

Article

Restoration, Indicators, and Participatory Solutions: Addressing Water Scarcity in Mediterranean Agriculture

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Abstract

Agricultural water resource management is increasingly challenged by climate variability, land degradation, and socio-economic pressures, particularly in the Mediterranean region. This study, conducted in 2023–2024 within the REACT4MED project (PRIMA initiative), addresses sustainable water use through a comparative analysis of organic and conventional farms in the Stornara and Tara area (Puglia, Italy). The research aimed to identify critical indicators for sustainable water management and develop ecosystem restoration strategies that can be replicated across similar Mediterranean agro-ecosystems. An interdisciplinary, participatory approach was adopted, combining technical analyses and stakeholder engagement through three workshops involving 30 participants from diverse sectors. Fieldwork and laboratory assessments included soil sampling and analysis of parameters such as pH, electrical conductivity, soil organic carbon, nutrients, and salinity. Cartographic studies of vegetation, land use, and pedological characterization supplemented the dataset. The key challenges identified were water loss in distribution systems, seawater intrusion, water pumping from unauthorized wells, and inadequate public policies. Soil quality was significantly influenced by salt stress, hence affecting crop productivity, while socio-economic factors affected farm income. Restoration strategies emphasized the need for water-efficient irrigation, less water-intensive crops, and green vegetation in infrastructure channels while incorporating also the native flora. Enhancing plant biodiversity through weed management in drainage channels proved beneficial for pathogen control. Proposed socio-economic measures include increased inclusion of women and youth in agricultural management activities. Integrated technical and participatory approaches are essential for effective water resource governance in Mediterranean agriculture. This study offers scalable, context-specific indicators and solutions for sustainable land and water management in the face of ongoing desertification and climate stress.

Keywords: sustainable water management; sustainability indicators; soil quality; participatory approach; organic and conventional farms; restoration actions



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1. Introduction

The correct management of water resources in agriculture is one of the most debated topics due to the ever-decreasing availability of this resource, especially in countries where desertification processes occur and are crucial [1–3]. The impact of agricultural livelihoods and water conservation in the wake of increasing drought requires a comprehensive understanding of the issues at all levels [4–6], from the political-administrative implementation

to manage water supply, through the economic trend, to the ecological-environmental often in conflict with each other [7,8].

The orientation toward crops that require low amounts of water (drought-resistant) is only one of the paths followed in various projects in the Mediterranean basin [9]. Still, it should not be the only one since this could lead to the disappearance of traditional and indigenous crops due to a decrease in agrobiodiversity at the field and ecotone belt levels [10,11]. This is often in contrast with community guidelines, which, instead, require the conservation and valorization of local crops, especially of the “minor crops” in terms of water consumption [12,13].

There is ample evidence that land degradation, desertification, and available water resources are major threats to the present and the future of Mediterranean arid and semiarid agro-ecosystems, creating an uncertain and unstable living environment that could lead to poverty and force domestic and even cross-border migration. Together with land degradation, the accelerated dryland expansion occurring in the Mediterranean climate change hot spot threatens the biological systems and the natural resources that sustain agriculture and forests [14–16]. To address these issues, a considerable number of international projects are already working to find solutions. One of them is the REACT4MED [17] project, which aims to improve the sustainable management of land and water to support agro-pastoral productivity, accelerate innovation and technological diffusion, reverse land degradation, and improve the livelihoods of Mediterranean communities. To achieve this, the project follows two conceptual directions: a top-down approach that introduces broad-scale concepts and methods that highlight good, cost-effective practices against land, water, and agro-ecosystem degradation as well as physical vulnerabilities, while a bottom-up, multi-actor approach is used to overcome obstacles and support their substantial out-scaling.

As stated, there are also other projects that have been designed with similar aims that promote stronger collaboration between scientists and farmers such as SUPROMED [<https://supromed.eu/index.php/en/>] (accessed on 24 February 2025), MEDWATERICE [<https://mel.cgiar.org/projects/medwaterice>] (accessed on 24 February 2025), and PRECIMED [<https://mel.cgiar.org/projects/precimed>] (PRIMA projects) (accessed on 12 March 2025). They have focused particularly on efficient water management [18]. Among the proposed advances are humidity sensors, telematics connections with meteorological stations, remote sensing of losses, and mobile data platforms. This is because the agricultural sector requires tools, assistance, and strong political will. Since research on sustainable agriculture and water management often fails to translate into practical applications, REACT4MED was designed to address these shortcomings and better align challenges with actionable, real-world outcomes.

REACT4MED has selected eight pilot areas in the Mediterranean (Turkey, Morocco, Israel, Egypt, Cyprus, Greece, Spain, and Italy) that were chosen specifically for their capacity to implement large-scale land degradation restoration actions and lay the foundations for follow-up actions even after the project duration. These restoration actions include conservation agriculture (Morocco), terracing (Cyprus), cover crops (Spain), forestation (Greece), soil salinization (Turkey), loss of biodiversity (Israel and Greece), irrigation technology (Turkey), and water management (Italy) (Figure 1).

This paper aims to identify critical indicators at the farm level for sustainable water management and develop ecosystem restoration strategies. The test areas are two farms of the Stornara and Tara consortium (Figure 1), in the province of Taranto (southern Italy), which is a public institution for the management of water resources. This focus is particularly relevant to safeguarding water availability, maintaining soil health, and enhancing resilience against environmental stressors, given the fragility of Mediterranean agro-ecosystems.



Figure 1. REACT4MED pilot areas in relation to SDGs (Sustainable Development Goals) and Italian georeferenced pilot area map (in red). Picture by Enrico Vito Perrino.

To achieve the scope, an interdisciplinary, participatory approach was adopted, combining rigorous technical analyses with stakeholder engagement. Such an approach ensured that the strategies developed were grounded in local knowledge and practical realities, fostering ownership and increasing the likelihood of successful implementation. The integration of scientific assessment with stakeholder input addresses a common gap in sustainable management practices, which often overlook socio-economic and institutional dimensions.

