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Assessment of Soil Management Practices Enhancing Resilience of Small-Scale Agroecosystems: Case of Mount-Lebanon

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Abstract: Soil resilience has become a central theme in research aimed at understanding the impacts of human activities on the environment and mitigating the negative effects of soil disturbance. To evaluate how soil management practices affect soil resilience, 26 small farms were studied in a mountainous district of Lebanon. Farms were categorized into conventional (C), neutral (N), and regenerative (R), based on the practices adopted including tillage, amendments, rotation, cover crops, residues management, and pest control. Common practices included intercropping (85%), residue retention (73%), cover crops (61%), and organic amendments (46%). Qualitative assessment of soil health used indicators from Latin American Society for Agroecology (SOCLA) as well as from 'Tool for Agroecological Performance Evaluation' of the FAO. The indicators aligned with the classification of farms into their respective C/N/R groups. The sustainability scores were 4.28 (Low) for conventional, 6.34 (Moderate) for neutral, and 7.88 (Good) for regenerative farms. Quantitative analysis determined for 15 selected farms showed significant differences in soil organic matter (1.86% C, 2.75% N, 3.32% R), soil respiration (156C, 296N, 380R mg $C\text{-}CO_2$. week^{-1}), and earthworm abundance/liter (2.92C, 4.24N, 5.72R). The Soil Quality Index (SQI) provided an accurate representation of the current soil health condition, with increment from 0.05, 0.27 (low), to 0.49 (good) in conventional, neutral, and regenerative farms, respectively. The research highlights that soil resilience is influenced by a combination of intricate factors, encompassing biotic interactions, as well as physical, chemical, and biological processes. Particularly in regions like the Mediterranean basin, adopting sustainable soil management practices contributes to enduring productivity while preserving the functional integrity and resilience characteristics of the soil.

Keywords: resilience; regenerative capacity; sustainability; soil management practices; soil quality index; soil health

Introduction

Soil resilience is a dynamic characteristic that heavily relies on the condition of the soil (intrinsic and extrinsic factors) at the moment of evaluation (Corstanje et al., 2015). Defined as the "capacity of a soil to recover its structural and functional integrity after a disturbance" (Blanco-Canqui and Lal, 2010), resilience is most likely a holistic meta-function of a community, soil or an entire ecosystem, formed from all its individual qualities, in connection with ongoing processes, driven by biota interactions (Ludwig et al., 2018). Maintaining soil resilience necessitates special conservation efforts and ongoing care to create the necessary conditions (De Andrade Bonetti et al., 2017; Seipel et al., 2019). Yet, this potential is a consequence of previous and current soil management, as well as the possibility of future soil response to disturbances (Ludwig et al., 2018). In fact, practices leading to soil degradation must be neutralized by applying others leading to improvement in soil resilience (Cowie et al., 2019). As a driver for sustainable food systems, regenerative agriculture (RA) just recently gained attention (Schreefel et al. 2020). Despite the lack of a scientific and well detailed definition, RA is considered as a farming approach with potential for self-renewal and resiliency,

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enhancement of soil health, protection of biodiversity, improvement of soil-water dynamics, and carbon sequestration.

Moreover, increasing efforts have been aligned to restoring the ecological resilience and productivity of land through several interventions (Haddad et al., 2021). On that account, repeated annual compost additions were an advisable practice to restore or to preserve soil fertility in Mediterranean regions (Iovieno *et al.*, 2009). This practice is particularly relevant to agricultural soils with lower levels of organic carbon compared to natural soils (Romanya and Rovira, 2011; Darwish *et al.*, 2018). In addition, many benefits have been associated with the use of cover crops. They reduced soil erosion and runoff, improved nitrogen cycling, weed and pest control, enhanced soil quality and increased yields (Baldivieso-Freitas *et al.*, 2018). In a study from Lebanon, oat (*Avena sativa*) was used as a strategic overwinter cover crop to suppress or reduce weed and enhance nutrient cycling compared to forage radish and Narbon vetch (Rouphael *et al.*, 2019). Therefore, the adoption of sustainable practices in soil management is essential in the Mediterranean basin (Aznar-Sanchez *et al.*, 2020), particularly, increasing organic matter content to maintain soil productivity and reduce erosion and desertification (Zdruli and Zucca, 2018).

