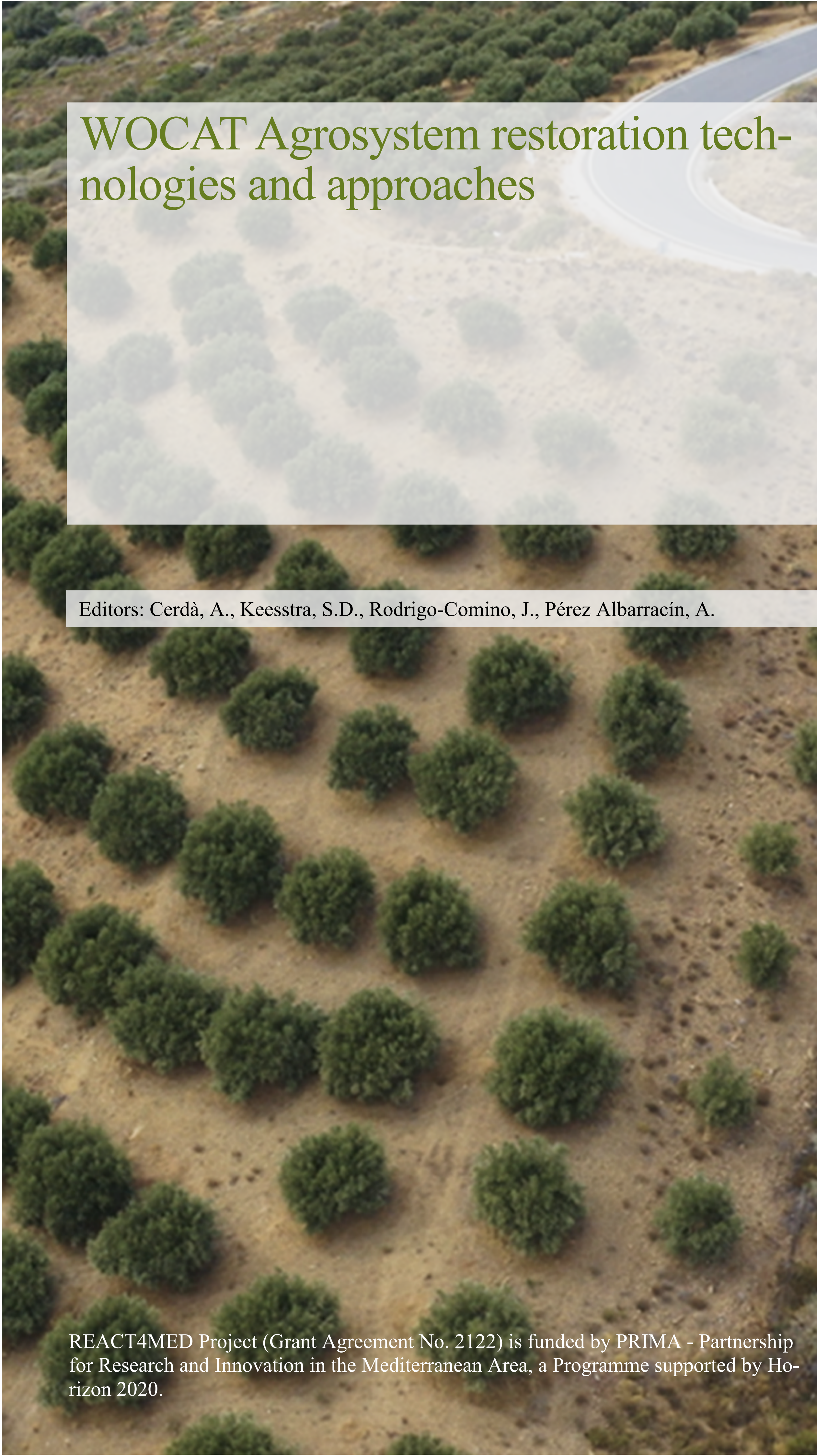

WOCAT Agrosystem restoration technologies and approaches

Editors: Cerdà, A., Keesstra, S.D., Rodrigo-Comino, J., Pérez Albarracín, A.

PRIMA
PARTNERSHIP FOR RESEARCH AND INNOVATION IN THE MEDITERRANEAN AREA

REACT4MED

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0. Executive Summary

REACT4MED seeks to *enhance Sustainable Land and Water Management (SLWM)* across the Mediterranean region in order to increase agropastoral productivity, accelerate technological innovation and its dissemination, reverse land degradation and improve the livelihoods of Mediterranean communities

The WOCAT (World Overview of Conservation Approaches and Technologies) is a global network and knowledge platform focused on sustainable land management (SLM) The objective of the WOCAT is to help land users, researchers, and policymakers document, share, and scale up practices that prevent land degradation, improve soil and water management, and support climate resilience.

The Global Database on Sustainable Land Management (SLM) of WOCAT (the World Overview of Conservation Approaches and Technologies) provides free access to the documentation of field-tested SLM practices from different places in the world and offers practitioners the opportunity to share their own SLM practices. Due to its long-term presence and wealth of knowledge, WOCAT's Database has been officially recognized by the UNCCD as the primary recommended Global Database for SLM best practices.

This report reviews the WOCAT contribution to REACT4MED and the contribution of REACT4MED to WOCAT. The WOCAT database distinguish between the SLM technologies with 1482 study sites, and the SLM approaches with 565 cases. The WOCAT is present in 137 countries and is developed upon the contribution of 565 users. In the WOCAT, the Mediterranean countries show a list of 167 technologies and approaches that can contribute to restore the degraded Mediterranean landscapes. In this section, we review each country contribution. A detailed review country by country is shown in this report. The examples developed by REACT4MED for WOCAT for each partner: Greece, Spain, Italy, Turkiye, Morocco, Cyprus and Egypt.

A *technology* as a physical practice on the land (e.g. agronomic, structural, vegetative measures) to combat land degradation or improve productivity. An *approach* as the “how” — the institutional, social or managerial context that enables implementation of technologies (stakeholders, governance, financing, etc.).

The global database — accessible via WOCAT’s website — remains the primary repository for these practices in the world and a key source of information.

WOCAT provides knowledge, REACT4MED provides field-tested implementation. The WOCAT contribution generates opportunities for knowledge sharing. RREACT4MED has the potential to feed new Mediterranean-specific SLM knowledge into WOCAT, filling existing regional gaps and enhanced evidence-based restoration. The combination of WOCAT knowledge and REACT4MED monitoring improves sustainability, efficiency, and replicability of Mediterranean land restoration efforts. There is a long-term impact as Linking REACT4MED outputs to WOCAT ensures that local lessons can benefit the broader SLM community worldwide, beyond the pilot areas.

We conclude that WOCAT and REACT4MED mutually reinforce each other. WOCAT informs pilots and pilot areas of REACT4MED generate new knowledge for WOCAT. Pilot areas act as living labs, testing practices in real-world Mediterranean context. Linking monitoring and evaluation to WOCAT ensures scalability, replicability, and global knowledge sharing.

1. Introduction

1.1 The REACT4MED contribution to restore the degraded Mediterranean Ecosystems

REACT4MED seeks to *enhance Sustainable Land and Water Management (SLWM)* across the Mediterranean region in order to increase agropastoral productivity, accelerate technological innovation and its dissemination, reverse land degradation and improve the livelihoods of Mediterranean communities. REACT4MED addresses the threats of soil degradation, desertification, erosion, water stress, biodiversity loss and climate-change impacts, which affect arid and semi-arid agro-ecosystems around the Mediterranean.

Along the last 42 months, the whole team of REACT4MED contributed to: i) capitalize on past knowledge and review existing practices (compile and critically review scientific and practical knowledge from previous restoration projects and collect and integrate best-practice sustainable land-management and agro-ecological restoration techniques); ii) identify and overcome barriers to restoration at local scales (understand obstacles preventing successful application or scaling of restoration actions from a social, economic, institutional, environmental and use a "bottom-up, multi-actor approach" involving local stakeholders (farmers, communities, decision-makers) to tailor restoration strategies to specific contexts; iii) develop harmonized assessment indicators (define a set of standard indicators — technological, environmental, climate-related, socio-cultural and economic — to evaluate and monitor land and water restoration actions across different geographic areas); iv) provide decision-support tools and methodologies (create practical methodologies and tools that support both participatory and scientific decision-making, combining "top-down" broad-scale methods with "bottom-up" local knowledge and build a georeferenced, science-based toolbox (land degradation decision-support system — sometimes referred to as "LanDS") to help identify critical areas for restoration and guide where to prioritize actions, considering past, present and future (climate / socioeconomic) scenarios; v) implement and upscale restoration actions in pilot areas (apply restoration measures (e.g. soil conservation practices, erosion control, reforestation, improved irrigation, sustainable agriculture) in selected pilot areas across the Mediterranean — from Spain, Italy, Greece, Cyprus, Turkey, Israel, Morocco, Egypt and evaluate cost-effectiveness and benefits of these actions; support policymakers to adopt and replicate successful practices more broadly; vi) foster capacity-building, dissemination, policy guidance and long-term uptake (engage local communities, stakeholders and decision-makers to encourage adoption of sustainable practices and provide policy recommendations and governance strategies to enable the mainstreaming of restoration measures across the Mediterranean and Ensure that outputs (data, tools, guidelines) are accessible and usable beyond the lifetime of the project.

REACT4MED seeks to *enhance Sustainable Land and Water Management (SLWM)* across the Mediterranean region in order to: increase agropastoral productivity; accelerate technological innovation and its dissemination; reverse land degradation; and improve the livelihoods of Mediterranean communities.

REACT4MED emphasizes the Mediterranean context: the region has been losing significant amounts of fertile soil (approx. 0.5 tons per hectare per year) due to erosion, and faces pressure on water resources, climate change impacts, unsustainable land use — threatening ecosystems, agricultural productivity, and livelihoods. The project prioritizes social and economic improvement for Mediterranean communities, especially vulnerable ones, aiming to combine ecological restoration with increased resilience, food security, and sustainable rural development.

1.2 The WOCAT contribution to understand the land degradation and restoration at the Mediterranean

The deliverable D2.2 WOCAT agro-ecosystem restoration technologies and approaches is developed by the University of Valencia along the last 6 months of the REACT4MED project. A report on the agro-ecosystem restoration technologies and approaches documented in WOCAT applied or applicable to the Mediterranean region, including those implemented within the ERLLs (Ecosystem Restoration Living Laboratories).

The Ecosystem Restoration Living Labs) within the REACT4MED research Project are real-world sites in the Mediterranean (like Cyprus, Greece, Italy, Spain) where scientists and local stakeholders test and develop solutions for land degradation and desertification, focusing on sustainable water/land management, boosting farming, and using tech like machine learning to create data-driven restoration plans. Essentially, REACT4MED uses these hands-on Living Labs to bridge science with practical, community-involved restoration actions in vulnerable Mediterranean agro-ecosystems, funded by PRIMA

The WOCAT (World Overview of Conservation Approaches and Technologies) is a global network and knowledge platform focused on sustainable land management (SLM) The objective of the WOCAT is to help land users, researchers, and policymakers document, share, and scale up practices that prevent land degradation, improve soil and water management, and support climate resilience.