Fieldwork and laboratory assessments provided robust data on key soil parameters that are vital indicators of soil and water quality. These parameters serve as measurable benchmarks for assessing ecosystem health and the effectiveness of restoration efforts. Additionally, cartographic studies detailing vegetation cover, land-use patterns, and pedological characteristics enriched the dataset, allowing for a comprehensive spatial understanding of the landscape's condition and vulnerabilities.

By combining these diverse methods, the study contributes valuable, replicable strategies tailored to Mediterranean agro-ecosystems, which face unique environmental and socio-economic challenges. The relevance of this work lies not only in advancing scientific knowledge but also in providing practical inspiration for policymakers, land managers, and communities striving for sustainable resource use and ecosystem resilience in water-scarce regions.

2. Materials and Methods

Study sites are located in 2 different farms in the Puglia Region (southern Italy) in the province of Taranto. The study on the two sites (organic farm—OF; conventional farm—CF) was conducted at different levels:

- Technical and thematic cartographies. Framing of the potential vegetation was based on the cartography of the Vegetation of Italy [19], while land use and pedological

cartographies were based on the maps provided by the SIT (Territorial Information System) [20].

- Soil sampling in two farms (Organic Farm = OF and Conventional Farm = CF), with 3 and 2 sampling sites, respectively, repeated during two different seasons (winter 2023 and summer 2024) to evaluate different data for environmental changes, especially for water availability (Table 1). In total, 10 soil samples were collected at depths between 0–25 and 0–30 cm through a manual auger, numbering them by starting with the winter season (w) and the organic (OF1w, OF2w, and OF3w) and conventional (CF1w and CF2w) farms and followed by the summer season (s), always starting with the organic farm (OF1s, OF2s, and OF3s) and followed by the conventional farms (CF1s and CF2s). After collecting samples, soils were air dried and crushed with a mortar prior to sieving at 2 mm size. Soil analysis was performed by the Laboratory of agricultural and environmental chemistry of CIHEAM Bari. The particle-size distribution analysis was performed using the pipette method [21], while the textural class was defined according to the USDA classification. Soil pH was determined in water and saline solution (CaCl_2 0.01 M) at 1:2.5, *w/v*. Electrical conductivity (EC) was measured on soil water extracts (1:2, *w/v*). Soil organic C was determined by the Walkley and Black method [22], while total N was measured following the Kjeldahl method [23]. Available P was measured on sodium bicarbonate alkaline soil extracts and measured by the Olsen method [24]. Total carbonate content was quantified using a Dietrich–Fruhling calcimeter apparatus, and the exchangeable bases (K, Ca, Mg, and Na) were extracted with barium chloride and triethanolamine solution and quantified by ICP-OES.
- Three stakeholder Italian pilot area meetings were held for the evaluation of critical issues and solutions to be adopted [7 February 2023, 3 October 2023, 6 December 2024]. Each meeting included the presence of two stakeholder groups with different roles and expertise, first representing the issues raised in the discussion for each individual group and then the solutions to be adopted in the topics proposed by the REACT4MED project. The characteristics of the stakeholders and their affiliations, genders, and ages are highlighted in Table 2.

2.1. First Stakeholder Meeting

The first meeting was held in Massafra (Taranto) on 7 February 2023 to identify specific agronomic-environmental problems and possible solutions through the active involvement of invited stakeholders. The focus was concentrated on three major issues: water supply, the reuse of shallow waters, and salinity control. To initiate a shared understanding of the complexity surrounding such problems, participatory visual dialogue was facilitated using the rich picture methodology. This method, rooted in systems thinking, was employed to capture and represent diverse stakeholder perceptions of the problem situation in a visually structured format, drawing on their personal and professional experiences. Rich pictures served both as a means of individual expression and collective sense-making, supporting the identification of critical challenges and potential intervention points.

Participants were assigned to small, mixed-background groups to ensure a diversity of perspectives. Within their groups, participants collaboratively constructed visual representations of the problems affecting the agricultural system in the study area. They were encouraged to use drawings and symbols to express their viewpoints, fostering indirect dialogue through imagery. Each group was tasked with identifying and noting five key challenges arising from their collective depiction.

To further elaborate on the outcomes of the rich pictures, a structured participatory workshop session using moderation cards, was conducted to consolidate stakeholder

knowledge regarding possible solutions to the previously defined problems, in terms of ongoing or potential restoration actions and relevant indicators.

Post-workshop, all output materials were elaborated to represent the shared perception of the problem situation and possible solutions. This served both as the output of the first workshop and the input for following workshops and planning activities.

2.2. Second Stakeholders' Meeting

The *second workshop* was held at CIHEAM Bari in Valenzano on 3 October 2023. The workshop aimed to capture and collect the visions of agriculture in 2043 through the active involvement of local stakeholders. As part of the participatory methodology implemented in the REACT4MED project, a group-envisioning exercise was conducted to co-develop stakeholder-informed future scenarios for sustainable agriculture in the Stornara and Tara pilot areas (Puglia, Italy). The aim of this activity was to explore long-term aspirations, values, and priorities among local actors and foster shared ownership over potential future development pathways. The specific objectives of the envisioning exercise were to encourage participants to imagine and articulate desirable futures for the local agricultural system, identify the values stakeholders associate with positive or negative development trajectories, promote awareness of dynamic conditions and the potential for transformation over time, and foster a sense of agency and collaborative responsibility in shaping the future.

For this aim, participants were divided into heterogeneous groups, with each group consisting of a maximum of six members and facilitated by a trained moderator. Group composition aimed to ensure diversity in terms of gender, professional background, and institutional affiliation, encouraging a broad representation of perspectives.

The envisioning process began with the individual identification of five key elements that each participant associated with a desirable agricultural future in the study area by the year 2043. These elements could include social, economic, environmental, or technical aspects.

Moderators then guided the groups in detailing and expanding the vision. Through structured questioning, participants were encouraged to clarify what exactly they envisioned for each element, why these elements were important, and how these visions differed from the current agricultural reality.

