofo <i>et al.</i> , 2019a).
Soil acidification	A slight acidification (about 0.5 points of pH in the first 90 cm of soil), mainly due to the higher SOC and mineral N forms, was observed in the S_{mng} system (Sofo <i>et al.</i> , 2019b).
Soil biodiversity	The S_{mng} system had higher abundance and activity of soil fauna (particularly earthworms), paralleled by enhanced litter decomposition and soil bioturbation (Sofo, Mininni and Ricciuti, 2020).
Soil compaction	Soil compaction, evaluated in terms of soil macroporosity, was significantly lower in the S_{mng} system (Celano <i>et al.</i> , 2011; Palese <i>et al.</i> , 2014). In the C_{mng} system, the occurrence of soil crusting and of compacted layers along the profile hindered infiltration and percolation of rainfall water influencing the soil water content (Celano <i>et al.</i> , 2011; Palese <i>et al.</i> , 2014).
Soil water management	The S_{mng} system was able to better store water from rainfall, received during the autumn-winter period, especially in the deepest soil layer. The increase in SOC and the higher macroporosity in the S_{mng} system caused a higher soil water holding capacity, compared to the C_{mng} system (Celano <i>et al.</i> , 2011; Palese <i>et al.</i> , 2014).

6.3 On production

In the S_{mng} system, higher olive yield occurred, compared to the C_{mng} system (8.4 vs 6.3 t/ha/yr, mean 2001–2016), due to higher soil water availability and, partially, to the reduction of the “off” years (years without fruits) and the larger fruit size of the S_{mng} plants.

6.4 Mitigation of and adaptation to climate change

As explained in the paragraph 5, S_{mng} soil was a significant sink for C, especially because of the supplies of the organic resources internal to the system (cover crops, pruning material). The S_{mng} system was also able to fix in its above-ground (yield, pruning material, leaf turnover, spontaneous vegetation) and below-ground components (root systems of olive trees and spontaneous vegetation), and a higher total amount of CO₂ than C_{mng} (more than the double). Spontaneous vegetation (above and below-ground parts) was the most important pool sequestering about 35 percent of the total fixed CO₂. Pruning material had a substantial importance in CO₂ fixation (Palese *et al.*, 2013).

The soil of the S_{mng} system showed an increased abundance of N-fixing bacteria and less denitrifying bacteria (Sofa *et al.*, 2010, 2019b), so acting as sinks also for N and releasing less N oxides (NO_x) (these latter are strong GHG). Higher N as result of its biological fixation often determines more chance to produce NO_x under higher soil water content but, in our case, the localized drip irrigation applied in the S_{mng} system minimized water excess and accumulation, so reducing denitrification and the consequent NO_x release (Sofa *et al.*, 2010).

6.5 Socio-economic benefits

The S_{mng} system was a much more effective management model in terms of productivity and profitability. The economic analysis showed that the gross profit of the S_{mng} was considerably higher (6276 €/ha) than the C_{mng} (1517 €/ha). This was due to the higher yield and its superior quality, which means that it can negotiate better market price than the C_{mng} system (Pergola *et al.*, 2013).

7. Potential drawbacks to the practice

7.1 Tradeoffs of the sustainable management system with other soil threats

Table 64. Soil threats

Soil threats	(See references in Section 6.2)
Soil erosion	No tradeoffs
Nutrient imbalance and cycles	It is important to mow weeds and grasses during spring, before the starting of nutrients competition with olive trees.
Soil water management	It is important to mow weeds and grasses during spring, before the starting of water competition with olive trees.

7.2 Increases in greenhouse gas emissions

Emissions of CO_2eq/kg of olives, calculated according to the Life Cycle Assessment (LCA) methodology, were 0.08 kg in the S_{mng} system and 0.11 kg in the C_{mng} system (Pergola *et al.*, 2013).

7.3 Decreases in production (food/fuel/feed/timber/fibre)

Reduction of olive production can occur if spontaneous cover crops are not promptly mowed before competing for water and nutrients with olive trees.

8. Recommendations before implementing the practice

It takes some time to have the first positive results, in terms of soil quality and olive yield after the conversion from C_{mng} to S_{mng} .

9. Potential barriers for adoption

Table 65. Potential barriers to adoption

Barrier	YES/NO	
Cultural	Yes	Olive growing is often based on the application of traditional horticultural practices. These are practices handed down over time, and they often have no scientific and physiological basis. Therefore, it is hard to convince farmers to adopt new technologies.
Economic	Yes	Conversion to a sustainable system has some initial costs.
Institutional	Yes	Lack of specific legislation and low bureaucracy.
Knowledge	Yes	Conversion to a sustainable system requires the dissemination of technical and scientific knowledge to farmers.