The Global Database on Sustainable Land Management (SLM) of WOCAT (the World Overview of Conservation Approaches and Technologies) provides free access to the documentation of field-tested SLM practices from different places in the world and offers practitioners the opportunity to share their own SLM practices. Due to its long-term presence and wealth of knowledge, WOCAT's Database has been officially recognized by the UNCCD as the primary recommended Global Database for SLM best practices.

SLM in the context of WOCAT is defined as the use of land resources - including soil, water, vegetation and animals - to produce goods and provide services to meet human needs, while ensuring the long-term productive potential of these resources and sustaining their environmental functions. A SLM practice can be either an SLM Technology or an SLM Approach.

The objective of documenting and assessing SLM practices in WOCAT is to share and spread valuable knowledge in land management, support evidence-based decision-making and scale up identified good practices, thereby contributing to preventing and reducing land degradation and to restoring degraded land.

WOCAT is a global network and database that documents “good practices” — sustainable land-management (SLM) technologies and approaches. Its purpose is to share and scale knowledge to combat land degradation, support sustainable land/water/soil use, biodiversity, climate adaptation. REACT4MED is an EU/PRIMA-funded project (2022–2025) aiming at “Inclusive Outscaling of Agro-ecosystem Restoration Actions for the Mediterranean” — i.e. restoring degraded agro-ecosystems, improving land/water management (SLWM), increasing agropastoral productivity and resilience in Mediterranean regions. REACT4MED contributed to the WOCAT and this report informs about this issue.

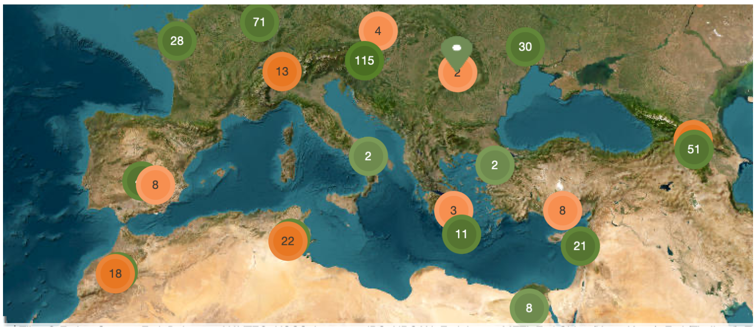


Figure 1. The Mediterranean Global Database on Sustainable Land Management (SLM) of WOCAT (the World Overview of Conservation Approaches and Technologies) show an even distribution of the SLM in the Mediterranean basin.

The WOCAT database distinguish between the SLM technologies with 1482 study sites, and the SLM approaches with 565 cases. The WOCAT is present in 137 countries and is developed upon the contribution of 565 users.
A *technology* as a physical practice on the land (e.g. agronomic, structural, vegetative measures) to combat land degradation or improve productivity. An *approach* as the "how" — the institutional, social or managerial context that enables implementation of technologies (stakeholders, governance, financing, etc.).
The global database — accessible via WOCAT's website — remains the primary repository for these practices in the world and a key source of information.

1.3 The WOCAT country by country

In the WOCAT, the Mediterranean countries show a list of 167 technologies and approaches that can contribute to restore the degraded Mediterranean landscapes. In this section, we review each country contribution.

1.3.1 Spain

The WOCAT data set show 35 cases in Spain. From the 35 cases we found 29 technologies and 6 approaches). The SLM found in Spain are related to cover the impact f forest fires (Natural post-fire revegetation and Selective Forest clearing to prevent large forest fires) and on agriculture land (Traditional tillage in sloping vineyard and Sustainable citrus orchard farming (Spain). Then, solutions to the high erosion rates in agriculture land in citrus, vineyards, olive and almonds are found.

SLM Practice / Technology	Short description / use / objective

Reforestation of degraded agricultural land	Reforestation of degraded agricultural lands using native forest species, to restore degraded abandoned soils.
Straw mulching to improve soil quality	Application of straw mulching on bare soils to reduce erosion, improve water retention and increase soil organic matter.
Maintaining a 15th century irrigation system for a small orchard	Continued use (from centuries ago) of a traditional irrigation system for home gardens — intercropping, use of organic fertilizer, sustainable water management and mixed cultivation.
Multi-specific plantation of semiarid woody species on slopes	Planting of woody species adapted to semi-arid climate on degraded slopes for restoration, erosion control and recovery of vegetation cover.
Seedling	Planting seedlings to restore vegetation cover after fires, reduce post-fire erosion.
Ecological production of almonds and olives using green manure	Organic production of almond and olive trees in dry conditions using green manure to increase fertility, reduce erosion and improve sustainability.

Table 1. Examples of the WOCAT SLM technologies in Spain.

1.3.2 Italy

The WOCAT data set show 2 cases in Italy. From the 22 cases we found 19 SLM technologies and 3 SLM approaches). The SLM found in Italy are related to cover the organic farming in table grapes, cover crops, afforestation, crop rotation, biochar, conservation agriculture and controlled grazing.

SLM Practice / Technology	Short description / use / objective
Reconstitution of Soils	Pedotechnique for treating organic & non-organic materials (waste/residues) to restore degraded / sealed / desertified soils — creating “new soil” (anthroposol) for ecological/land restoration.
Selective Cutting (forest management)	Selective removal of damaged or dried trees to reduce fire risk, prevent forest degradation, and promote natural regeneration of woodlands.
Root-oriented cover crops	Use of cover crops with deep / strong root growth between annual crops to improve soil quality, structure and sustainability in agricultural land.
Controlled grazing in deciduous woods (alternative to rangeland grazing)	Seasonal/controlled grazing in deciduous woodlands during summer dryness to relieve pressure on dry rangelands; helps prevent over-grazing and land degradation.

Table 2. Examples of the WOCAT SLM technologies in Italy.

1.3.3 Turkiye

The WOCAT dataset has been active in Türkiye via projects such as the "Integrated Natural Resources Management for Resilient Landscapes in Central Asia and Turkey (CACILM-II)". The project addresses drought-prone and salt-affected agricultural landscapes, promoting SLM practices relevant to Türkiye.

According to the WOCAT country-project page for Türkiye, WOCAT supports efforts for evaluating land degradation, promoting good practices, combating desertification, adapting to climate change, conserving biodiversity, and disseminating SLM knowledge. The total cases of studies in Turkiye were 11.

SLM Practice / Technology	Short description / use / objective
Woven Wood Fences	Wooden fences (posts + woven branches) built on slopes in semi-arid croplands (Central Anatolia — Eskişehir region) to reduce overland flow and soil erosion, thus improving infiltration and reducing soil loss
Rotational Grazing	Practice of managing livestock grazing on pasturelands in a periodic and regulated manner — helps prevent overgrazing, land degradation and supports sustainable pasture management
Water management	Cisterns are water collection structures which form part of a cultural heritage dating back some 2000 years. While cisterns are commonly used to store drinking water, in the sloping fields of Tarsus they serve as a form of water insurance structure for orchards during dry periods.

Table 3. Examples of the WOCAT SLM technologies in Türkiye.

1.3.4 Egypt

The WOCAT dataset show 3 study cases in Egypt. The WOCAT's documented practices — especially soil-drainage + soil-amelioration (as in "Calcareous soils management") — may be highly relevant for degraded, saline or water-logged soils in arid/semi-arid zones like many parts of Egypt.

Water-scarce irrigated farming practices may offer insights on optimizing irrigation, land use and sustaining productivity under water stress.

WOCAT can therefore be a useful reference when designing SLM or land-restoration projects in Egypt (or similar climates), as long as you filter and adapt practices to local soils, climate, socio-economic conditions.

SLM Practice / Technology	Short description / use / objective
Calcareous soils management	Management of calcareous (high-calcium carbonate) and often water-logged soils: combines structural drainage (surface drains laid out on slopes toward outlet) + chemical amendment (application of ammonia gas after seedbed preparation) to reduce alkalinity/pH and improve soil drainage. Helps recover degraded soils, improve soil quality and raise productivity (crops & fodder).
Water-scarce irrigated farming	Addresses water scarcity and low yields — typical challenges in many Egyptian agricultural areas with limited freshwater. The practice aims to optimize water use under irrigated farming systems, adapting SLM principles to Egypt's semi-arid/dry conditions

Table 4. Examples of the WOCAT SLM technologies in Egypt.

1.3.5 Morocco

The WOCAT dataset show 64 study cases in Morocco. Morocco faces water stress, land degradation, desertification and pressures on agriculture and ecosystems. In this context, sustainable land management via WOCAT's documented practices can be very helpful to improve land productivity, water-use efficiency, and resilience to climate change. WOCAT's evidence-based, globally-shared database allows Moroccan authorities, NGOs, researchers or farmers to learn from other contexts (both within Morocco and worldwide) — which can speed up adoption of suitable practices without reinventing the wheel.

Through WOCAT-based interventions, Morocco could better combat desertification, soil erosion, water scarcity, while supporting agriculture and rural livelihoods. The WOCAT database includes "good practice" entries from Morocco — for example soil and water conservation (SWC) measures used in Moroccan contexts. Some practices documented for Morocco include: soil bunds (or dikes) in tree plantations, contour tillage, stone-lines, perhaps terraces or other erosion-control measures — often aiming to improve rainwater harvesting, soil moisture retention and prevent erosion.

The WOCAT framework has also been used in Morocco (and the broader region) as part of water-management and land-restoration initiatives — for example in a "Green Water Credits" (GWC) project for sustainable water/soil management.

SLM Practice / Technology	Short description / use / objective
Dry-stone walls along contour lines	Stone/wall structures along contour lines to reduce runoff and soil erosion on slopes — example from the Loukkos watershed (Rif Occidental).

Rehabilitation by setting-aside / exclusion from grazing	An approach to allow vegetation regeneration by excluding grazing (and other pressures) — used as a restoration strategy in degraded áreas.
Traditional water-irrigation management system at Qcer Tatiouine	A community-based irrigation management approach — involving local water-user groups, traditional water institutions/management, aiming sustainable water use.
Improved / adapted crop-variety development ("Speed Breeding Platform")	An agriculture-oriented SLM approach documented under WOCAT: faster breeding of improved crop varieties (cereals, legumes) to increase resilience and productivity under climate variability.
Eevaluated for water/soil management in a "Green Water Credits / watershed-modelling"	These were selected from WOCAT database as promising practices for soil–water conservation and tested (with modelling) for watershed management in Morocco.

Table 5. Examples of the WOCAT SLM technologies in Morocco.

1.3.6 Israel

The WOCAT dataset show 1 study case in Israel. Although Israel is affected by land degradation and desertification the WOCAT's documented practices are not studied. The unique WOCAT case is converting conventional monoculture farmland into a food forest-based agroforestry system restores soil health, increases vegetation cover, enhances biodiversity while diversifying production. The intervention improves soil organic matter and ecological resilience through multi-storey planting, reduced soil disturbance, and nature-based land management.

SLM Practice / Technology	**Short description / use / objective**
Conversion of conventional monoculture farmland into a food forest	Converting conventional monoculture farmland into a food forest-based agroforestry system restores soil health, increases vegetation cover, enhances biodiversity while diversifying production. The intervention improves soil organic matter and ecological resilience through multi-storey planting, reduced soil disturbance, and nature-based land management.