The outcome of the activity was a structured summary of their vision, including a clear and accessible list of key elements and their associated details, in the form of a narrative description contextualizing the vision, highlighting interconnections between elements, and offering qualitative depth.

2.3. Third Stakeholders' Meeting

The *third workshop meeting* was held at CIHEAM Bari in Valenzano on 6 December 2024. The workshop aimed to capture and collect key issues related to agriculture in the pilot area through the active involvement of local stakeholders. To better address the working activities, the main outcomes from the 1st and 2nd stakeholders' workshops were presented to participants. This introduction was essential to ensure a better understanding of the final objective of the workshop—the cost–benefit impacts from the proposed restoration action and their implications for social justice—and identify the obstacles, barriers, and opportunities from the present to the future vision.

To assess the equity implications of restoration actions implemented within the Stornara and Tara pilot areas, a social justice inquiry was conducted as part of the REACT4MED participatory framework. This exercise aimed to understand how the perceived costs and benefits of selected restoration measures—specifically, organic agriculture—were distributed across different stakeholder groups and how these distributions might influence social equity and cohesion within the community.

The methodology followed a defined structure, conducted in a facilitated group setting with local stakeholders. The first step was dedicated to the identification and allocation of costs and benefits of the restoration action, relative to a baseline scenario (e.g., conventional farming or non-restored land). These impacts were not limited to financial aspects but included non-monetary factors such as access to improved products, employment opportunities, improvements in soil health, and administrative burdens.

Each participant contributed individually, taking turns to explain and document specific impacts on color-coded post-it notes. These were categorized as either costs or benefits and assigned to one or more actor groups, namely, implementing farmers or landowners, other farmers, or public and government actors (e.g., local or national).

Following the categorization exercise, the group was engaged in a guided reflection on how the distribution of costs and benefits across actor groups could affect the local community and society at large. These insights contributed to the broader assessment of the restoration measure's effectiveness, going beyond environmental performance to include social sustainability considerations.

To support the strategic planning of restoration actions and their broader adoption beyond the pilot area, a backcasting methodology was employed as part of the participatory activities during the third workshop. This approach, suitable for addressing complex and long-term sustainability challenges, involved co-developing transformative pathways starting from a collectively envisioned future and tracing backward to identify the necessary changes, actors, and enabling conditions to realize that future.

The exercise built directly upon the envisioning process conducted in the second workshop, where stakeholders described a desirable future scenario for agriculture in the Stornara and Tara areas by the year 2043. Participants were now invited to engage in a reverse analysis, identifying key steps and system changes that would be needed to achieve that vision.

The primary goals of the backcasting exercise were to identify the major changes, barriers, and opportunities involved in upscaling and outscaling restoration practices and define specific actions and responsible actors required at different stages of the transition.

Stakeholders were encouraged to adopt a systems thinking approach, drawing connections between domains and anticipating cross-sectoral impacts. Discussions were visually documented in a roadmap format, mapping transitions and responsibilities over time (short-term (0–5 years), medium-term (5–10 years), and long-term (10–20 years)).

This roadmap serves as a practical tool to guide decision-makers and practitioners in scaling restoration practices and was integrated into the REACT4MED decision-support framework to inform policy recommendations and regional planning strategies.

2.4. Identification of Indicators

The technical-cartographic maps and soil data for both farms and results of stakeholder meetings allowed us to identify many context-specific indicators and metrics to assess the performance and impacts of ecosystem restoration actions. This process provided a foundational list of biophysical and socio-economic indicators related to soil, water, and vegetation dynamics. The indicators—such as soil organic carbon stocks, water use efficiency, and normalized difference vegetation index (NDVI) trends—were selected for their ability to reflect changes in land functionality and productivity in response to restoration actions.

In addition to the biophysical metrics, socio-economic indicators were also considered essential to evaluate the broader impacts of restoration on farming livelihoods, market access, gender inclusion, and youth engagement.

The development and validation of indicators occurred within the framework of the 3 stakeholders' workshops that, as previously explained, followed a multi-actor, transdisci-

plinary approach, ensuring that a broad and diverse set of voices informed the selection and prioritization of indicators.

Initial workshops were conducted to identify local challenges related to land degradation and water scarcity and gather stakeholders' insights on restoration needs. This was followed by envisioning exercises in which participants co-created future scenarios for sustainable agriculture in 2043. These narratives were later analyzed to extract and cluster key themes and elements relevant to indicator development.

Based on the qualitative data gathered during the envisioning exercises and group discussions, a set of proposed indicators was distilled to represent critical components of land and water management, ecosystem resilience, and socio-economic well-being. Each indicator was then evaluated according to two main criteria: data availability, ensuring feasibility for regular monitoring, and relevance and impact, assessing the indicator's sensitivity to changes in ecosystem condition and its ability to reflect progress toward restoration goals.

The identified context-specific indicators reflect local concerns of the Stornara and Tara areas, such as the overuse of groundwater through private wells, the seasonal mismatch between water availability and crop needs, and the pressure on traditional crops due to market fluctuations.

Following the initial identification, the proposed indicators were subjected to a final round of stakeholder validation, both through in-person feedback sessions and follow-up online consultations. This iterative process ensured that the selected metrics were both scientifically robust and locally legitimate, aligning closely with stakeholder priorities and knowledge systems.

The final output of this process was a tailored suite of indicators that not only facilitate the monitoring and evaluation of restoration actions within the pilot area but also support their potential upscaling and replicability in other Mediterranean regions with comparable conditions.

3. Results and Discussion

3.1. Bioclimate, Potential Vegetation, and Land Use

The climate of the pilot area is semi-arid to sub-humid and is referred to as "Maritime-Mediterranean", which is typical of the coastal areas of the Mediterranean region. Precipitation ranges between a minimum of 400 mm and a maximum of 730 mm. The average yearly rainfall is around 550 mm, 35% of which occurs during the winter months, 32% during fall, and 33% during spring and summer. There is very little summer precipitation, thus summer droughts are frequent, and irrigation is usually needed from April to September. Because of the semi-arid climatic conditions, profitable farming in the area depends largely on irrigation.