Photo

SUSTAINABLE MANAGEMENT (S_{mg})



CONVENTIONAL MANAGEMENT (C_{mg})



Photo 31. Comparison between the two different soil management types in the studied olive orchard

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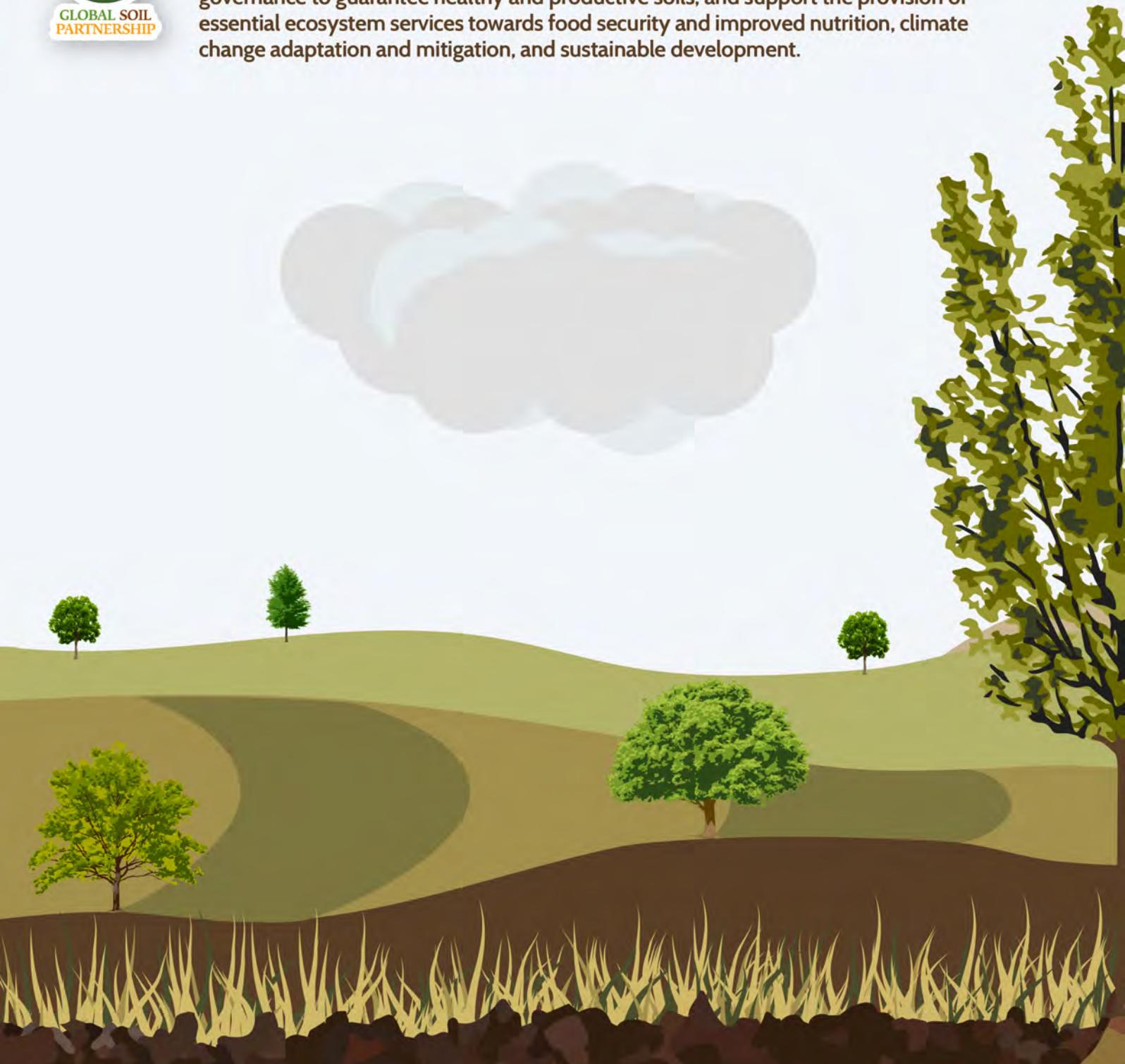








The Global Soil Partnership (GSP) is a globally recognized mechanism established in 2012. Our mission is to position soils in the Global Agenda through collective action. Our key objectives are to promote Sustainable Soil Management (SSM) and improve soil governance to guarantee healthy and productive soils, and support the provision of essential ecosystem services towards food security and improved nutrition, climate change adaptation and mitigation, and sustainable development.



Thanks to the financial support of



European
Commission



Ministry of Finance of the
Russian Federation

ISBN 978-92-5-134897-0



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CB6598EN/1/09.21