The methods for assessing soil sustainability and resilience remain subjects of ongoing deliberation (Mizuta et al., 2021). Whether soil resilience is to be maintained or restored, it is necessary to measure or quantify it. Previous methods have been developed to quantify the resilience of soil organisms, and soil properties to disturbance from a time-series of the response (engineering resilience). Many of the metrics of resilience are based on a comparison of a function between a disturbed and a control soil (Todman et al., 2016). More precisely, the capacity for soil to withstand physical changes has been demonstrated by observing alterations in pore volume and strength during and post compaction. Additionally, resilience in terms of soil structure has been assessed by analyzing the stability and size range of soil aggregates under wet and dry conditions, as well as tracking vertical soil shifts subsequent to compaction. On the biological front, the ability of soil to bounce back has been measured by examining shifts in the short-term decomposition of plant residues, levels of dissolved organic carbon, catabolic functions, specific groups of microbial functions, and the size and activity of microbial biomass as reactions to disturbances (Gregory et al., 2009). In fact, the complexity in measuring soil resilience traces back to the multi-functionality of soils, a pivotal role in deriving resilience (Ludwig *et al.*, 2018). Thus, a common approach is the use of scoring functions to map indicator values to a dimensionless scale reflecting their contribution to the considered soil function (Andrews et al., 2004; Vogel et al., 2019).

In Lebanon, few studies focused on the connection between soil management practices and soil resilience. Furthermore, most of the research on soil conditions has overlooked mountainous areas because of their rugged topography. However, these areas are particularly interesting because they host farmers who manage agriculture through self-sufficiency, subsistence and market-oriented approaches. Within this framework, this study investigated the soil management practices adopted by farmers in Mount-Lebanon. Based on the fact that soil resilience is a function of healthy soil, the hypothesis was that a number of management practices could be used as a scaling and sorting technique to assess soil health. Farmers were grouped under 'Regenerative', 'Conventional' and 'Neutral' according to the known effects of common practices on maintaining or restoring soil health. The purpose was to assess sustainability and resilience using a qualitative approach, as well as a quantitative one, the soil quality index. The objective was to find the level of agreement between the sorting technique and the classification of these mountainous agroecosystems according to the qualitative and quantitative selected indicators.

Materials and methods

Study area

The study area, located in *Aley* district, *Mount-Lebanon* governate, has a sub-humid Med climate with a mean annual precipitation of 800 to 1000 mm. The municipalities of *Ain El Jdideh* (33.8066ºN, 35.63028ºE; 930m asl, 133ha), *Ghaboun* (33.7816ºN, 35.59505ºE; 630m asl, 212ha), *Maasraiti* (33.74736ºN, 35.63496ºE; 505m asl, 87ha) and *Ramlieh* (33.74778ºN, 35.64822ºE; 650m asl; 356ha) were selected for the study. The region has a rugged topography characterized by valleys and deep clefts, with steep slopes that form drainage basins for waterways and springs (Halwani *et al.,* 2020).

The area is semi-urbanized, cultivated mainly with rainfed and irrigated wheat, fruit trees, tobacco, and vegetables (Verner *et al.,* 2018). Terraced land (Terric Anthrosols) is mainly used for fruit trees and distributed among hilly to mountainous landscapes dominated by limestones (Darwish et al., 2005). Soil type varies with topography, where deep Inceptisols and shallow Entisols, Cambisols and Leptisols occupy the mountain landscape, while Luvisols cover the mild steep slopes, and Fluvisols, Vertisols the flat lands. The land use pattern of the four municipalities was represented through an elaborate map (Figure 1), employing software ArcGIS pro (3.0) based on updated land cover of 2001, Sentinel image 10m. Despite a high diversity of landscape, natural vegetation and agricultural activity dominate major parts of the areas.