The area of the two farms investigated is shown in Figure 2 without the anthropic pressure (potential vegetation) and therefore without cultivated areas [19]. Both farms fall into the hygrophilous vegetation of *Alno Quercion ilicis* or *Populion albae* (264), alliance plant communities typical of slightly humid soil that stand out from the surrounding dominant vegetation of *Thymus capitatae-Pinus halepensis* (247), which is more acidophil and drier, therefore suggesting that the soil of the two farms is favorable to cultivation as they are genetically more humid than the surrounding areas.

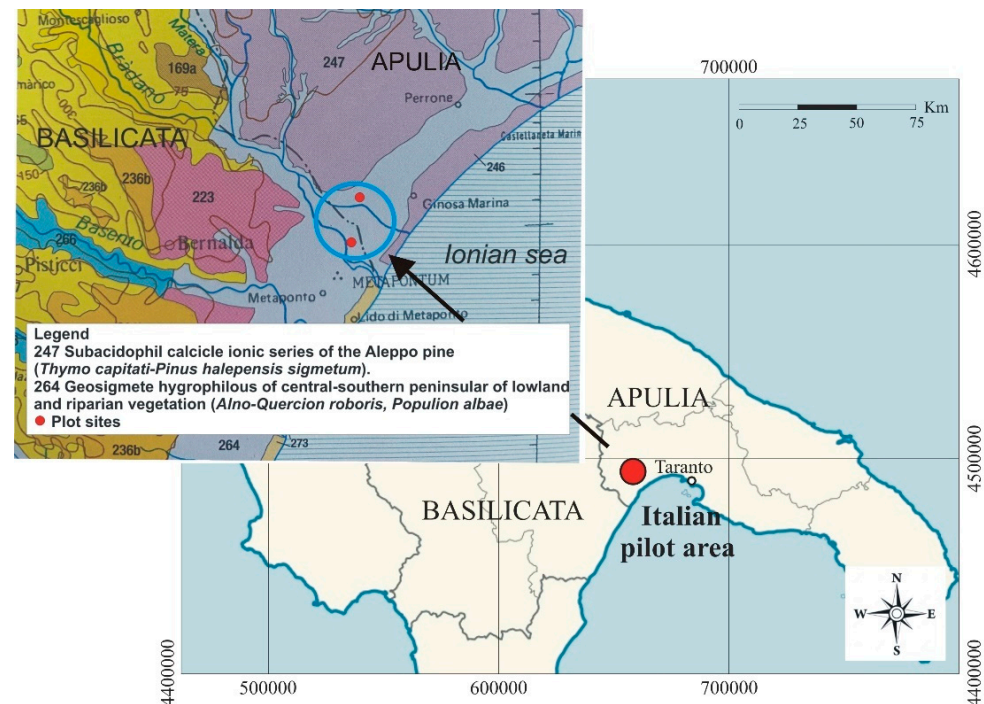


Figure 2. Section map from potential vegetation map of Italy [19] (on the left) in the studied area.

Based on the available maps of land use [20], it is possible to gain an idea of the agricultural vocation of the investigated area through the trend over time from the Corine Land Cover 1990 map to the Corine Land Cover 1999 map (Figure 3). It can be observed that in 1990, the area was cultivated and there was a clear transition, mostly confirmed by direct observations in the field, from an agricultural system with vineyards (221), non-irrigated arable land (211), and annual crops associated with permanent crops (241) [CORINE 1990] to non-irrigated arable land (211) [CORINE 1999], as expected for a humid soil area.

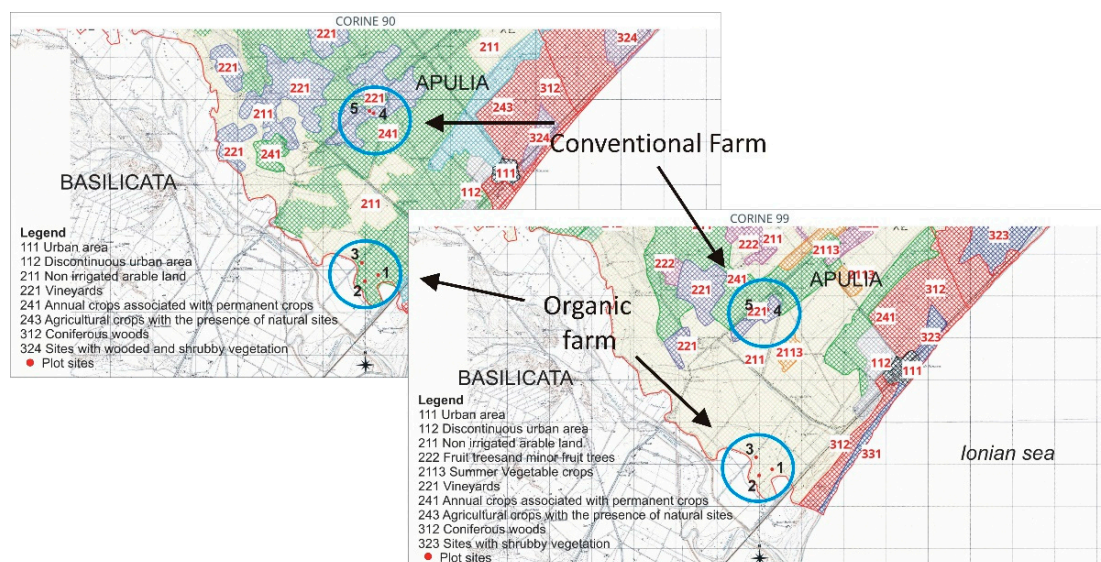


Figure 3. Land cover trend (1990 on the left and 1999 on the right) by CORINE with the five plots across the two farms (organic and conventional farms).