Table 6. The unique example of the WOCAT SLM technologies in Israel.

1.3.7 Greece

According to a WOCAT overview Greece had 13 documented SLM "technologies" and 6 documented SLM "approaches" in the global database. The WOCAT database includes 19 SLM measures for Greece. This is a modest but significant set of WOCAT-documented SLM practices from Greece, which reflect different land uses, threats (erosion, water stress), and mitigation strategies.

The number of documented practices for Greece is relatively small compared to many countries. This suggests that not all potentially suitable SLM practices may have been documented.

SLM Practice / Technology	Short description / use / objective
Olive groves under no-tillage operations	A practice applied in Crete (region: Chania, province Kissamos) where olive groves are managed without tillage and without herbicide application. Soil is left covered (weeds, plant residues) to enhance soil aggregation, reduce soil erosion (especially water-erosion), improve water infiltration, and lower input/costs.
Sustainable development of olive groves II	The implementation approach corresponding to the no-tillage olive grove practice — includes use of soil-surface nets (plastic nets) to protect soil, stakeholder decisions, and adaptation to local farming traditions in Crete
Water-harvesting / livestock water-point system	Though not always Greece-specific, WOCAT includes SLM technologies for integrated water harvesting + livestock watering systems — relevant for dryland and semi-arid Mediterranean environments.
Agroforestry, permanent green cover and cover crops in perennial woody crops	According to a basin-wide analysis covering the Mediterranean (which included Greek cases), agroforestry and green covers in woody perennial crops (like olive groves) provide multiple ecosystem services — improving soil and water conservation, resilience to climate change, and supporting land-use sustainability.

Table 7. The WOCAT SLM technologies in Greece.

1.3.8 Cyprus

The WOCAT dataset show 3 study case in Cyprus. The most relevant for the REACT4MED is the one related to the dry-stone terraces. In the documented area (e.g. the watershed of Peristerona Watershed, northeast Pitsilia), the total area covered by terraces under this SLM Technology is listed as ~ 30.9 km which is an example of sustainable management. Research measuring soil erosion confirmed that well-maintained terraces dramatically reduce soil loss compared with collapsed/abandoned terraces. The community-based rehabilitation approach was seen as a viable SLM strategy: local participation, engaging volunteers including ex-residents, and combining traditional masonry/terrace-building skills with scientific guidance. The documented dry-stone terraces are a good example of a SLM technology well adapted to steep-slope Mediterranean mountain landscapes; they help control erosion, retain soil moisture, and maintain productive use of fragile lands. The community-based approach shows that social / institutional aspects matter: reviving traditional practices requires collective action, local motivation, and combining scientific and traditional knowledge.

The number of documented SLM practices in Cyprus appears small.

SLM Practice / Technology	**Short description / use / objective**
Dry-stone agricultural terraces	Traditional stone-walled terraces on steep mountain slopes (especially in the mountainous areas around the Troodos Mountains). Built along contour lines to create relatively flat platforms for cultivation, these terraces reduce soil erosion, retain moisture, stabilize slopes, and allow agriculture on steep land that otherwise would degrade quickly
Community-based maintenance & rehabilitation of terraces	Due to rural depopulation and reduced farming, many terraces were abandoned — walls collapsed, leading to degradation and erosion. This approach involves local communities, farmers, experts and researchers working together to rehabilitate and maintain dry-stone terraces; hands-on events have been used, combining local knowledge and scientific support. This helps preserve both productive capacity and cultural landscape

Table 8. The WOCAT SLM technologies in Greece.

1.3.9 Portugal

Portugal shows a reduced amount of 7 SLM technologies, and 1 SLM approach. This is a modest contribution focussed mainly in fire affected land.

SLM Practice / Technology	**Short description / use / objective**
Hydromulching	Technique used in Portugal for reducing runoff and soil erosion — applied e.g. in forests altered by human land-use (pine/eucalypt plantations).
Post-fire Forest Residue Mulch	A soil-water-conservation / forest-management technology documented by WOCAT for Portugal — relevant in contexts of wildfire risk, vegetation cover loss, erosion, etc.

Table 9. The WOCAT technologies in Portugal.

1.3.10 France

The overview of Mediterranean countries included in WOCAT's global database, France is listed with 8 documented SLM technologies and 1 documented SLM approach. WOCAT covers France, though the number of cases recorded seems modest compared with some other Mediterranean countries, in comparison to the population and the Surface of France. Most of the technologies shown in the WOCAT France are also found in the temperate climatic zone of France, which reduces the number of actions in Mediterranean types ecosystems such as the ones researched by the REACT4MED.

SLM Practice / Technology	Short description / use / objective
Alley Cropping	Biodiversity, biological pest control, erosion reduction, increased infiltration, climate resilience
Hedgerow establishment on an agro-pastoral farm	Runoff reduction, erosion control, biodiversity, water quality, shade for livestock
Crop rotation	Fertility preservation, less erosion, increased productive stability.
Bocage	Landscape restoration, ecological connectivity, control of strong winds.

Table 10. The WOCAT technologies in France.

1.3.11 Tunisia

Tunisia is an active participant in WOCAT through the "DS-SLM" project, coordinated nationally by DG-ACTA (Ministry of Agriculture). The country has ~39 documented SLM (Sustainable Land Management) measures in the WOCAT system, including both technologies and approaches.WOCAT documents Tunisia's main land degradation challenges: i) Soil erosion (water & wind); ii) Water scarcity and drought, iii) loss of vegetation; iv) salinization and declining soil fertility; v) fragile rainfed agriculture in arid/semi-arid climate.

SLM Practice / Technology	Short description / use / objective
Runoff harvesting in mountainous drylands	Harvest runoff in <200 mm rainfall zones; reduce erosion; enable agriculture in harsh terrain.
Earthen bunds/dikes for water harvesting	Capture rainfall and runoff for infiltration or small crops; improve soil moisture in semi-arid zones..
Mechanical Bench Terraces	Reduce erosion, retain water, allow stable agriculture/vegetation on slopes.
Contour Tillage	Reduce runoff, conserve water & soil, prevent erosion

Individual Dry-Stone Basins around Trees	Increase infiltration for individual trees; improve survival and productivity; reduce drought stress.
Drought-Tolerant Barley Variety "Kounouz"	Improve yields under drought, reduce risk, enhance food security.
Small-Scale Seed Cleaning Unit	Improve seed quality, raise yields, reduce reliance on commercial seeds.
Small-Scale Nutrient-Dense Feed Pellet Production Technology (livestock/forage)	Use agricultural by-products to produce local feed; reduce costs; improve livestock resilience.
Territorial Observatory for Natural Resource Management	Improve governance, monitoring, and evidence-based decisions for SLM.
"Mind the Gap" — Technology Scaling & Dissemination Strategy	Facilitate adoption of SLM technologies; overcome social/institutional barriers; scale innovation

Table 11. The WOCAT technologies in Tunisia.

1.3.12 Argelia, Libia, Albania, Croatia, Bosnia-Herzegovina, Slovenia, Macedonia, Siria, Lebanon, Palestina and Kosovo.

Argelia, Libia, Albania, Croatia, Bosnia-Herzegovina, Slovenia, Macedonia, Siria, Lebanon, Palestina and Kosovo shown very little information. Bosnia-Herzegovina shown two SLM cases and Siria five. And Albania, Croatia and Macedonia and Kosovo do not show any WOCAT information.

There is at least one SLM "technology" from Lebanon in the global WOCAT database: Al Yakloum runoff pond. According to its WOCAT entry, this pond collects runoff from a local catchment; water is led via a channel (with a sediment trap) and used to irrigate about 5 ha of orchard through a precision-irrigation system. There is also a "best practice" from earlier (under the older / archived "PRAIS" reporting system) for Lebanon: Promotion of industrial Hemp in the framework of Sustainable Land Management Programme for Livelihood Development in Lebanon. This covers cropland and aims at land-degradation prevention/mitigation/adaptation via crop diversification and livelihood support,

In Siria the WOCAT Global SLM Database includes at least one SLM technology from Syria called Semi-Circle Stone Bunds for olive trees. WOCAT defines itself as a system to document and share SLM practices (technologies + approaches) worldwide to combat land degradation, support sustainable land use, water/soil conservation, and climate-resilience.

№	Pilot area	Country	Key characteristics / context
1	Troodos Mountains	Cyprus	Mountainous region; steep slopes; small farms. Selected for terrace restoration, soil/water conservation in fragile mountain agro-ecosystems.
2	Archanon–Asterousion (Peza), near Heraklion, Crete	Greece	Intensive agriculture (olive, grapes, vegetables) with strong water demand; region affected by water stress and ecosystem pressure.
3	Stornara and Tara (Apulia)	Italy	Area tied to irrigation consortium / water-distribution systems — relevant for testing improved irrigation technologies, water-use efficiency and restoration measures.
4	Cànyoles (Valencia region)	Spain	Intensive irrigated agriculture (citrus, horticulture), high mechanization — prone to soil degradation, compaction, erosion, runoff under current management.
5	Merchouch (Bouregreg watershed)	Morocco	Semi-arid region with degraded soils — pilot aims to test restoration actions, soil/water conservation, and sustainable water/land management under climate stress.
6	Bethlehem of Galilee	Israel	Area affected by soil degradation and biodiversity loss under conventional agriculture; restoration includes regenerative agriculture, soil/water conservation, biodiversity-friendly practices.
7	Lower Gediz / Menemen Plain (Gediz Basin)	Türkiye (Turkey)	Alluvial plain in a major river basin — suitable for studying irrigation, soil salinization, water management, and sustainable cropping under basin-scale pressures.
8	Tamia (Fayoum Governorate)	Egypt	Semi-arid/dryland context, with soils vulnerable to salinization, waterlogging, and land degradation — a target for restoration, alternative water use, soil rehabilitation.

Table 13. REACT4MED study sites

2. The REACT4MED contribution to WOCAT

REACT4MED researched along the last 42 months solutions to the land degradation in the Mediterranean. The study sites are located in Cyprus, Israel, Spain, Italy, Morocco, Egypt, Greece and Türkiye.

Depending on the local context, REACT4MED applies different restoration / sustainable land-management measures in the pilot areas. Some of the key strategies included: i) soil-erosion control and water-conservation: terracing (mountain slopes), mulching, soil-cover, conservation agricultura; ii) sustainable irrigation and water-use efficiency: improved irrigation tech, optimized water distribution, soil moisture management especially in irrigated plains; iii) soil fertility and salinity management: soil amendments, better cropping systems, agro-ecosystem diversification, soil-water-land integration under semi-arid climates; iv) biodiversity restoration and ecosystem services: agroforestry, mixed cropping, restoration of degraded soils/landscapes, biodiversity-compatible farming and forestry; and v) scaling & decision support: beyond pilot-level, a main output is a decision-support toolbox (georeferenced, indicator-based) to help policymakers identify priority zones across the Mediterranean for upscaling restoration measures under future climate and socioeconomic scenarios.