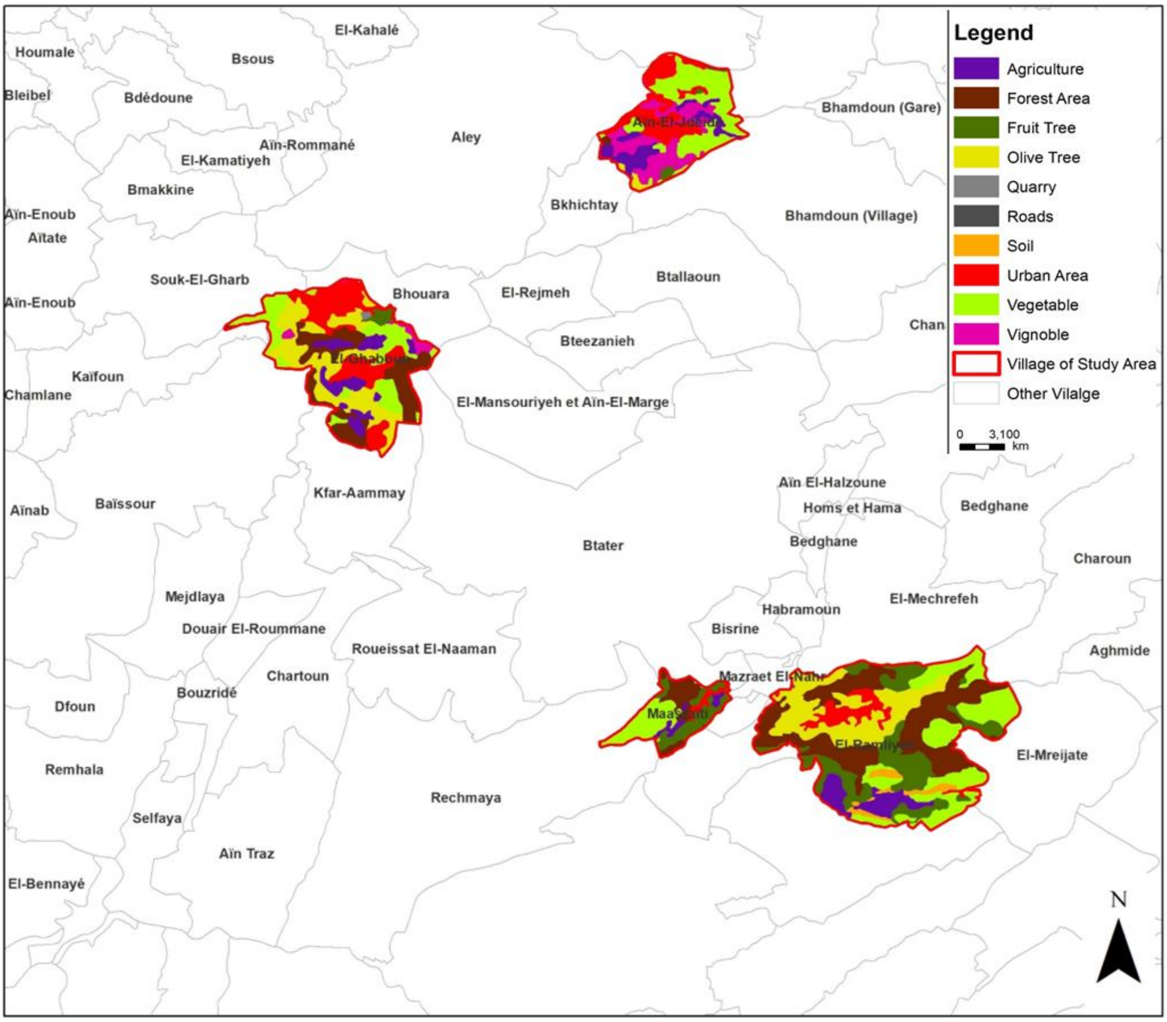

Figure 1. Map illustrating the land use pattern in the four municipalities of the study region.

Qualitative assessment

Farm history and soil management practices were obtained by visiting and interviewing all 26 farmers. Respondents were selected by means of snowball sampling in a way to achieve broad geographical coverage. Only small-scale agroecosystems (0.1-1.5 ha) cultivated with vegetables and fruit trees were considered. Based on the crop seasonality, nine farmers had their land predominantly occupied by annual crops (>70% of the land cover), while six farmers grew mostly perennials.

For the soil amendment, five farmers adopted the use of manure solely with different application frequency and placement. On the contrary, eight farmers combined the use of synthetic fertilizers and manure amendment. Meanwhile, one farmer applied synthetic fertilizers only and another farmer applied composted vegetable waste and manure. Based on the intensity and frequency of soil tillage, eight farmers adopted conventional tillage practices while five farmers applied reduced tillage practices, and only two farmers resorted to no-till.

In order to classify the farms, the management practices were separated into conventional and regenerative (Table 1). Then each conventional practice was assigned a negative score (-1) while a positive one (+1) was provided to each regenerative practice. A neutral value (0) was given for concomitant 'C' and 'R' practices. Based on this, a scoring line (-5 to +5) was established. Farmers ranging between (-5 to -2) were categorized under 'conventional', those between (-1 to +1) under 'neutral', and farmers given between (+2 to +5) under 'regenerative'. A total of 6 conventional, 11 neutral and 9 regenerative farmers were obtained.

Table 1. List of regenerative and conventional practices used to score the 26 studied farms into a conventional/neutral/regenerative class.