However, since 1999, the gradual transition to intensive cultivation has led to the unsustainable exploitation of the soil with consequent degradation and greater water demand. Today, the crops grown in the irrigated area are mainly citrus, table grapes, fruit

stones, olive, and summer vegetables. The supplied water gets drained or evaporated in 2 or 3 days because of the degraded soil. Thus, the current irrigation delivery schedule (every 10 days) is inadequate for the prevailing farming conditions.

In terms of table grape varieties used, the organic farm operates in the same silty soil with a greater variety of Autumn Crisp (OF1), Arra 30 (OF2), and Sweet Globe (OF3). Instead, the conventional farm cultivates the Regal variety (CF1) in sandy-loam soil and Autumn Crisp (CF2) in loamy soil.

3.2. Soil Analysis

The results of the soil analysis are reported in Table 1. Concerning the organic farms (OF1w and OF1s, OF2w and OF2s, OF3w and OF3s), the soil is ascribed to the silty-clay textural class, with a sub-alkaline pH, low EC, and negligible total carbonate. Despite organic management, these soils are poor in organic matter and total Nitrogen, thus the resulting C/N ratio is unbalanced with the highest peak for OF1s. Additionally, these soils can benefit from a boost of all the macronutrients and micronutrients with the unique exception of Calcium. In the conventional farms (CF1w and CF1s, CF2w and CF2s), we recorded two different textural classes (sandy-loam and loam), and as in the case of the organic farms, the soils do not differ in pH, low EC, and negligible total carbonates. However, the soil organic carbon and total nitrogen are even lower than in the organic farm, resulting in a more unbalanced C/N ratio. The slightly higher amount of available P in this farm corresponds to the very low exchangeable cation contents. Even in this farm, the proper management of nutrients is advised.

According to Wang et al. [25], soils with the appropriate amount of both sand and silt are beneficial for higher sugar content in grapes, while sandy soils contribute to the presence of polyphenols and tannins in wine. On the other hand, according to Echeverría et al. [26], more than just the textural class is important for the particle size distribution in water dynamics that affects grape development and productivity.

Soil organic carbon content is low in all the treatments, and further practices aimed at improving soil organic matter should be implemented for its positive impact on overall soil fertility [27]. In terms of total nitrogen, all the samples, independently of the season and from the site, can be reinforced, with special attention to the CF site. Moreover, an adjustment of the C/N ratio can lead to a balanced revitalization of soil chemical and biological fertility [28]. Total carbonate has significantly higher values in the OF than the CF, with the main implication related to the availability of P for plant uptake [29]. In turn, available P values are comparable to the higher average values recorded in the OF rather than in the CF. However, current P availability is not sufficient for supporting plant productivity, and a proper fertilization plan could be advocated, even in terms of exchangeable cations (K, Ca, Mg, and Na). The OF has values higher than the CF, with Ca reaching the highest concentration values in OF2s and OF3w. The great prevalence of calcium compared to other macro-elements highlights and confirms a) the calcareous nature of the soil at a regional level and b) the need to adopt agricultural practices for balancing the Ca with other exchangeable cations. Moreover, the lack of K, Mg, and Na in the soil could affect their net accumulation in berries [30].

Table 1. Soil chemical characteristics in two different seasons of 2024 from two farms (organic and conventional). Source: Laboratory of agricultural and environmental chemistry (CIHEAM Bari). Legend: P = plot, OF = Organic Farm, CF = Conventional Farm, w = winter, s = summer.

Farm		Organic Farm						Conventional Farm			
Samples code		OF1w	OF2w	OF3w	OF1s	OF2s	OF3s	CF1w	CF2w	CF1s	CF2s
Date		18 December 2023	18 December 2023	18 December 2023	18 July 2024	18 July 2024	18 July 2024	18 December 2023	18 December 2023	18 July 2024	18 July 2024
Geographic coordinates (UTM 33T m)		656,852 E 4,474,979 N	656,923 E 4,474,550 N	657,233 E 4,474,691 N	656,852 E 4,474,979 N	656,923 E 4,474,550 N	657,233 E 4,474,691 N	657,031 E 4,478,547 N	657,127 E 4,478,495 N	657,031 E 4,478,547 N	657,127 E 4,478,495 N
Season of year 2024 Variety of table grapes	unit	Winter <i>Autumn Crisp</i>	Winter <i>Arra 30</i>	Winter <i>Sweet Globe</i>	Summer <i>Autumn Crisp</i>	Summer <i>Arra 30</i>	Summer <i>Sweet Globe</i>	Winter <i>Regal</i>	Winter <i>Autumn Crisp</i>	Summer <i>Regal</i>	Summer <i>Autumn Crisp</i>
Depths	cm	25	30	30	30	30	30	30	30	30	30
Sand (2–0.05 mm)	g/kg ^{−1}	55	64	46	29	76	44	753	482	752	481
Silt (0.05–0.002 mm)	g/kg ^{−1}	525	581	500	496	587	492	245	512	150	309
Clay (<0.002 mm)	g/kg ^{−1}	420	355	454	475	337	465	2	6	98	210
Textural Class (USDA)	-	Silty-Clay	Silty-Clay	Silty-Clay	Silty-Clay	Silty-Clay	Silty-Clay	Sandy Loam	Loam	Sandy Loam	Loam
pH (H ₂ O 1:2.5)	-	8.4	8.4	8.2	8.5	8.5	8.5	8.1	8.3	7.7	8.5
pH (CaCl ₂ 1:2.5)	-	7.6	7.7	7.4	7.7	7.6	7.7	7.2	7.5	6.9	7.6
Electrical conductivity (1:2 25 °C)	dS/m	0.2	0.3	0.4	0.2	0.3	0.3	0.1	0.1	0.4	0.3
Total Carbonate	g/kg ^{−1}	165	174	146	176	187	175	3	67	1	83
Organic Carbon	g/kg ^{−1}	13.6	9.4	13.0	9.9	11.2	12.0	6.2	5.9	4.7	7.5
Organic Matter	g/kg ^{−1}	23.5	16.2	22.4	17.0	19.2	20.6	10.7	10.2	8.0	12.9
Total Nitrogen	g/kg ^{−1}	1.4	1.1	1.3	1.5	1.1	1.3	0.7	0.9	0.6	0.9
C/N ratio	-	9.9	8.6	9.8	6.4	9.8	9.4	8.3	6.5	7.4	7.9
Available P	mg/kg ^{−1}	24	10	12	20	19	15	38	34	72	40
Available P ₂ O ₅	mg/kg ^{−1}	55	24	27	45	43	34	86	77	164	91
Exchangeable K	mg/kg ^{−1}	566	357	462	356	393	394	120	320	66	298
Exchangeable Ca	mg/kg ^{−1}	4611	3980	5076	4461	3693	4614	1005	3430	1020	3410
Exchangeable Mg	mg/kg ^{−1}	515	522	465	602	563	519	111	381	186	467
Exchangeable Na	mg/kg ^{−1}	87	195	197	137	162	176	55	63	134	201