The pilot areas in REACT4MED were chosen because they represent a diversity of Mediterranean climates, soils, land-uses, socio-economic conditions and degradation pressures. This enables the project to test restoration measures across a wide range of contexts (mountains, irrigated plains, semi-arid zones, watershed areas, intensive agriculture, small-scale farms). This diversity ensures that the project's findings, tools and recommendations have a broad relevance and can be adapted or transferred across Mediterranean countries — including possibly to your area of interest.

Nº	Pilot area	Country	REACT4MED for WOCAT
1	Troodos Mountains	Cyprus	Agiculture Terraces with Dry-Stone Walls.
2	Archanon–Asterousion (Peza), near Heraklion, Crete	Greece	Aplication of Water by Drip Irrigation
3	Stornara and Tara (Apulia)	Italy	Organic Farming of Table Grapes.
4	Cànyoles (Valencia)	Spain	Chipped Pruned Branches.
5	Merchouch (Bouregreg watershed)	Morocco	No-Till Technology
6	Bethlehem of Galilee	Israel	Conversion of Conventional Monoculture farmland into a food forest
7	Lower Gediz / Menemen Plain (Gediz Basin)	Türkiye (Turkey)	Fodder Crop Production

№	Pilot area	Country	REACT4MED for WOCAT
8	Tamia (Fayoum Governorate)	Egypt	Mechanized Raised Bed (MRB) Technology in a wheat based production system.

3. Conclusion

The WOCAT repository is a useful tool to select proper managements for the Mediterranean and achieve sustainability. Both WOCAT and REACT4MED aim to combat land degradation, promote sustainable land/water management, and support ecosystem restoration. The knowledge-based action of WOCAT provides a global database of tested SLM practices, which REACT4MED can use to select, adapt, or scale restoration actions across Mediterranean pilot areas. Evidence-driven restoration developed by REACT4MED pilots benefit from WOCAT's standardized data on effectiveness, costs, benefits, and contexts of SLM practices. REACT4MED use WOCAT as a source of inspiration, technical guidance, and best practices. Conversely, successful REACT4MED interventions are being documented in WOCAT, enriching the global SLM knowledge base. There is a mutual reinforcement as WOCAT and REACT4MED are complementary. WOCAT provides knowledge, REACT4MED provides field-tested implementation. The WOCAT contribution generates opportunities for knowledge sharing. RREACT4MED has the potential to feed new Mediterranean-specific SLM knowledge into WOCAT, filling existing regional gaps and enhanced evidence-based restoration. The combination of WOCAT knowledge and REACT4MED monitoring improves sustainability, efficiency, and replicability of Mediterranean land restoration efforts. There is a long-term impact as Linking REACT4MED outputs to WOCAT ensures that local lessons can benefit the broader SLM community worldwide, beyond the pilot areas.
We conclude that WOCAT and REACT4MED mutually reinforce each other. WOCAT informs pilots and pilot areas of REACT4MED generate new knowledge for WOCAT. Pilot areas act as living labs, testing practices in real-world Mediterranean context. Linking monitoring and evaluation to WOCAT ensures scalability, replicability, and global knowledge sharing.

4. References

This report is based on the documents and information found at the WOCAT webpage. https://wocat.net/

Participatory rehabilitation of dry-stone terraces (Christos Zoumides)

Community-based maintenance and rehabilitation of agricultural terraces in mountain environments (Cyprus)

Κοινοτική συμμέτοχη για συντήρηση και αποκατάσταση ορεινών γεωργικών αναβαθμίδων (Greek)

DESCRIPTION

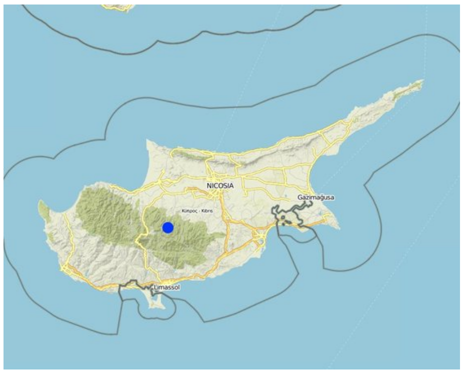
Maintenance and rehabilitation of traditional dry-stone terrace walls for agricultural use, through science-society cooperation, community engagement and motivation, and assistance to land users.

Aims / objectives: The main objective of the approach is the restoration and rehabilitation of traditional dry-stone terraces in Mediterranean mountain environments. Large areas around mountain communities have been converted to agricultural terraces. The depopulation of these rural mountain communities and the high farming costs have led to the gradual reduction of farming activities. Consequently, many of the mountain terraces are no longer cultivated and dry-stone walls are not well maintained, causing a domino effect of collapsing terraces. Soil erosion by water has been identified as the main soil threat in degraded and poorly vegetated terraces.
The approach has been developed by the Cyprus Institute research team and aims at motivating the mountain communities, land users/owners, local institutions and other interested stakeholders to better organise themselves and collaborate and join forces in maintaining these terraces.

Methods: The approach is based on participatory principles. More precisely, the science-society cooperation approach is materialised through the organization of practical (hands-on) public events, where dry-stone experts guide the participants, land users/owners, local population, expats (families that have moved to the urban areas) and scientific stakeholders, in collectively maintaining collapsed and/or poorly maintained terraces. All parties engaged in the implementation of the approach on voluntary basis.

Stages of implementation: A pool of local and external stakeholders was prepared by the research team using snowball sampling. Key stakeholders identified include community leaders, land users/owners, dry-stone experts, local institutions, agricultural extension services and farmer unions.
Leaders of the three mountain communities agreed to co-organise with the research team one participatory terrace rehabilitation event in each community. Land users/owners, expats and other interested stakeholders (general public) were identified as the main target groups of these events. Each community identified dry-stone experts that were willing to work and lead the workshops on voluntary basis. Demonstration sites were selected by the research team, the community leaders and dry-stone experts, based on the extent of terrace degradation, accessibility/visibility of the site and feasibility criteria. Farmer unions and extension service officers were also engaged in the process. The events were advertised through social media, as well as with flyers and posters in central locations within the communities.
During the events, information was provided by researchers and dry-stone experts to raise the awareness of participants on the environmental and cultural importance of dry-stone

LOCATION



Location: Northeast Pitsilia, Nicosia, Cyprus

Geo-reference of selected sites

- 33.04999, 34.96667

Initiation date: 2015

Year of termination: 2018

Type of Approach

- [ ] traditional/ indigenous
- [ ] recent local initiative/ innovative
- [ ] project/ programme based
- [x] Recent local initiative in the framework of the RECARE research project

terraces. In addition, the learning-by-doing process was guided by experts who explained to the participants the best practices in reconstructing the collapsed terraced walls.
Three public events were organized in the first year and a similar set of three events will be organized in the second year. Additional funds are being sought to continue these activities. The sustainability of communal terrace maintenance will also be discussed with the community leaders and active volunteers during the second year.

Role of stakeholders: The research team conceptualised the approach. The organisation tasks for the participatory rehabilitation events were shared among the research team and the local communities. Expats (families that have moved to the urban areas) associations and farmer unions informed their members to join the events. Dry-stone experts had the leading role during the events, as the reconstruction of collapsed terrace walls was based on their guidance. Extension service officers provided information on available subsidy schemes. During the events all stakeholders, including land users/owners and other interested people, worked together to maintain the terraces.

Other important information: The events attracted people beyond the stakeholders originally identified; the approach was adopted by other projects/communities in Cyprus.

Stakeholders restore collapsed dry-stone terrace walls following instructions given by experts. (Christos Zoumides)

Participatory rehabilitation of dry-stone terraces (Christos Zoumides)

APPROACH AIMS AND ENABLING ENVIRONMENT

Main aims / objectives of the approach

The Approach focused mainly on SLM with other activities (terrace maintenance, hands-on training, community conservation, participatory approach, stakeholder engagement, awareness-raising)

• To strengthen science-society cooperation in solving land degradation issues in terraced mountain environments.
• To build capacity for planning, organisation and implementation of participatory soil conservation activities, eventually leading to sustainable local institutions that maintain traditional know-how and specialised in terrace maintenance.
• To improve joint learning activities between farmers, terrace experts and interested stakeholders.
• To rehabilitate abandoned and collapsed terraces, reduce soil erosion and maintain the production capacity of soils in Troodos Mountains.

The SLM Approach addressed the following problems: • Collapsing of dry-stone walls, surface run-off and loss of soil (erosion) in sloping land that has been accumulated behind the terrace walls
• Depopulation of mountain rural communities and land abandonment
• Loss of indigenous knowledge
• Weak institutional organisation and limited incentives (low economic returns) for terrace maintenance

Conditions enabling the implementation of the Technology/ ies applied under the Approach

Conditions hindering the implementation of the Technology/ ies applied under the Approach

- **Social/ cultural/ religious norms and values**: Land abandonment, rural depopulation, lack of motivation. Treatment through the SLM Approach: Organise frequent terrace maintenance events to stimulate interest, invite and engage expats to participate.
- **Availability/ access to financial resources and services**: Low economic return from terrace agriculture. Treatment through the SLM Approach: Engage, motivate and train volunteers through public terrace maintenance events.
- **Institutional setting**: There are no formal or informal institutions for terrace rehabilitation. Treatment through the SLM Approach: The sustainability of communal terrace maintenance will be discussed with the community leaders and active volunteers during the second year.
- **Legal framework (land tenure, land and water use rights)**: Terraced land is privately owned; no maintenance can be done without the approval of land owners. Demonstration sites are privately owned; the rehabilitation events on terraces were undertaken with the approval of land owners. Treatment through the SLM Approach: Community leaders request the approval of land owners.

- **Knowledge about SLM, access to technical support**: Loss of indigenous knowledge Treatment through the SLM Approach: The terrace events are led by terrace artisans (dry-stone experts) to practically demonstrate and pass the technical know-how to the next generation. Efforts were made to engage terrace experts from different communities.
- **Workload, availability of manpower**: Terrace maintenance is a laborious activity. Treatment through the SLM Approach: The pubic terrace maintenance events aim to build the capacity of a large group of people (volunteers) to engage in terrace maintenance.

PARTICIPATION AND ROLES OF STAKEHOLDERS INVOLVED

Stakeholders involved in the Approach and their roles

What stakeholders / implementing bodies were involved in the Approach?	Specify stakeholders	Describe roles of stakeholders
local land users/ local communities	Land users including terrace artisans	Land users were involved as individuals. Representatives of farmers unions were engaged in the process
researchers	The Cyprus Institute (research institution)	Terrace experts, researchers and extension services
private sector	The Cyprus Institute (research institution)	
local government	Local community councils	
national government (planners, decision-makers)		
international organization		
People (volunteers) that attended the hands-on events	Participants of the event (mountain communities, interested stakeholders)	

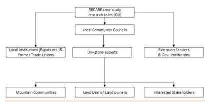
Lead agency

The approach was primarily designed by The Cyprus Institute (research institution) [1]. The rehabilitation events are co-organised with the support of local community councils, land users and terrace experts [2].