Regenerative practices	Conventional practices
Conservation (No-tillage) or reduced	Excessive tillage practices
Compost amendments/green manure	Synthetic fertilizers
Crop rotation	No crop rotation
Intercropping/mixed cropping	Monoculture
Cover crops	No cover crops
Improved irrigation technique	Furrow irrigation
Organic or biological pest and diseases treatment	Pesticide treatment (herbicides, insecticides, etc.)
Mixing crop and weed residues with soil, usage as organic mulch, or in composting	Burning or eliminating organic residues

To reduce the number of respondent farmers, five farms were randomly selected from each category. This was done using a stratified sampling method, which is a probability sampling method (Parsons, 2017). Soil health status, in these 15 agroecosystems, was assessed with soil indicators developed by Latin American Society for Agroecology (*la Sociedad Cientifica Latino americana de Agroecologia* = SOCLA) (Nicholls et al., 2004). But the number of soil indicators was reduced from 10 to 6 indicators (referred to as I1, I2, I3, I5, I6 and I7 in Table 2). SOCLA indicators reflected on the structure of the soil, status of soil residues, color, odor, organic matter, soil cover, presence of invertebrates and erosion. A 'crop diversity' indicator (I4 in Table 2) from 'Tool for Agroecological Performance Evaluation' (TAPE) (FAO, 2019) raised the number to seven. These indicators will be referred to, hereafter, as *SOCLA*.

Table 2. Soil quality indicators (I) with corresponding characteristics and estimated values used to obtain the SOCLA evaluation. Indicator I4 was adapted from the FAO (2019). Indicators I1, I2, I3, I5, I6 and I7 correspond to the SOCLA evaluation of soils.

Indicator	Established value	Characteristics	Field score
Structure I1	1-3	Loose soil, powder exhibiting no visible aggregates	
	4-6	Small number of aggregates, readily breakable	
	7-10	Well-formed aggregates, difficult to break	
Status of residues	1-3	Organic residues decomposing slowly	
	4-6	Presence of last years' decomposing residues	

I2	7-10	Heterogenous nature of residues, most are well decomposed	
Color, odor, and organic matter I3	1-3	No presence of humus with pale and chemical odor	
	4-6	Moderate amount of humus, light brown, odorless	
	7-10	Abundant humus, fresh odor, dark brown	
Crop diversity I4	1-3	Monoculture covering 80% of cultivated area	
	4-6	Two to three crops/tree species	
	7-10	More than three crops and varieties	
Soil cover I5	1-3	No crops, bare soil	
	4-6	Vegetative cover or residues covering less than 50% of land	
	7-10	Vegetative cover or residues covering more than 50% of land	
Erosion I6	1-3	Severe presence of small gullies or fallen stone walls	
	4-6	Evident but low erosion signs	
	7-10	No visible signs of erosion	
Invertebrates activity I7	1-3	No earthworms	
	4-6	Few earthworms	
	7-10	Abundant presence of earthworms	

Based on FAO's guidelines for soil description (FAO, 2006), agroecosystems were visited in summer 2022, when the soil is dry or slightly moist. Each indicator was assigned with a score between 1 and 10 (1 being the least desirable value, 5 a moderate or threshold value and 10 the most preferred value). Status of residues (I2) was based on the abundance and heterogeneity of decomposing residues. Crop diversity (I4) was evaluated on field and illustrated using drone-based images. The indicator used to study soil cover (I5) was based on either the standing crops percentage cover of the cultivated land or dead organic residues such as mulches. The assessment of soil erosion was based on the presence and intensity of small gullies in the cultivated land and on the integrity of the stone-terraces.

Soil sampling and analysis

Soil sampling was performed according to standard methods for the near surface (0–15 cm). Five sub-samples were collected using a spade, then mixed well to obtain a composite soil sample. Samples were air-dried then sieved (<2 mm). Soil samples (15 of them) were analyzed for available phosphorus P_2O_5 (mg/kg soil) measured based on Olsen method (ISO 11263:1994), exchangeable potassium K_2O (mg/kg soil) (NF X31-108:1998), total organic matter content (%) (Walkley-Black method) at the laboratory of the Lebanese Agricultural Research Institute (LARI) in Tal Al-Amara in Bekaa region.

The earthworms count took place *in-situ* between 12-20 of January 2023. Three soil pits (10×10×10cm) were dug in each field, followed by hand sorting. After sampling each agroecosystem, the number of the three pits was averaged. The used technique yields satisfactory results for earthworms of more than 0.2 g live weight, but it has the disadvantage of low extraction efficiency for smaller worms (Jiménez *et al.*, 2006). Despite it being time-consuming, labor intensive, harmful to earthworms during collection and less efficient in soils with high clay content or dense root mat, this technique was beneficial because of the small sample sizes (Singh *et al.*, 2016).

