Food and Agriculture Organization of the United Nations

VOLUME 4

CASE STUDIES

RECARBONIZING GLOBAL SOILS

A technical manual of recommended management practices

CROPLAND, GRASSLAND, INTEGRATED SYSTEMS AND FARMING APPROACHES

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INTERGOVERNMENTAL TECHNICAL PANEL ON SOILS

GLOBAL SOIL PARTNERSHIP

VOLUME 4

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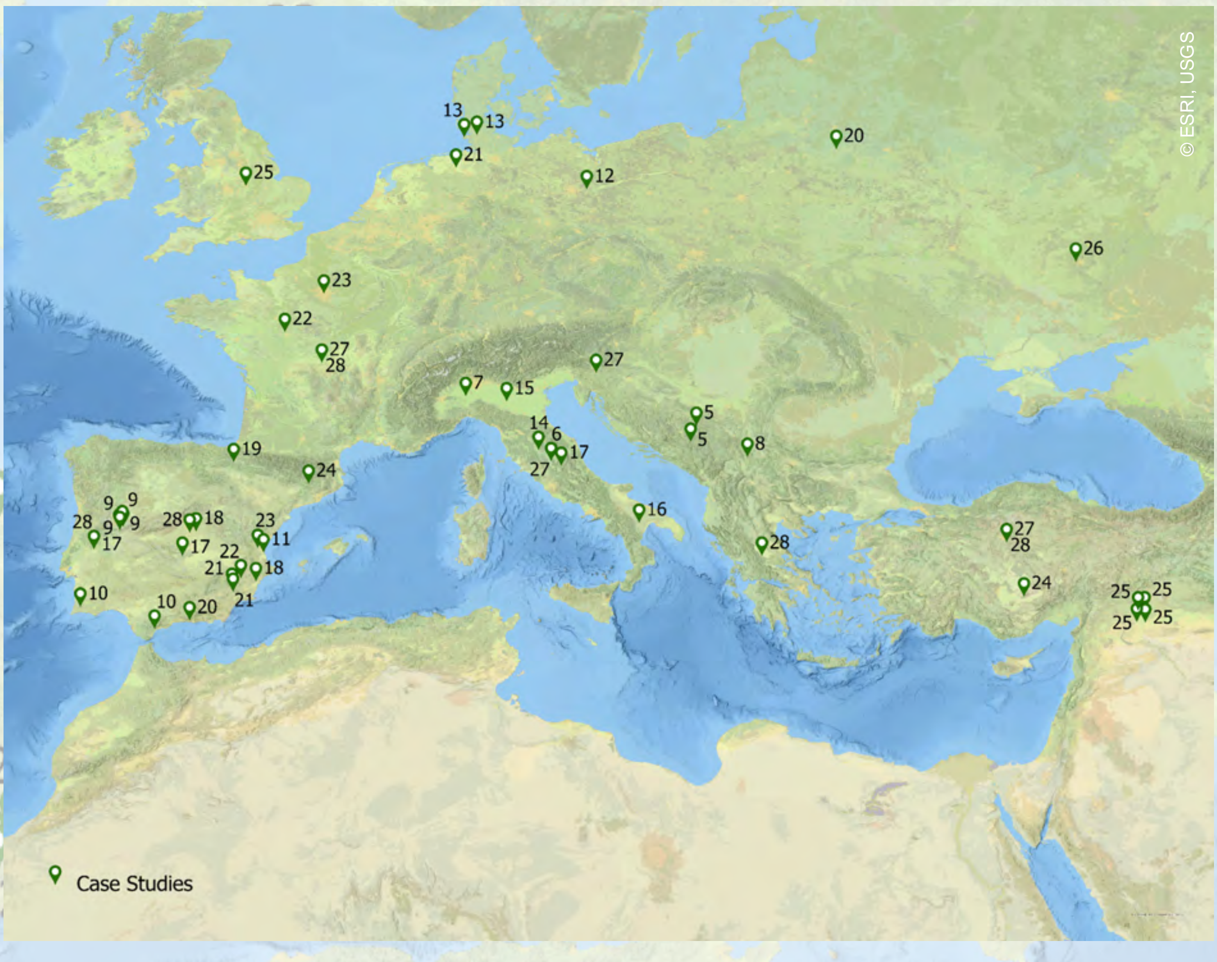

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Case Study ID	Region	Title	Practice 1	Practice 2	Practice 3	Duration
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25	Eurasia	Irrigated wheat-maize-cotton in the Harran Plain, Southeast Turkey	Crop rotation	Adapted irrigation		30
26	Europe	Organo-mineral 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 m^3/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-NO_3^- 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 *et al.* (2019a, 2019b); Palese *et al.* (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	

[a] The baseline SOC stock corresponds to Cmng after 20 years, that remains statistically unchanged during the whole experimental period

[b] Each 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 (Smng and Cmng)

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/cm^3), 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 m^3/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 (Sofo *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 (Sofo *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 × 10^6 g^{-1} soil and 21.4 fungal CFU × 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 in a 25 × 25 × 25-cm deep soil block; in the C_{mng} system: 10.0 bacterial CFU × 10^6 g^{-1} soil and 2.9 fungal CFU × 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 × 25 × 25-cm deep soil block) (Sofo *et al.*, 2014; Sofo, Mininni and Ricciuti, 2020). Soil microorganisms and macrofauna responded positively to a sustainable orchard management characterized by periodic applications of locally derived organic matter (Sofo *et al.*, 2010, 2014).

6.2 Minimization of threats to soil functions

Table 63. Soil threats

Soil threats	
Soil erosion	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 *et al.*, 2015). 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 *et al.*, 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.
Nutrient imbalance and cycles	In the S_{mgn} system: 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 (Sofo *et al.*, 2019a); higher N fixation and enhanced N-cycle were found (Pascazio *et al.*, 2018; Sofo *et al.*, 2010, 2019b)

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 *et al.*, 2019b).
Soil contamination / pollution	The irrigation with treated urban wastewater in the S_{mgn} system did not cause contamination with potential human pathogenic bacteria or other contaminants/pollutants (Palese *et al.*, 2009; Sofo *et al.*, 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_{mgn} system (Sofo *et al.*, 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 *et al.*, 2011; Palese *et al.*, 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 *et al.*, 2011; Palese *et al.*, 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 *et al.*, 2011; Palese *et al.*, 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 CO_2 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 CO_2. Pruning material had a substantial importance in CO_2 fixation (Palese *et al.*, 2013).

The soil of the S_{mng} system showed an increased abundance of N-fixing bacteria and less denitrifying bacteria (Sofo *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 (Sofo *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_{mng}) CONVENTIONAL MANAGEMENT (C_{mng})

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.

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