Involvement of local land users/ local communities in the different phases of the Approach

	none	passive	external support	interactive	self-mobilization	
initiation/ motivation				✓		Jointly developed by The Cyprus Institute (research institution) and local community leaders
planning				✓		Jointly developed by a research institution, terrace artisans and local community leaders
implementation				✓		Jointly implemented by all stakeholders involved
monitoring/ evaluation	✓					Monitoring and evaluation of the approach and the restored terraces is undertaken by The Cyprus Institute scientists
Research	✓					

Flow chart



Author: Christos Zoumides

The research team identified key stakeholders using snowball sampling; these include community leaders, dry-stone experts, local institutions, agricultural extension services and farmer unions. Community leaders agreed to co-organise with the research team community-based terrace rehabilitation events; land users/owners, mountain communities and other interested stakeholders (general public) were identified as the main target groups of these participatory events. Dry-stone experts had the leading role during the events, as the reconstruction of collapsed terrace walls was based on their guidance. During the events all stakeholders, including land users/owners and other interested people, worked together to maintain the terraces. In addition, information was provided by researchers to raise the awareness of participants on the environmental and cultural importance of dry-stone terraces.

Decision-making on the selection of SLM Technology

Decisions were taken by

- ☐ land users alone (self-initiative)
- ☐ mainly land users, supported by SLM specialists
- ☐ all relevant actors, as part of a participatory approach
- ☐ mainly SLM specialists, following consultation with land users
- ☐ SLM specialists alone
- ☐ politicians/ leaders
- ☑ by SLM specialists (researchers) in collaboration

Decisions were made based on

- ☐ evaluation of well-documented SLM knowledge (evidence-based decision-making)
- ☐ research findings
- ☐ personal experience and opinions (undocumented)

TECHNICAL SUPPORT, CAPACITY BUILDING, AND KNOWLEDGE MANAGEMENT

The following activities or services have been part of the approach

- ☑ Capacity building/ training
- ☑ Advisory service
- ☑ Institution strengthening (organizational development)
- ☑ Monitoring and evaluation
- ☑ Research

Capacity building/ training

Training was provided to the following stakeholders
- ☑ land users
- ☐ field staff/ advisers
- ☑ Participants of the events

Form of training
- ☐ on-the-job
- ☐ farmer-to-farmer
- ☑ demonstration areas
- ☐ public meetings
- ☐ courses

Subjects covered

How dry-stone terraces are restored and maintained (technique) and their importance in reducing soil erosion in mountain slopes (awareness).

Advisory service

Advisory service was provided
- ☐ on land users' fields
- ☑ at permanent centres

Name of method used for advisory service: Demonstration of terrace maintenance by experts; participation of land users and the general public; Key elements: Selection and preparation of collapsed terraces to be restored (terrace experts, researchers, community leaders), Demonstration and hands-on terrace maintenance workshops with the participation of land users and the general public; good and bad practices explained.; One agricultural extension service officer participated in these events, discussed the method with land users and SLM experts and provided information on available subsidies.

Advisory service is inadequate to ensure the continuation of land conservation activities; Extension services provide general directions on terrace maintenance and available subsidy schemes to interested land users; they are not sufficiently trained in dry-stone wall construction and they have insufficient human and financial resources.

Institution strengthening

Institutions have been strengthened / established
- ☐ no
- ☐ yes, a little
- ☑ yes, moderately
- ☐ yes, greatly

at the following level
- ☑ local
- ☐ regional
- ☐ national

Describe institution, roles and responsibilities, members, etc.

Type of support
- ☐ financial
- ☑ capacity building/ training
- ☐ equipment

Further details

One of the aims of the approach is to develop sustainable local institutions for terrace maintenance; this will be discussed with the community leaders and active volunteers during the second year.

Monitoring and evaluation

bio-physical aspects were regular monitored by project staff through measurements; indicators: Erosion rate (Sediment Traps) technical aspects were regular monitored by project staff through measurements; indicators: Terrace wall displacement (3D terrace model) no. of land users involved aspects were ad hoc monitored by project staff through measurements; indicators: No. of land users (attendance list) Number of non-land users involved aspects were ad hoc monitored by project staff through measurements; indicators: Number of non-land users involved There were no changes in the Approach as a result of monitoring and evaluation: Monitoring is at its early stage. There were no changes in the Technology as a result of monitoring and evaluation: Dry-stone terracing is a well-established indigenous technology for the mountain communities; the technical know-how however is gradually disappearing due to rural depopulation and land abandonment.

Research

Research treated the following topics
- ☐ sociology
- ☐ economics / marketing
- ☐ ecology
- ☑ technology
- ☑ Monitoring/modelling erosion, particip. research

By researchers: Monitoring and modelling soil erosion (PESERA model), monitoring the stability of dry-stone terrace walls (3D model) and participatory research.

Research was carried out on-farm

FINANCING AND EXTERNAL MATERIAL SUPPORT

Annual budget in USD for the SLM component
- ☑ < 2,000
- ☐ 2,000-10,000
- ☐ 10,000-100,000
- ☐ 100,000-1,000,000
- ☐ > 1,000,000

Precise annual budget: n.a.

Approach costs were met by the following donors: private sector (Cost for snacks and drinks offered to the event’s participants): 50.0%; local government (district, county, municipality, village etc) (Cost for preparing the site for restoration, stones.): 50.0%

The following services or incentives have been provided to land users
- ☐ Financial/ material support provided to land users
- ☐ Subsidies for specific inputs
- ☐ Credit
- ☐ Other incentives or instruments

IMPACT ANALYSIS AND CONCLUDING STATEMENTS

Impacts of the Approach

	No	Yes, little	Yes, moderately	Yes, greatly
Did the Approach help land users to implement and maintain SLM Technologies?			☑	

Well maintained terraces improve drainage and minimise soil loss.

Did the Approach empower socially and economically disadvantaged groups?
No socially and economically disadvantaged groups were identified.

Did the Approach improve issues of land tenure/ user rights that hindered implementation of SLM Technologies?
Property rights was not an issue for the implementation of the approach. The problem is unlikely to be overcome in the near future. Property rights are not expected to become an issue for the implementation of the approach; stakeholders have been collaborating without raising such concerns.

Did other land users / projects adopt the Approach?
The approach has been adopted by another project in Cyprus (Local Development Pilot Project for the Wine-villages of Limassol – LDPP); many participants express their interest in organizing similar events in other communities in Cyprus.

Main motivation of land users to implement SLM

- [ ] increased production
- [ ] increased profit(ability), improved cost-benefit-ratio
- [ ] reduced land degradation
- [ ] reduced risk of disasters
- [x] reduced workload
- [ ] payments/ subsidies
- [ ] rules and regulations (fines)/ enforcement
- [ ] prestige, social pressure/ social cohesion
- [x] affiliation to movement/ project/ group/ networks
- [ ] environmental consciousness
- [ ] customs and beliefs, morals
- [ ] enhanced SLM knowledge and skills
- [x] aesthetic improvement
- [ ] conflict mitigation
- [x] environmental consciousness, moral, health

Sustainability of Approach activities

Can the land users sustain what hat been implemented through the Approach (without external support)?

- [ ] no
- [x] yes
- [ ] uncertain

Local communities can potentially organise better themselves and with the collaboration of land users/owners and SLM experts, they can organise such community-based conservation events on an annual basis. Thus the approach can eventually be sustained without scientific (external) support.

CONCLUSIONS AND LESSONS LEARNT

Strengths: land user's view

- Participation of people reduced the workload required to maintain terraces. (How to sustain/ enhance this strength: More frequent events are welcomed.)
- Community based conservation activities have contributed to better institutional organisation. (How to sustain/ enhance this strength: Engage more local stakeholders in future events.)

Strengths: compiler's or other key resource person's view

- Community conservation was insofar successful in maintaining selected demonstration sites. (How to sustain/ enhance this strength: Maintain the interest of stakeholders by organising similar events on an annual basis.)
- Capacity building activities increase the participation of stakeholders. (How to sustain/ enhance this strength: Continue the approach for further engagement.)

Weaknesses/ disadvantages/ risks: land user's viewhow to overcome

- Mountain farming is less cost-effective than in the plains. Motivate the younger generation to engage in part-time farming.
- The approach cannot be implemented on bigger scale without economic incentives. Utilise available community/subsidy funds for small cash compensation to experts.
- Small holdings and land fragmentation are constraints for cost-effective agriculture. Reconsideration of land consolidation schemes.

Weaknesses/ disadvantages/ risks: compiler's or other key resource person's viewhow to overcome

- Aging of the dry-stone experts. Train young land users/owners on dry-stone terracing.
- The community leaders tend to be more conservative than the SLM experts. Gradually convince them to think bigger.

REFERENCES

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Editors

Reviewer
Fabian Ottiger

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Last update: July 24, 2017

Resource persons

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Adriana Burggemann - SLM specialist

Full description in the WOCAT database

https://qcat.wocat.net/en/wocat/approaches/view/approaches_2537/

Linked SLM data

Technologies: Agricultural terraces with dry-stone walls https://qcat.wocat.net/en/wocat/technologies/view/technologies_1702/
Technologies: Agricultural terraces with dry-stone walls https://qcat.wocat.net/en/wocat/technologies/view/technologies_1702/

Documentation was faciliated by

Institution

- The Cyprus Institute (The Cyprus Institute) - Cyprus

Project

- Preventing and Remediating degradation of soils in Europe through Land Care (EU-RECARE)

Well-maintained grapevine terraces supported by dry-stone walls (Christos Zoumides (The Cyprus Institute, 2121 Nicosia, Cyprus))

Agricultural terraces with dry-stone walls (Cyprus)

Γεωργικές αναβαθμίδες με τοίχους ξερολιθιάς (Greek)

DESCRIPTION

Dry-stone terraces built to create agricultural land, minimise soil erosion and retain soil moisture on steep mountain slopes.

Dry-stone terraces consist of a series of nearly levelled platforms built along contour lines at suitable intervals. These structures characterise a large part of the landscape in Cyprus, and especially in communities around Troodos Mountains where large areas have been converted to agricultural terraces. The typical terraces found in the study-area are narrow (1-3 m) to medium-base (3-6 m) bench terraces, constructed by cutting and filling in slopes between 20-40%. The terraces are supported by walls, whereby stone is the only construction material without any binding mortar.

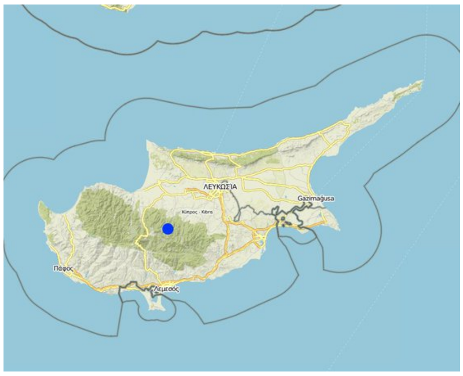
Terracing is one of the oldest means of cultivating slopes while saving soil and water. Due to the steep terrain of Troodos Mountains, the establishment of terraces acts as sediment trap storing the washed-off soil material within the slope. In general, terraces were created to stop or reduce the degrading effect of soil erosion by intercepting and controlling the surface run-off velocity and by facilitating its slower infiltration. In such a way, the sediment that accumulates behind the terraces has created suitable land for farming. In addition, the construction of dry-stone walls serves a dual purpose: to clear the land from large rock and stones, and to enhance the stability of the bench terraces against loss of top-soil. This is a type of technology that was very much used in the past and seen today as an important cultural landscape and heritage for these communities.