Soil respiration analysis of the 15 soil samples was obtained using the chemical titration procedure (Haney et al, 2008). For this, a pre-incubation phase consisted of wetting 25g of the dry soil (< 4 mm) up to 50% water-filled pore space, for 21 days at ambient temperature (22-25ºC) in darkness. Five replicates of each soil sample were included, in addition to a soilless control. After this, vials already attached in the jars, were filled with 10mL of NaOH (0.5N). The jars were incubated after tightly closing them with plastic tapes, ensuring that CO_2 evolved was trapped in NaOH solution. After 24 hours, 8mL of barium chloride ($BaCl_2$) was added to the vials and excess alkali was back titrated with hydrochloric acid (HCl 0.25N) to a phenolphthalein end point. The control was used to correct for the CO_2 in the jar. Finally, the amount of mg CO_2-C in 25g^{-1}was calculated as follows (Anderson,1982):

$$CO_2\text{-C (mg/25 g soil.day}^{-1}) = (\text{Volume}_{Control} - \text{Volume}_{Soil}) * M * E$$

M= normality of acid; E= equivalent weight. To express the data in terms of carbon, E = 6.

The results, normalized with respect to time, were expressed as C mineralized (mg/kg of soil/week).

Quantitative Assessment: Sustainable Management Assessment Framework (SMAF)

Soil management assessment framework (SMAF) was conducted using a three-step process: (1) indicator selection, (2) indicator interpretation, (3) integration into an index (Wienhold *et al.*, 2009; Mukherjee and Lal, 2014). As part of step one, biological [soil respiration rate (mgC-CO_2/d), earthworm abundance] and chemical [available phosphorus (P_2O_5), exchangeable potassium (K_2O), organic matter (OM%), pH] indicators were analyzed. Step two of the SMAF consisted of the interpretations of the laboratory values (Arshad and Martin, 2002; Andrews et al., 2004) and the identification of the minimum and maximum threshold values. For soil pH (min = 4.01, max = 8.5), available phosphorus (min = 10, max = 30) and exchangeable potassium (min = 100, max = 500), these thresholds were as reported in the literature (Amacher et al., 2007). The values of OM (%) were adapted to the soil textural class, increasing from loamy (min = 1.6, max = 3.1) to clay (min = 2.1, max = 3.4) soils.

For the soil respiration rate, the maximum threshold adapted from (NRCS-USDA, 2014), was reduced from 2 000 mg C-CO_2/kg soil/week (state of high and excessive SOM content) to 1 200 mg (a state of ideal and sufficient SOM). This step was mandatory to obtain reliable classification of soil respiration rate adapted to the Mediterranean conditions. For the second bio-indicator, that is the earthworm's abundance (density/L of soil) a minimum and maximum threshold values (min = 2, max = 5 per liter of soil) were assigned, based on experts' opinion.

Step three of the SMAF involved the integration of all measured soil attributes into a composite index. The simple additive integration technique was used in this study (Mukherjee and Lal, 2014):

$$SQI = \frac{\sum SQIi - SQImin}{SQImax - SQImin}$$

Where:

SQIi= total sum of individual soil property index values

SQImin= minimum value of the soil quality index

SQImax= maximum value of the soil quality index

Soil quality index (SQI) values were distributed in five classes: very good (score: 0.80-1.00), good (0.60-0.79), moderate (0.35-0.59), low (0.20-0.34) and very low (0.00-0.19) (Mulyono *et al.*2019).

Statistical analysis

The collected data was tabulated using the software Microsoft Excel 2013. All statistical analyses were performed using IBM SPSS version 23.0 statistical package. The analysis of variances (ANOVA) was performed on the entire data set indicators, to compare the statistical differences between categories assigned and the mean differences were adjudged by Tukey HSD test at a $P_{value} \leq 0.05$.

Results and discussion

Soil management practices

The practice implemented by most farmers (84.6%) was intercropping/mixed cropping (Figure 2). This strategy was followed by farmers in response to the economic crisis in recent years. Products diversification aimed to provide the daily supply of fruits and vegetables, to prepare preserved food

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for winter season, and to increase farms income. This interpretation goes in line with the finding that agricultural diversity is promoted by small farmers (Haddad *et al.*, 2021; FAO, 2020).

The second most common practice refers to the retention of weeds and crop residues (73.1%). In previous years, some farmers applied, prior to tillage, herbicides for weed management. Following the aggravated economic situation, farmers preferred to adopt this low-cost practice. However, tillage practices were still prominent as only 26.9% of respondents adopted reduced or no-till system, referred to as conservation tillage (Figure 2). This situation is justified by the high reliance of no-till on herbicides for weed control (d'Emden *et al.*,2008) and by the fact that tillage is deeply rooted among many farmers (Failla *et al.*, 2021).

Unlike tillage practices, cover crops were grown by 61.5% of farmers (Figure 2). The most likely winter crops included fava beans, peas, chickpeas, onion, garlic, chard, and some brassica crops. These are favored as cash crops as they contribute to the diversification of farm produce. As for the use of amendments (compost and manure), only 46.1% of respondents were dependent solely on them. This could be linked to their recent price increases and higher costs of transportation and application. Amendments were added every two to three years, except for mixed farms where they are applied annually. Practices requiring a significant investment were less attractive, as these small holders produce with limited resources and investments, yet they ensure the diversification of crops cultivated, finding in consistency with Dal *et al.* (2021).