3.3. Stakeholder Engagement and Participatory Workshops

As part of the REACT4MED project activities in the Italian pilot area of Stornara and Tara (Puglia), a series of participatory stakeholder workshops was conducted to identify land degradation challenges, co-develop restoration strategies, and define measurable indicators for sustainable land and water management (Figure 4). The workshops brought together a range of actors including farmers, researchers, technicians, and institutional representatives, ensuring the inclusion of gender and sectoral diversity. Three structured meetings were held, each building upon the outcomes of the previous one. Table 2 shows that among the stakeholders who participated in the three meetings, males are prevalent compared to females, and the age is between 30 and 50 years old. The interest dropped in the last meeting, with fewer participants.

Table 2. Numbers and characteristics of stakeholders (per organization) in the three Italian workshop meetings.

Name of Organization (Participant List)	Gender	Age Group (Years)	Stakeholder Group	Workshop Meeting		
				1st	2nd	3rd
CIHEAM-Bari	Male	>50	organization	x	x	x
CIHEAM-Bari	Female	30–50	organization		x	
CIHEAM-Bari	Male	30–50	organization	x	x	x
Softwater	Male	30–50	organization	x		
Apulia Region	Male	30–50	1	x	x	x
Apulia Region	Male	30–50	1	x		x
Consortium of Taranto	Male	>50	1	x	x	x
Consortium of Taranto	Male	30–50	1	x		
Consortium of Taranto	Male	30–50	1	x		
Regional Basin Authority	Male	30–50	1	x		
ARPA, Taranto District	Female	30–50	1	x		
Apulia Region	Male	>50	2	x	x	
Farmer	Male	>50	2	x		
Consortium of Taranto	Male	30–50	2	x		
Technician programmer	Male	>50	2	x		
Nat. Res. Center-IRSA	Male	30–50	1		x	x
Nat. Res. Center-IRSA	Male	30–50	2		x	
Nat. Res. Center-ISPA	Female	>50	1		x	x
University of Bari	Female	≤30	1		x	
Agrotechnician	Male	>50	2		x	x
Agrotechnician	Male	30–50	1		x	
Taranto Province	Male	>50	2		x	
Farmer	Female	30–50	2		x	
Farmer	Female	≤30	1			x
Farmer	Male	>50	1			x
Agrotechnician	Male	>50	1			x
Total			30	14	14	11

- The first stakeholders' meeting (Massafra, 7 February 2023). During the first session, stakeholders expressed their thoughts in very inspiring drawings. Then, a representative for each group showed their findings in the plenary session. The second session focused on the identification of the solutions to the previously defined problems. Each stakeholder received moderation cards in two different colors, representing actions and indicators. At the end of the session, the results were presented in the plenary by a group representative and subsequently used as feedback for the multi-operational Land degradation Decision-Support Toolbox (LanDS) developed in the framework of

the project to provide harmonized land degradation assessment and impact evaluation of restoration measures.

- The *second workshop meeting (CIHEAM Bari, 3 October 2023)*. Since some of the participants did not attend the first workshop, the context of the REACT4MED project was presented, emphasizing the source of financing, the focus on restoration actions, and partnerships. Specifically, the objectives of the Italian pilot area were shown to focus on (a) improving the sustainable management of land and water to support greater agricultural productivity, (b) accelerating innovation and technological diffusion, and (c) reversing land degradation. In addition, the main outcomes of the first stakeholders' workshop were presented. This introduction was essential to allow the participants a better understanding of the main goal of the workshop: to describe a future vision of the agricultural system in 2043 (working on defining the needs of the agricultural system and the main differences compared to the current situation in the pilot area). The focus of the workshop was related to the agricultural sector, taking into consideration that the pilot area of Stornara and Tara is an irrigation consortium. The agenda for the working day was as follows:
 - (a) Description of the exercise. Taking into consideration the roles and institutions of the stakeholders, two groups were formed, ensuring (i) the same number of participants per group, (ii) at least one woman in each group, and (iii) a representative from the agricultural sector in each group. Both groups worked to create their vision for the future.
 - (b) The first step of the exercise was the explanation of what a vision is, what the main prerequisites are, the guiding principles, and the guiding questions for our specific case study. To open the participant's mind to the envisioning process, a short narrative was read. Then, stakeholders were invited to design an inspiring and personal vision by writing their ideas on moderation cards, after which each shared his/her idea. The final step was to work in groups: stakeholders were left free to create and discuss a desirable common vision, by using cards, writing, or drawings on a big sheet of paper to express their perception.
- The *third stakeholders' meeting (CIHEAM Bari, 6 December 2024)*. The focus of the workshop was related to the agricultural sector, taking into consideration that the pilot area of Stornara and Tara is an irrigation consortium. With nine participants in total, we decided to let them work in a single group. The first step of the exercise was the presentation in the plenary of PowerPoint slides about the social justice inquiry and what was expected of participants. Then, the facilitators encouraged the group to reflect on the impact of the restoration action proposed for the pilot area, that is "Organic agriculture", and contribute their personal views on relevant costs and benefits, how these costs and benefits are distributed across actor groups, and finally, what effect this has on the community. Participants were asked to write their inputs directly on the matrix. The activity was animated by a stimulating discussion among all participants, who contributed actively to compiling the matrix.