The construction of dry-stone walls was usually completed by the family who owned the field. Men undertook the building while the rest of the family carried the stones; assistance was also offered by relatives and friends of the family. First, the topography, the height and shape of the terrace is evaluated. Using a fuse, the craftsman shapes a straight line which would follow while building the wall. The foundations are created by excavating a pit of ~0.3-0.5 m, depending on the type of soils and the size of the wall; fuse, pick, mattock and shovel are the typical tools used. The pit is filled with large, irregular-shaped stones.

The stones are used in their natural shape for the construction of the walls without any processing. They are separated according to their shape, size and texture. The stones usually come from the cleaning of fields which will be cultivated or from a small-scale quarrying of the mountain slope using pick and lever. Large and irregular stones are used for the foundations, and the more regular ones for the construction of walls. The smaller stones are placed in between the large stones as the linchpin, to provide better stability to the structure.
The wall follows the land inclination and is laid over the foundation. Large stones are placed on the lower courses of the wall and on the exterior side. The stones are placed by hand one over the other, while smaller stones and rubbles are put between them in order to achieve more stability and better positioning; the stones cross both vertically and horizontally in order to avoid the creation of columns which will make the structure less stable. The wall is built lengthwise following the foundations and it reclines inwards; declination from the foundations does not exceed 5%. The back side of the wall is filled-up with more irregular stones which are not suitable to be placed on the front side. The filling connects the wall with the soil and stabilises the structure, and allows the drainage of water that is collected from the terrace and is discharged through the stones of the wall.

Terrace farming of grapes, nut and fruit trees, along with natural (mainly sclerophylous) vegetation constitute the predominant land uses in this area. The total population in the eight mountain communities of Peristerona Watershed has decreased by more than 50% over the past 30 years. The depopulation of mountain communities is associated with the urbanisation trends and the high farming costs which led to the gradual reduction of agricultural activities in the area. These socio-economic attributes form the main constraining factors for soil conservation. Thus, although terraces have a particularly beneficial effect in maintaining the productive capacity of soils in these communities, the significant changes in the socio-economic structure of the agricultural population over the last decades and the high maintenance and labour required, has led farmers to gradually abandon terrace farming.

LOCATION



Location: Northeast Pitsilia, Nicosia, Cyprus

No. of Technology sites analysed:

Geo-reference of selected sites
- 33.04999, 34.96667

Spread of the Technology: evenly spread over an area (30.9 km²)

In a permanently protected area?:

Date of implementation: more than 50 years ago (traditional)

Type of introduction
- [ ] through land users' innovation
- [x] as part of a traditional system (> 50 years)
- [ ] during experiments/ research
- [ ] through projects/ external interventions

Consequently, many of the mountain terraces are no longer cultivated and dry stone walls are not maintained, causing sometimes a domino effect of collapsing terraces.


Collapsing dry-stone walls (Christos Zoumides)

CLASSIFICATION OF THE TECHNOLOGY

Main purpose
- [ ] improve production
- [x] reduce, prevent, restore land degradation
- [ ] conserve ecosystem
- [ ] protect a watershed/ downstream areas – in combination with other Technologies
- [ ] preserve/ improve biodiversity
- [ ] reduce risk of disasters
- [ ] adapt to climate change/ extremes and its impacts
- [ ] mitigate climate change and its impacts
- [ ] create beneficial economic impact
- [ ] create beneficial social impact

Land use


Cropland
- Tree and shrub cropping: fruits, other, grapes, tree nuts (brazil nuts, pistachio, walnuts, almonds, etc.)

Number of growing seasons per year: 1

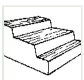
Water supply
- [x] rainfed
- [ ] mixed rainfed-irrigated
- [ ] full irrigation

Purpose related to land degradation
- [x] prevent land degradation
- [ ] reduce land degradation
- [x] restore/ rehabilitate severely degraded land
- [ ] adapt to land degradation
- [ ] not applicable

Degradation addressed


soil erosion by water - Wt: loss of topsoil/ surface erosion, Wo: offsite degradation effects

SLM group
- cross-slope measure

SLM measures


structural measures - S1: Terraces

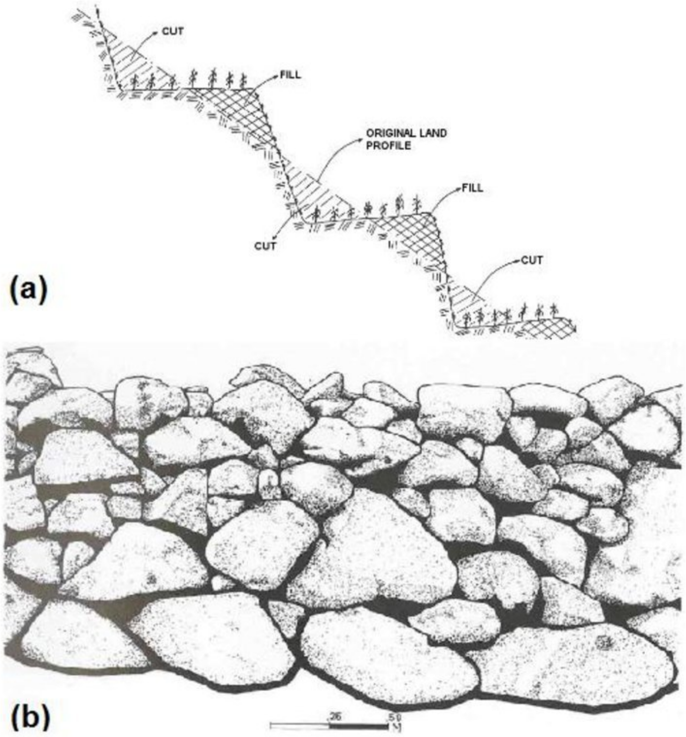
TECHNICAL DRAWING

Technical specifications

(a) The typical terraces found in the study-area are narrow (1-3 m) to medium-base (3-6 m) bench terraces, constructed by cutting and filling in slopes between 20-40%. The height of terraces range between 0.75 to 2 meters, depending on the steepness and the morphology of each slope.

(b) The terraces are supported by walls, whereby stone - typically volcanic rock - is the only construction material without any binding mortar. Large and irregular stones are used for the foundations, while the more regular for the construction of walls. The smaller stones are placed in between the large stones as the linchpin, to provide better stability to the structure. The wall is built lengthwise following the foundations and it reclines inwards; declination from the foundations does not exceed 5%. The back side of the wall is filled-up with more irregular stones which are not suitable to be placed on the front side. The filling connects the wall with the soil and stabilises the structure, and allows the drainage of water that is collected from the terrace and is discharged through the stones of the wall.

Northeast Pitsilia, Nicosia
Technical knowledge required for land users: moderate (To maintain dry-stone wall terraces)
Technical knowledge required for Dry-stone artisans (experts builders): high (To reconstruct collapsed terraces)
Main technical functions: reduction of slope angle, sediment retention / trapping, sediment harvesting
Secondary technical functions: increase of infiltration, increase / maintain water stored in soil
Terrace: bench level
Vertical interval between structures (m): 1-2
Spacing between structures (m): 1-15
Construction material (stone): Natural volcanic rock available on the sites (mostly gabbro & diabase)
Lateral gradient along the structure: 0-8%



Author: a: FAO, 2000 & b: TPH, 2007

ESTABLISHMENT AND MAINTENANCE: ACTIVITIES, INPUTS AND COSTS

Calculation of inputs and costs
- Costs are calculated:
- Currency used for cost calculation: **Euro**
- Exchange rate (to USD): 1 USD = 0.88 Euro
- Average wage cost of hired labour per day: 72.97

Most important factors affecting the costs
The principal input cost for the construction and maintenance of terraces is manual labour. There are only few dry-stone builders in the area.

Establishment activities
1. Land leveling and foundation (Timing/ frequency: Early autumn or late spring)
2. Collection and transfer of stones (Timing/ frequency: Early autumn or late spring)
3. Construction of stone-wall (Timing/ frequency: Early autumn or late spring)

Establishment inputs and costs

Specify input	Unit	Quantity	Costs per Unit (Euro)	Total costs per input (Euro)	% of costs borne by land users
Labour					
Labour		4000.0	45.6	182400.0	100.0
Total costs for establishment of the Technology				**182'400.0**	
Total costs for establishment of the Technology in USD				*207'272.73*	

Maintenance activities
1. Repairing collapsed walls (Timing/ frequency: Early autumn (before onset of rains), only on collapsed walls)

Maintenance inputs and costs

Specify input	Unit	Quantity	Costs per Unit (Euro)	Total costs per input (Euro)	% of costs borne by land users
Labour					
Labour		200.0	9.12	1824.0	100.0
Total costs for maintenance of the Technology				**1'824.0**	
Total costs for maintenance of the Technology in USD				*2'072.73*	

NATURAL ENVIRONMENT

Average annual rainfall
- ☐ < 250 mm
- ☑ 251-500 mm
- ☑ 501-750 mm

Agro-climatic zone
- ☐ humid
- ☑ sub-humid
- ☑ semi-arid

Specifications on climate
500-750mm: Seasonal rainfall (October to May) - Peristerona watershed upstream

- [ ] 751-1,000 mm
- [ ] 1,001-1,500 mm
- [ ] 1,501-2,000 mm
- [ ] 2,001-3,000 mm
- [ ] 3,001-4,000 mm
- [ ] > 4,000 mm

- [ ] arid

250-500mm: Seasonal rainfall (October to May) - Peristerona watershed downstream
Thermal climate class: subtropics. Below 1000m a.s.l.
Thermal climate class: temperate. Above 1000m a.s.l.

Slope
- [ ] flat (0-2%)
- [ ] gentle (3-5%)
- [ ] moderate (6-10%)
- [ ] rolling (11-15%)
- [x] hilly (16-30%)
- [x] steep (31-60%)
- [ ] very steep (>60%)

Landforms
- [ ] plateau/plains
- [ ] ridges
- [x] mountain slopes
- [x] hill slopes
- [ ] footslopes
- [ ] valley floors

Altitude
- [ ] 0-100 m a.s.l.
- [ ] 101-500 m a.s.l.
- [ ] 501-1,000 m a.s.l.
- [x] 1,001-1,500 m a.s.l.
- [ ] 1,501-2,000 m a.s.l.
- [ ] 2,001-2,500 m a.s.l.
- [ ] 2,501-3,000 m a.s.l.
- [ ] 3,001-4,000 m a.s.l.
- [ ] > 4,000 m a.s.l.