Some practices, such as improved drip irrigation (38.5%), conservation tillage (26.9%), crop rotations (19.2%) and organic or biologic pest and disease management (11.5%), were confined to regenerative and to a lesser extent to neutral farms. Regenerative practices were weakly adopted in conventional farms, with a noticeable absence of synergism. For example, some farmers use organic amendments with varying frequency, placement, and quantities but practice improper tillage intensity. Further, most of them were dependent on furrow irrigation, while the mismanagement of irrigation could be a potential cause for soil degradation (Darwish, 2012). Another risk is soil water erosion, especially between the beginning of Autumn and the end of Spring, either because the soil is unprotected or only partially protected (Boulal *et al.*, 2011). However, farmers growing winter cover crops manage to mitigate water erosion in winter season (Rouphael *et al.*, 2019). Contrarily, irrigation-induced erosion is dependent on other management practices. For example, associating no-tillage with the leaving of residues lowered runoff, a key erosive agent (Boulal *et al.* 2011). Briefly, combining various practices can increase the profitability of sustainable practices as it can provide several synergistic benefits (Aznar-Sanchez, 2020).

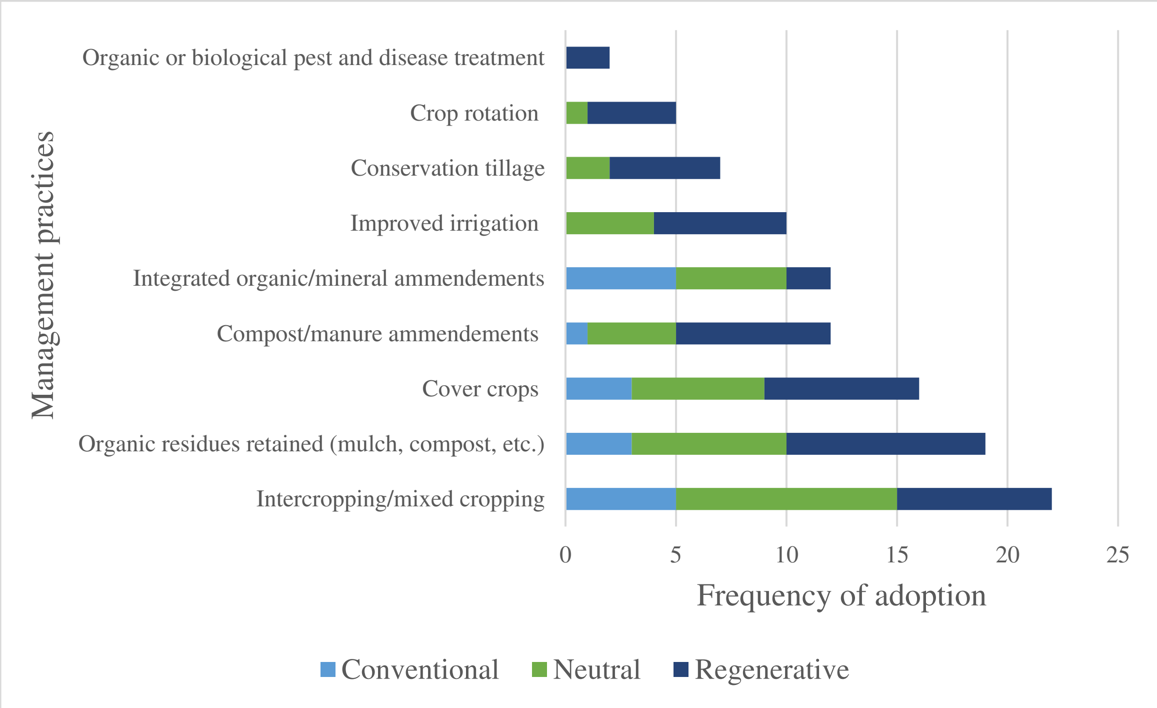

Figure 2. Distribution and frequency of regenerative soil management practices adopted by respondent farmers (n=26).

Soil qualitative assessment

Sustainability of soil management was assessed using the seven indicators presented in Table 2. Soil structure (I1) assessment was dependent on the qualitative evaluation of aggregate stability (Figure 3). Low scores characterize soils with poor and powdery structure, while high scores are associated with intact aggregates. The set of images are classified based on aggregate strength (intact, crumbly, and powdery soils).

Figure 3. Soil aggregates visualization associated with different management practices and soil texture. Scores classified based on intact, friable, crumble and powdery soils.