Figure 4. Stakeholder meetings. Plenary session in the first meeting (a), stakeholder group in the second meeting (b), and stakeholder group in the third meeting (c).

Across all three workshops, stakeholders consistently highlighted the following critical issues:

- Mismatch between crop types and local pedoclimatic conditions, due to limited suitability assessments.
- The continuous collection of soil data to establish efficient irrigation and nutrition scheduling through fertigation.
- It was clear that many farmers use groundwater through private wells for irrigation, but when this process occurs along the coast, it causes saline water intrusion, which is associated with soil salinity buildup. Furthermore, the water withdrawn from the wells compared to that supplied by the consortium is of poor quality due not only to salinity but also to chemical contaminants originating from the use of petrol in agricultural machinery.
- It was emphasized to increase water-storing capacities with new reservoirs by collecting good-quality water useful for irrigation as alternative sources of rainwater. The largest amount of water volumes in the pilot area are coming from sources external to the Apulia Region's territory (rivers and reservoirs are in the bordering Basilicata region). The water amount allocated to the consortium is a fixed quota not dependent on the irrigation volumes required by farmers. Consequently, during the summer seasons, it is difficult for the consortium to satisfy the requests.

- Improve the efficiency of water resources management through innovation and precision agriculture (e.g., network georeferencing and modern technologies), as well as training of specialized technicians.
- Finance technological innovation (e.g., use of drones, weather stations, laboratory analysis) to optimize water use based on soil and climate conditions to increase the efficient use of water and fertilizers.
- Improvement and lessening of the regulatory framework and bureaucratic procedures to supply water when it is needed by the sector operators.
- Stakeholders proposed actionable strategies aligned with REACT4MED's objectives to reverse land degradation while ensuring agricultural productivity: the territory must fully connect with intersectoral policies of tourism and the environment. The governance inside the irrigation consortium of Stornara and Tara is participatory and must be based on farmers and producers managing water supply based on their requests.
- Applying cultivation techniques properly, suggested by the ensured technical assistance in a sustainable vision, such as:
 - Reducing the number of times the land is plowed each year.
 - Enhancing plant diversity by planting local aromatic and medicinal plants along field edges.
 - Making compost from agricultural waste along with manure and humus produced on the farm.
 - Using natural methods to manage plant diseases.
 - Minimizing reliance on heavy machinery, which can harm soil structure and damage plant roots and beneficial microorganisms.
 - Adopting agricultural practices that improve soil health by increasing organic matter and preventing excessive water accumulation in the fields.
- Farmers' production must be oriented to the yield of typical local crops and protected by trademark certification to enhance inclusion in foreign but also niche markets. Overall, the farming system is dominated by table grape production.
- Economic sustainability must be fully combined with environmental sustainability: technological innovation serves to ensure alternative (non-conventional) forms of water sources.
- The crops produced in the area must be suited to the pedoclimatic conditions, respecting the vocation of the territory, fit for high-quality produce, and characterized by rich agro-biodiversity. These basic elements allow a productive agricultural system of quality winemaking, olive growing, and horticulture.
- The local community must be fully engaged in the territorial development, highlighting well-working social sustainability. People have easy access to real-time information (technical, social, economic, and legal) on how to start a farm business, what the territory offers, and how to enhance it with specialized technical support.
- The land regime must avoid fragmentation, and farmers must be involved in cooperatives and benefit from loan forms and optimal solutions from an economic point of view since they are more stable, which allows for more effective implementation of strategies and policies.
- People must have full use of the agricultural lands, confirming the multifunctional role of such a sector not only for food security but also as a place to spend good times and enjoy excellent local products.

3.4. Expected Benefits from Restoration Actions and Best Practices

- Reducing soil tillage to maintain the natural soil structure and therewith water retention.

- Enhancing plant diversity by planting local aromatic and medicinal plants along field edges to reduce harmful pathogens and avoid chemical inputs to the farm, which reduces the risk of salinization.
- Abstinence from mineral fertilizers.
- Decreasing the risk of salinization.
- Using compost and manure as fertilizers.
- Increasing soil organic matter and water retention.
- Minimizing reliance on heavy machinery.
- Protecting soil structure and plant roots and thereby improving water intake by plants.
- Covering bare soils by intercropping or mulching.
- Decreasing evaporation.
- Increasing soil organic matter and therewith water retention and soil health.
- Preventing excessive water accumulation in the fields through the adoption of canalizations and well recovery.
- Decreasing the risk of salinization.

3.5. Indicators

The main indicators were found by merging the research results with those of the stakeholder meetings (Figure 5). Specifically, the main indicators are the result of (a) problems encountered in the meetings with stakeholders (governance, policy, management, and technical aspects); (b) cartographic data on land use and vegetation of the study area (research aspects); and (c) soil analysis through five soil samplings in the two farms of the study area (research aspects). The clusters of indicators are:

- Soil quality and effect of salt stress on crop yield (or water stress index), useful for defining crop tolerance to soil salinity.
- Socio-economic indicators to evaluate and define data on agricultural income of the main crops grown in the pilot area, market opportunities and obstacles to change, labor shortages, and the role of youth and women in agriculture.
- Weed management along drainage channels.
- Conservation of plant biodiversity in the surrounding areas to prevent attacks by current and future pathogens,
- Climatic analysis of extreme events.
- Climate risk and vulnerability assessment to ensure it is proportionate to the scope of the activity and the expected duration.
- Early warning systems.

3.6. Implications and Recommendations

This study's identification of critical soil and water constraints, combined with stakeholder insights, underscores the necessity for tailored restoration strategies that address both biophysical and socio-economic dimensions.

Soil analyses reveal low organic matter and nutrient deficiencies across both organic and conventional farms, despite differences in management practices. The unbalanced C/N ratios and limited availability of key macronutrients, alongside the calcareous nature of the soils, indicate that soil fertility is currently suboptimal. These conditions contribute to poor soil structure and reduced water retention capacity, as evidenced by rapid irrigation water loss, thereby exacerbating water demand and limiting crop performance.