Technology is applied in
- [ ] convex situations
- [ ] concave situations
- [x] not relevant

Soil depth
- [ ] very shallow (0-20 cm)
- [x] shallow (21-50 cm)
- [x] moderately deep (51-80 cm)
- [ ] deep (81-120 cm)
- [ ] very deep (> 120 cm)

Soil texture (topsoil)
- [x] coarse/ light (sandy)
- [x] medium (loamy, silty)
- [ ] fine/ heavy (clay)

Soil texture (> 20 cm below surface)
- [ ] coarse/ light (sandy)
- [ ] medium (loamy, silty)
- [ ] fine/ heavy (clay)

Topsoil organic matter content
- [ ] high (>3%)
- [x] medium (1-3%)
- [x] low (<1%)

Groundwater table
- [ ] on surface
- [ ] < 5 m
- [ ] 5-50 m
- [x] > 50 m

Availability of surface water
- [ ] excess
- [ ] good
- [x] medium
- [ ] poor/ none

Water quality (untreated)
- [x] good drinking water
- [ ] poor drinking water (treatment required)
- [ ] for agricultural use only (irrigation)
- [ ] unusable

Water quality refers to:

Is salinity a problem?
- [ ] Ja
- [ ] Nee

Occurrence of flooding
- [ ] Ja
- [ ] Nee

Species diversity
- [ ] high
- [x] medium
- [ ] low

Habitat diversity
- [ ] high
- [ ] medium
- [ ] low

CHARACTERISTICS OF LAND USERS APPLYING THE TECHNOLOGY

Market orientation
- [ ] subsistence (self-supply)
- [x] mixed (subsistence/ commercial)
- [ ] commercial/ market

Off-farm income
- [ ] less than 10% of all income
- [x] 10-50% of all income
- [ ] > 50% of all income

Relative level of wealth
- [ ] very poor
- [ ] poor
- [x] average
- [ ] rich
- [ ] very rich

Level of mechanization
- [x] manual work
- [ ] animal traction
- [x] mechanized/ motorized

Sedentary or nomadic
- [x] Sedentary
- [ ] Semi-nomadic
- [ ] Nomadic

Individuals or groups
- [x] individual/ household
- [ ] groups/ community
- [ ] cooperative
- [ ] employee (company, government)

Gender
- [x] women
- [x] men

Age
- [ ] children
- [ ] youth
- [ ] middle-aged
- [ ] elderly

Area used per household
- [ ] < 0.5 ha
- [ ] 0.5-1 ha
- [ ] 1-2 ha
- [x] 2-5 ha
- [ ] 5-15 ha
- [ ] 15-50 ha
- [ ] 50-100 ha
- [ ] 100-500 ha
- [ ] 500-1,000 ha
- [ ] 1,000-10,000 ha
- [ ] > 10,000 ha

Scale
- [x] small-scale
- [ ] medium-scale
- [ ] large-scale

Land ownership
- [ ] state
- [ ] company
- [ ] communal/ village
- [ ] group
- [ ] individual, not titled
- [x] individual, titled

Land use rights
- [ ] open access (unorganized)
- [ ] communal (organized)
- [ ] leased
- [x] individual

Water use rights
- [ ] open access (unorganized)
- [ ] communal (organized)
- [ ] leased
- [ ] individual

Access to services and infrastructure

health	poor	✓			good
education	poor	✓			good
technical assistance	poor	✓			good
employment (e.g. off-farm)	poor	✓			good
markets	poor	✓			good
energy	poor			✓	good
roads and transport	poor			✓	good
drinking water and sanitation	poor			✓	good
financial services	poor		✓		good

IMPACTS

Socio-economic impacts

Crop production

Impact		Rating		Comment
Crop production	decreased	[ ][ ][ ][ ][✓][ ][ ]	increased	Terraces create agricultural land for crop production in slopes. However, the establishment of terraces does not imply increased crop yield.
production area (new land under cultivation/ use)	decreased	[ ][ ][ ][ ][ ][ ][✓]	increased	Without terraces on mountain slopes, crop farming would have been almost impossible
demand for irrigation water	increased	[ ][ ][ ][ ][ ][✓][ ]	decreased	Well constructed and maintained terraces improve water drainage and retain soil moisture.
expenses on agricultural inputs	increased	[ ][✓][ ][ ][ ][ ][ ]	decreased	More costly to grown on mountain terraces than in the plains. Also, maintenance of collapsed terrace walls is costly.
farm income	decreased	[ ][ ][ ][ ][ ][✓][ ]	increased	Farming in the study-site is practiced almost exclusively on terraces; well maintained terraces can increase farm income.
workload	increased	[ ][✓][ ][ ][ ][ ][ ]	decreased	Maintenance of collapsed terrace walls requires manual labour

Socio-cultural impacts

Impact		Rating		Comment
food security/ self-sufficiency	reduced	[ ][ ][ ][ ][✓][ ][ ]	improved	Partly for those land users that still practice mountain terrace farming.
cultural opportunities (eg spiritual, aesthetic, others)	reduced	[ ][ ][ ][ ][ ][✓][ ]	improved	When terraces are maintained/rehabilitated through community-based activities.
recreational opportunities	reduced	[ ][ ][ ][ ][ ][✓][ ]	improved	When terraces are maintained/rehabilitated through community-based activities.
community institutions	weakened	[ ][ ][ ][ ][ ][✓][ ]	strengthened	When terraces are maintained/rehabilitated through community-based activities.
SLM/ land degradation knowledge	reduced	[ ][ ][ ][ ][ ][ ][✓]	improved	Dry-stone terracing is the typical soil conservation technology in the study-site
conflict mitigation	worsened	[ ][ ][ ][ ][ ][ ][✓]	improved	
Contribution to human well-being	decreased	[ ][ ][ ][ ][ ][✓][ ]	increased	Terraced landscapes in the Troodos mountains represent a longstanding tradition of self-sustained communities. In the past, terrace farming was a main activity and has contributed to the livelihoods and well-being of these communities. Nowadays, terrace farming is still practiced by much fewer land users, mainly on part-time basis.

Ecological impacts

Impact		Rating		Comment
harvesting/ collection of water (runoff, dew, snow, etc)	reduced	[ ][ ][ ][ ][ ][ ][✓]	improved	One of the main functions of terraces.
surface runoff	increased	[ ][ ][ ][ ][ ][ ][✓]	decreased	One of the main functions of terraces.
soil cover	reduced	[ ][ ][ ][✓][ ][ ][ ]	improved	When terraces are maintained
soil loss	increased	[ ][ ][ ][ ][ ][ ][✓]	decreased	One of the main functions of terraces.
habitat diversity	decreased	[ ][ ][ ][ ][✓][ ][ ]	increased	Dry-stone terraces create biodiversity habitats, especially for reptiles and arthropods
fire risk	increased	[ ][ ][ ][ ][ ][✓][ ]	decreased	Well maintained terraces have less weeds than abandoned terraces, thus reducing the fire risk
Abandoned or poorly maintained terraces can result in increased	low impact	[ ][ ][ ][ ][ ][ ][✓]	high impact	

erosion, e.g. through the collapsing

Off-site impacts

downstream flooding (undesired)

increased ☐☐☐☐✓☐☐ reduced

Upstream terraces can reduce to a certain extent reduced downstream flooding

downstream siltation

increased ☐☐☐☐✓☐☐ decreased

Upstream terraces can reduce to a certain extent downstream siltation

damage on public/ private infrastructure

increased ☐☐☐☐☐☐✓ reduced

Well maintain terraces reduce damage (erosion) on public (e.g. roads) and private (e.g. neighbours fields) infrastructure

COST-BENEFIT ANALYSIS

Benefits compared with establishment costs

Short-term returns	very negative	☐✓☐☐☐☐☐	very positive
Long-term returns	very negative	☐☐☐☐☐✓☐	very positive

Benefits compared with maintenance costs

Short-term returns	very negative	☐☐✓☐☐☐☐	very positive
Long-term returns	very negative	☐☐☐☐☐✓☐	very positive

CLIMATE CHANGE

Gradual climate change

annual temperature increase	not well at all	☐☐☐✓☐	very well	

Climate-related extremes (disasters)

local rainstorm	not well at all	☐✓☐☐☐	very well	
local windstorm	not well at all	☐☐☐☐☐	very well	Answer: not known
drought	not well at all	☐☐☐✓☐	very well	
general (river) flood	not well at all	☐✓☐☐☐	very well	

Other climate-related consequences

reduced growing period	not well at all	☐☐☐✓☐	very well	

ADOPTION AND ADAPTATION

Percentage of land users in the area who have adopted the Technology

- ☐ single cases/ experimental
- ☐ 1-10%
- ☐ 11-50%
- ☑ > 50%

Number of households and/ or area covered

90% of the land user families and 8% of the stated area

Of all those who have adopted the Technology, how many have done so without receiving material incentives?

- ☐ 0-10%
- ☑ 11-50%
- ☐ 51-90%
- ☐ 91-100%

Has the Technology been modified recently to adapt to changing conditions?

- ☐ Ja
- ☐ Nee

To which changing conditions?

- ☐ climatic change/ extremes
- ☐ changing markets
- ☐ labour availability (e.g. due to migration)

CONCLUSIONS AND LESSONS LEARNT

Strengths: land user's view

Strengths: compiler's or other key resource person's view

- Indigenous technology of great agro-ecological value, adapted to local conditions.
- Soil maintained on steep mountain slopes, thus reducing soil loss due to water erosion.
- Terraces maintain the productive capacity of soils on steep slopes.
- Water retention and longer storage of soil moisture, thus improving water use efficiency.
- Terraces are part of cultural landscapes and heritage

Weaknesses/ disadvantages/ risks: land user's viewhow to overcome

Weaknesses/ disadvantages/ risks: compiler's or other key resource person's viewhow to overcome

- Maintenance of dry-stone wall terraces is costly and labour intensive. Promote community-based terrace maintenance and utilise available community/subsidy funds for small cash compensation to terrace experts.
- Terrace maintenance requires expert knowledge. Motivate the younger generation to engage in part-time terrace farming.
- Aging of the dry-stone experts. Train young land users/owners on dry-stone terracing.
- Technology does not lend itself to mechanisation. Not possible to overcome.

REFERENCES

Compiler
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Editors

Reviewer
Deborah Niggli
Alexandra Gavilano

Date of documentation: Okt. 30, 2015

Last update: Maart 18, 2019

Resource persons
Christos Zoumides - SLM specialist
Adriana Bruggeman - SLM specialist
Corrado Camera - SLM specialist

Full description in the WOCAT database
https://qcat.wocat.net/af/wocat/technologies/view/technologies_1702/

Linked SLM data
Approaches: Community-based maintenance and rehabilitation of agricultural terraces in mountain environments
https://qcat.wocat.net/af/wocat/approaches/view/approaches_2537/

Documentation was faciliated by

Institution
- The Cyprus Institute (The Cyprus Institute) - Cyprus

Project
- Preventing and Remediating degradation of soils in Europe through Land Care (EU-RECARE)

Key references

- FAO, 2000. Manual on integrated soil management and conservation practices. FAO Land and Water Bulletin 8, Rome, Italy: 230 pp.TPH, 2007. Dry stone constructions of Cyprus. PIO, Nicosia.:

Mature plantation of Ceratonia siliqua (I. Daliakopoulos)

Grazing land afforestation with Ceratonia siliqua (carob trees) in the Mediterranean (Greece)

Φύτευση βοσκότοπου με Ceratonia siliqua (χαρουπιές) στη Μεσόγειο (EL)

DESCRIPTION

Graze land forestation with Ceratonia siliqua (carob trees)

A stand of Ceratonia siliqua (carob trees) is established within an area used for grazing. Tree density is average (6 m grid configuration) and the majority of maintenance input is limited to the first 3 years. Once established, grazing can continue with few limitations. Ceratonia siliqua (carob tree) is very characteristic of the Mediterranean region, thus blending in very well with the local landscape, especially in the rugged agro-pastoral areas of the Mediterranean islands.
After the successful establishment of the plantation, intense irrigation is no longer required and livestock can be allowed in the afforested area which has been upgraded to an improved agro-pastoral or agroforestry land. This improvement facilitates a healthier ecosystem that mitigates land degradation by stabilizing soil, increasing infiltration and organic matter and promoting flora and fauna. In addition to those traits, Ceratonia siliqua is fire resistant and can promote market diversification for the farmer. The main drawback of this technology is the reduction in livestock and other crop production during the first decade of application until trees are mature.