The management of residues (I2) varied between the removal of organic residues and leaving them to decompose slowly or partially. The accumulation and decomposition of litter with earthworm activity were prominent in non-tilled agroecosystems. Weeds served as a spontaneous cover in some farms, while crop residues (grape vine and lima beans) were used as an organic mulch. In some cases, weeds were chopped and left as organic mulch while in others organic residues were eliminated or burned, leaving soil bare.

Concerning soil color, odor, and organic matter (I3), low scores are associated with soils of pale color, chemical odor, and low organic matter (Figure 4-a). Moderate scores are linked with soils having light brown color, odorless and some humus content (Figure 4-b, c and d). Contrarily, good scores are given to soils that revealed high content of humus, with a dark brown color and fresh odor (Figure 4-e and f).

Figure 4. Visual illustration of soil samples used as a benchmark for the assessment of soil color, odor, and organic matter indicator.

Next to the crop diversity (I4), soil cover (I5) and soil erosion (I6) were used as indicators. To protect soil and retain moisture in areas otherwise subject to erosion, stone-walls are built. However, land abandonment in recent decades has led to poor terrace maintenance, promoting their collapse and increasing erosion rates (Nunes *et al.,* 2016). Despite their ecological advantage, their maintenance is an economic burden for farmers. However, to protect the integrity of the walls some farmers left grass strips over their length; or planted deep root perennials such as oregano. In particular, one farmer implemented composting, straw mulching, no-tillage, drip irrigation and introduced small ruminants to restore the land after a decade of abandonment. Conservation systems, such as no-tillage and crop-livestock integration, have been proposed to recover degraded soils (de Andrade Bonetti *et al*., 2017), since they increase crop residues on the soil surface.

At the field level, the scores of *SOCLA* indicated an increasing level of soil management sustainability from conventional (4.28), to neutral (6.34) and regenerative (7.88) farms (Table 3). The conventional category included farmers whose level of sustainability ranged between 3.57 and 5.86, the neutral category included farmers whose level of sustainability ranged between 4.71 and 7.29. Contrarily, the regenerative category included farmers whose level of sustainability ranged between 7.29 and 8.29 (Table 3). Farmers characterized as neutral maintained a balance between practices that alter soil, creating neutral disturbances that have the potential to shift either for regenerative or conventional.

Table 3. Scores of the *SOCLA* tool (based on 7 indicators) and of the soil quality indicator (SQI) referring to the management of 15 farms classified as conventional, neutral or regenerative.

		Farm category		
		Conventional	Neutral	Regenerative
SOCLA	Mean	4.28	6.34	7.88
	Standard deviation	0.82	1.05	0.39
	Minimum	3.57	4.71	7.29
	Maximum	5.86	7.29	8.29
	Evaluation	Low (3-4.9)	Moderate (5-6.9)	Good (7-8)
SQI	Mean	0.05	0.27	0.49
	Standard deviation	0.15	0.15	0.11
	Minimum	- 0.15	0.09	0.39
	Maximum	0.29	0.49	0.67
	Evaluation (Mulyono *et al.* 2019)	Very low (<0.38)		Moderate (>0.44)

Soil quantitative assessment

Soils textural classes indicated a predominance of loamy (67% of them) and clayey (33% of them) soils, while $CaCO_3$ varied between 0.8 and 41% (10.83 ± 10.88) (data not shown). Their pH ranged between 6.60 and 7.70, with a mean value of 7.21. Based on the analysis of variance, the pH, available P_2O_5, exchangeable K_2O tests did not show a difference between classes (Table 4). Exchangeable potassium content as well as the available phosphorus are directly affected by the short-term addition of mineral fertilizers by farmers, which explains the lack of differences between agroecosystems.

Only SOM, soil respiration and earthworms gave a significant difference between categories (Table 4). The highest organic matter was attained under regenerative, followed by neutral then by conventional category (Table 4). For soil respiration and earthworm counts, the means under the regenerative farms were significantly higher than in the conventional category (Table 4). In the current study, soil organic matter was a potential indicator and showed positive correlation with earthworms and soil respiration rate (C-CO_2). These more resilient agroecosystems are characterized by more active microbial communities, as suggested by the higher rates of soil microbial respiration. However, since several years are required for a noticeable positive increment after implementing conservative management approaches (Blanco-Moure *et al.*, 2016; Darwish and Fadel, 2017), SOC is not suggested as a short-term indicator of soil health and is not always the best indicator of changes in soil management (Blanco-Moure *et al.*, 2016).

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Table 4. Mean distribution and standard deviation (std) of measured soil parameters (available phosphorus, exchangeable potassium, soil organic matter and soil respiration) under the three categories: C: conventional, N: neutral and R: regenerative farmers.