Stakeholder feedback highlights mismatches between crop selection and pedoclimatic conditions, groundwater salinization from over-extraction, and inadequate irrigation scheduling as significant challenges.

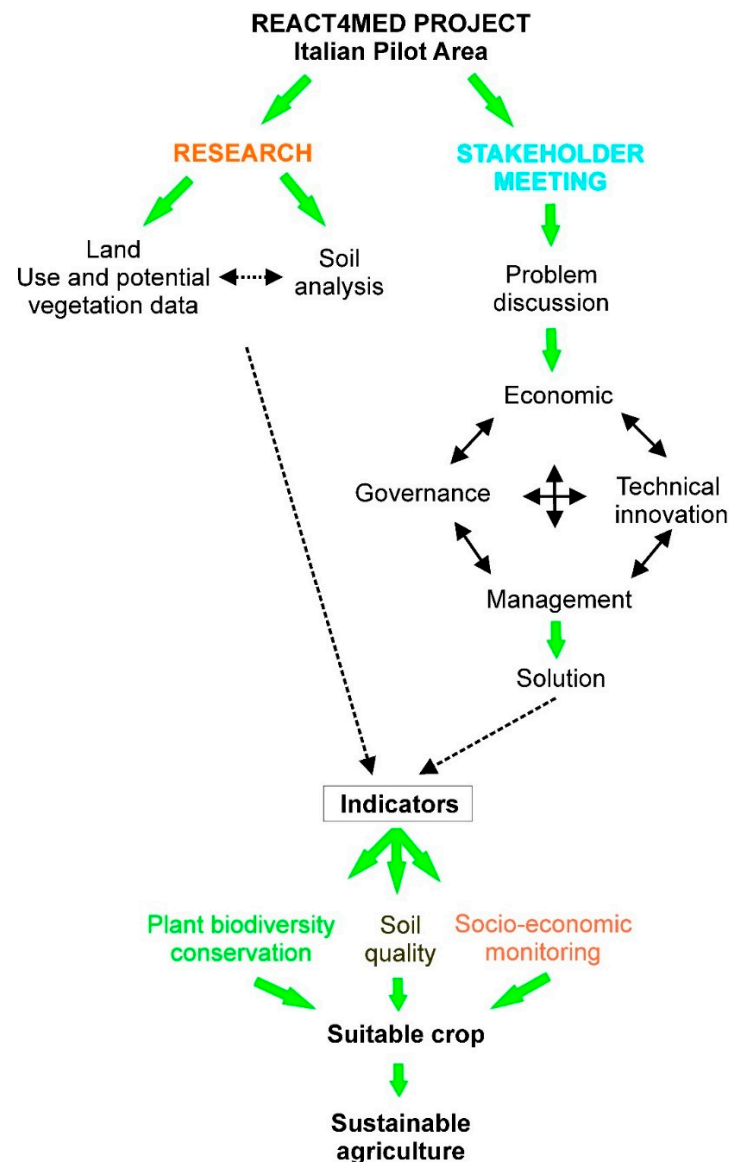


Figure 5. Relationships between the different methodological components adopted to identify the indicators.

Based on these findings, the adoption of integrated agronomic management practices is recommended, including:

- Reduction in tillage frequency to preserve soil structure and enhance water retention.
- Enhancement of plant biodiversity through the inclusion of local aromatic and medicinal species to improve soil health and pest management.
- Use of organic amendments (compost, manure) to increase soil organic matter and correct nutrient imbalances.
- Implementation of precision irrigation scheduling informed by continuous soil and climate monitoring to optimize water use efficiency.
- Mitigation of groundwater salinization by improving water sourcing and storage infrastructure.
- Strengthening participatory governance and technical support to ensure the adoption of sustainable practices aligned with local conditions.

Implementing these strategies can contribute to enhancing the resilience and productivity of agricultural landscapes while fostering long-term environmental and economic sustainability. Future efforts should prioritize scalable, evidence-based interventions tai-

lored to local conditions while fostering active collaboration among farmers, institutions, and researchers. The co-developed indicators and practices offer a replicable framework for other Mediterranean contexts facing similar land degradation challenges.

4. Conclusions

The major issues arising from the study, including the stakeholder meetings, include (1) water leakages in the distribution system, (2) unsuitable crop varieties, (3) the presence of non-licensed wells, (4) seawater intrusion into aquifers, and (5) public policy inadequacy.

This study has highlighted, for the first time, a scientific approach to deal with real environmental, economic, and political problems based on a thorough understanding of soil health and endorse the most suitable and appropriate strategies for sustainable agriculture. We believe that the data obtained can be useful for undertaking actions not only for the study area but also for those territories with similar environmental and management characteristics as the Mediterranean, thus leaving “open doors” to further refine the adopted methodology.

Summing up, in addition to well-known tools such as regenerative agriculture, organic farming, permaculture, agroecology, plant-based disease resistance, integrated pest management, compost tea, crop rotation, soil health management, and biostimulants, water management deserves particular importance. Apart from salt tolerance and other practical aspects concerning the quality of water used for irrigation mentioned in this work, which should receive more attention regardless, future research projects must be more oriented toward innovative technologies to test the therapeutic effects of “informed water” to control biotic and abiotic diseases/stresses, as some farmers in north Italy have been successful in controlling “Flavescenza dorata” in grape caused by *Candidatus Phytoplasma vitis*.

Overall, all stakeholders should be aware that the effectiveness of these approaches may vary depending on the specific crop and disease in question, as well as other factors such as climate, soil health, and the farmer’s level of expertise. Furthermore, it would be appropriate to establish active farmers’ associations, which do not yet exist in the area or are not involved, as demonstrated by the participation of farmers in the meetings, which did not occur as a trade association. For these and other reasons, the authors of this work plan to make a list of guidelines or recommendations after further research results become available.

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