Mean ± std						
CLASS	**pH**	**Av. P_2O_5 (mg/kg soil)**	**Ex. K_2O (mg/kg soil)**	**OM %**	**C-CO_2 mg.25g/d**	**Earthworm (#/L)**
C	7.2±0.27	83.6±51.5	235.2±100	1.86±0.79^{b}	156.2±70.4^{b}	2.9±1.86^{b}
N	7.1±0.37	171.6±17.1	510.2±312	2.75±0.72^{ab}	295.7±109.3^{a}	4.2±1.52^{ab}
R	7.3±0.27	170.1±108.2	507.8±134	3.32±0.54^{a}	380.5±56.5^{a}	5.7±0.80^{a}

Different letters indicate significant differences at significance level P<0.05 between values in columns for each parameter.

Soil Quality Index

The Soil quality index (SQI) was established to verify the former hypothesis 'management practices with varying degree could be used as a scaling and sorting technique of farmers'. SQI can also be used to assess soil health and resilience in different management schemes.

The results (Table 3) indicated that the lowest SQI was associated with the conventional category (0.05), followed by the neutral category (0.27), and the regenerative category (0.49). Based on the classification criteria (Mulyono *et al.*, 2019), the conventional and neutral categories presented very low SQI, while the regenerative category a moderate one.

This actual measure of soil health expressed very low to moderate grades. Farms belonging to the conventional and neutral categories were characterized by very low soil health. Contrarily, the regenerative category was classified with moderate soil health. Conventional farms pay a first bill to achieve an intensified crop, and a second one to fight and control pests and diseases. Neutral farmers may have a greater potential to shift towards regenerative practices, yet the conditions required to step this transition is socio-economically bounded. This category may be resilient to future disturbances, but soil functions would be less efficient and consequently ecosystem services must be compromised. Regenerative farmers were environmentally driven and at the same time the healthy food supply was not totally dependent on the farm performance.

Soil management sustainability grades (*SOCLA* evaluation) are consistent with SQI classes. These findings are reasonably based on two scientific evidence. First, the reference document of the United Nations (UN) on the status of global soil resources stresses that most of the world's soil resources are in fair, poor or very poor conditions (FAO, 2015). Second, Mediterranean soils specifically have been characterized by low levels of organic matter in surface layers (Romanya and Rovira, 2011; Darwish *et al.*, 2018). Therefore in spite of numerous regenerative practices (Cowie *et al.*, 2019), the restoration of soil functions may take decades (Pey and Dolliver, 2020). Respondent farmers were totally driven towards sustaining their livelihoods. The management practices adopted were not always efficient in improving soil health in the long-term, since the goal is to ensure soil fertility for crop production in the short-term. The varying degree of disturbance under the three farming categories is clearly observable through soil health in this study.

Conclusion

The hypothesis positing that the degree of management practices could serve as a sorting mechanism for farmers has enabled a comprehensive assessment of the impact of these practices on soil resilience. The implementation of the proposed scoring technique facilitated the classification of 26 small farms into distinct categories: neutral, regenerative, and conventional production units. This selection encompassed a diverse range of smallholding farms, ensuring a continuous and ample supply of food through crop diversity and intensification efforts aimed at offsetting income losses.

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Responding to economic challenges, both conventional and regenerative farming practices have placed heightened demands on soil resources. However, the implementation of synergistic management practices, particularly evident in regenerative farms, has enabled a more sustainable approach to intensification by fostering soil resilience against disturbances. On the contrary, conventional farming methods have shown limited incorporation of regenerative practices.

Comparatively, regenerative farms have demonstrated significant enhancements in soil structure and fertility, thereby facilitating improved nutrient retention, heightened crop resilience, and reduced erosion. The enhanced soil structure in regenerative farms also enables efficient water absorption and retention, thereby mitigating the risk of drought stress for cultivated crops. Further, the integration of biodiversity in regenerative farms has led to well-balanced and resilient ecosystems, marked by stable yields, reduced input costs, and elevated economic viability. Neutral farms, characterized by varying levels of soil conservation practices, contribute a crucial balance to the study. Their inclusion prevents the introduction of bias by offering a more comprehensive evaluation of diverse soil conservation strategies.

The assessment methods, encompassing the soil management practices sustainability assessment (using SOCLA) and the Composite Soil Health Index (SQI), have consistently aligned with each other, reaffirming the viability and utility of the proposed hypothesis that clusters farmers based on their impact on soil health. The soil parameter values, including organic matter percentage (OM%), soil respiration (C-CO_2 mg/week), and earthworm abundance (per Liter), effectively corresponded to specific farming types. Notably, the culmination of synergistic soil management practices in regenerative farming led to a notably higher soil quality index (0.49), in contrast to the minimal value observed in conventional farms (0.05). The effectiveness of the rapid and efficient farm sorting methodology in distinguishing and evaluating soil health has been clearly established.

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