The purpose of this technology is multifold. The primary goal is to increase ecosystem services provided by the treated area, especially for grazing. The farmer takes advantage of the qualities of carob trees for providing:
(a) Fodder to the livestock from the carob pods as well as leaves from cuttings;
(b) Shade to the livestock during the summer months;
(c) Better soil retention, water infiltration etc.
A secondary goal is to increase market diversification with the direct exploitation of carob beans for various products, such as carob honey and carob flour. These products give added value to the land and allow the farmer to increase his income in a more sustainable way.
At the same time much is gained from various other ecosystem services relevant to habitat and supporting services for the fauna of the area, such as birds and honey-bees. The aesthetic value of the landscape which strongly linked with Cretan traditions and pastoralism lifestyle is enhanced. The touristic attraction of the area is greatly improved providing new options for recreational activities and exploitation through actions such as agro-tourism.

Initially, few structural measures are required, mostly related to preparing slopes and soil for sapling planting and establishing irrigation infrastructure. A palisade that will effectively prevent livestock from damaging young trees needs to be maintained during the first 10 years of application of the technology. 2-year-old saplings are planted in a grid configuration with spacing of 6 m and actively managed for at least 3 years. Management includes watering, fertilization and replacement of dead or weak saplings.

The average annual precipitation in the area is 690 mm and the climate is classified as subhumid. Average annual temperature is 17.5 oC with 7 months below 18 but above 5, thus classifying the area as subtropical. In the location where the technology is applied, land is mostly individually owned and distributed among a few families of a community of about 100 inhabitants. Although the financial means of the land user who applies this technology are more or less on par with those of the rest of the community, he has a wider empirical education and relatively higher social status acquired thought his involvement with the commons.

LOCATION

Location: Melidochorion/Kastriotis, Heraklion, Greece

No. of Technology sites analysed:

Geo-reference of selected sites
- n.a.

Spread of the Technology:

In a permanently protected area?:

Date of implementation: 10-50 years ago

Type of introduction
- ☐ through land users' innovation
- ☐ as part of a traditional system (> 50 years)
- ☐ during experiments/ research
- ☑ through projects/ external interventions

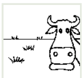
Pruned stand of Ceratonia siliqua (I. Daliakopoulos)

CLASSIFICATION OF THE TECHNOLOGY

Main purpose
- [x] improve production
- [x] reduce, prevent, restore land degradation
- [ ] conserve ecosystem
- [ ] protect a watershed/ downstream areas – in combination with other Technologies
- [ ] preserve/ improve biodiversity
- [ ] reduce risk of disasters
- [ ] adapt to climate change/ extremes and its impacts
- [ ] mitigate climate change and its impacts
- [ ] create beneficial economic impact
- [ ] create beneficial social impact

Land use
Land use mixed within the same land unit: Ja - Agro-pastoralism (incl. integrated crop-livestock)

Cropland
- Tree and shrub cropping: carob



Grazing land

Water supply
- [ ] rainfed
- [x] mixed rainfed-irrigated
- [ ] full irrigation

Purpose related to land degradation
- [x] prevent land degradation
- [ ] reduce land degradation
- [x] restore/ rehabilitate severely degraded land
- [ ] adapt to land degradation
- [ ] not applicable

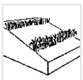
Degradation addressed

soil erosion by water - Wt: loss of topsoil/ surface erosion

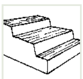
biological degradation - Bc: reduction of vegetation cover, Bq: quantity/ biomass decline

SLM group
- natural and semi-natural forest management
- agroforestry
- pastoralism and grazing land management

SLM measures



vegetative measures - V1: Tree and shrub cover



structural measures - S6: Walls, barriers, palisades, fences

TECHNICAL DRAWING

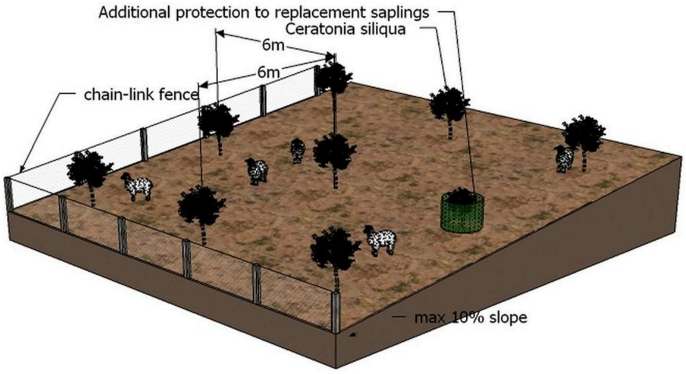
Technical specifications

A stand of Ceratonia siliqua (carob trees) is established within an area used for grazing. For at least 10 years the area is fenced adequately to exclude livestock; once trees are mature sheep can return to graze. If a tree needs to be replaced after establishment, it can be individually fenced.

Technical knowledge required for field staff / advisors: moderate (advice from technical staff is required for each of the plantation establishment stages)
Technical knowledge required for land users: moderate

Main technical functions: improvement of ground cover
Secondary technical functions: improvement of topsoil structure (compaction), stabilisation of soil (eg by tree roots against land slides), increase in organic matter, promotion of vegetation species and varieties (quality, eg palatable fodder), control of fires

Aligned: -linear
Vegetative material: T : trees / shrubs
Number of plants per (ha): 120
Vertical interval within rows / strips / blocks (m): 6
Width within rows / strips / blocks (m): 6
Trees/ shrubs species: Ceratonia siliqua
Construction material (other): chain-link fence



Author: I. Daliakopoulos

ESTABLISHMENT AND MAINTENANCE: ACTIVITIES, INPUTS AND COSTS

Calculation of inputs and costs

- Costs are calculated:
- Currency used for cost calculation: **Euro**
- Exchange rate (to USD): 1 USD = 0.73 Euro
- Average wage cost of hired labour per day: 80.00

Most important factors affecting the costs

n.a.

Establishment activities

1. Planting saplings (Timing/ frequency: Winter)
2. Grafting (Timing/ frequency: in the 4th year of establishment)
3. Slope/soil preparation (Timing/ frequency: Before planting)
4. Chain-link fencing (Timing/ frequency: Before planting)
5. Irrigation piping (Timing/ frequency: Before planting)

Establishment inputs and costs

Specify input	Unit	Quantity	Costs per Unit (Euro)	Total costs per input (Euro)	% of costs borne by land users
Labour					
labour	ha	1.0	3760.0	3760.0	
Equipment					
machine use	ha	1.0	3020.0	3020.0	
Plant material					
seedlings	ha	1.0	820.0	820.0	
Construction material					
chain-link fence	ha	1.0	1900.0	1900.0	
pipes	ha	1.0	270.0	270.0	
Total costs for establishment of the Technology				**9'770.0**	
Total costs for establishment of the Technology in USD				*13'383.56*	

Maintenance activities

1. Fertilization (Timing/ frequency: None)
2. Replacing dead or weak trees (Timing/ frequency: whenever necessary)
3. Pruning (Timing/ frequency: once a year)
4. Watering (Timing/ frequency: twice per month during summer, once per month during the rest of the year)

Maintenance inputs and costs

Specify input	Unit	Quantity	Costs per Unit (Euro)	Total costs per input (Euro)	% of costs borne by land users
Labour					
labour	ha	1.0	350.0	350.0	
Plant material					
seedlings	ha	1.0	280.0	280.0	
Fertilizers and biocides					
fertilizer	ha	1.0	160.0	160.0	

Construction material					
water	ha	1.0	6.0	6.0	
Total costs for maintenance of the Technology				**796.0**	
Total costs for maintenance of the Technology in USD				*1'090.41*	

NATURAL ENVIRONMENT

Average annual rainfall
- [ ] < 250 mm
- [ ] 251-500 mm
- [x] 501-750 mm
- [ ] 751-1,000 mm
- [ ] 1,001-1,500 mm
- [ ] 1,501-2,000 mm
- [ ] 2,001-3,000 mm
- [ ] 3,001-4,000 mm
- [ ] > 4,000 mm

Agro-climatic zone
- [ ] humid
- [x] sub-humid
- [ ] semi-arid
- [ ] arid

Specifications on climate
690 mm

Thermal climate class: subtropics

Slope
- [ ] flat (0-2%)
- [ ] gentle (3-5%)
- [x] moderate (6-10%)
- [ ] rolling (11-15%)
- [ ] hilly (16-30%)
- [ ] steep (31-60%)
- [ ] very steep (>60%)

Landforms
- [ ] plateau/plains
- [ ] ridges
- [ ] mountain slopes
- [x] hill slopes
- [x] footslopes
- [ ] valley floors

Altitude
- [x] 0-100 m a.s.l.
- [x] 101-500 m a.s.l.
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- [ ] 2,501-3,000 m a.s.l.
- [ ] 3,001-4,000 m a.s.l.
- [ ] > 4,000 m a.s.l.

Technology is applied in
- [ ] convex situations
- [ ] concave situations
- [ ] not relevant

Soil depth
- [x] very shallow (0-20 cm)
- [x] shallow (21-50 cm)
- [ ] moderately deep (51-80 cm)
- [ ] deep (81-120 cm)
- [ ] very deep (> 120 cm)

Soil texture (topsoil)
- [ ] coarse/ light (sandy)
- [ ] medium (loamy, silty)
- [ ] fine/ heavy (clay)

Soil texture (> 20 cm below surface)
- [ ] coarse/ light (sandy)
- [ ] medium (loamy, silty)
- [ ] fine/ heavy (clay)

Topsoil organic matter content
- [ ] high (>3%)
- [x] medium (1-3%)
- [ ] low (<1%)

Groundwater table
- [ ] on surface
- [ ] < 5 m
- [ ] 5-50 m
- [x] > 50 m

Availability of surface water
- [ ] excess
- [ ] good
- [x] medium
- [ ] poor/ none

Water quality (untreated)
- [x] good drinking water
- [ ] poor drinking water (treatment required)
- [ ] for agricultural use only (irrigation)
- [ ] unusable

Water quality refers to:

Is salinity a problem?
- [ ] Ja
- [ ] Nee

Occurrence of flooding
- [ ] Ja
- [ ] Nee

Species diversity
- [x] high
- [ ] medium
- [ ] low

Habitat diversity
- [ ] high
- [ ] medium
- [ ] low

CHARACTERISTICS OF LAND USERS APPLYING THE TECHNOLOGY

Market orientation
- [ ] subsistence (self-supply)
- [ ] mixed (subsistence/ commercial)
- [ ] commercial/ market

Off-farm income
- [ ] less than 10% of all income
- [ ] 10-50% of all income
- [x] > 50% of all income

Relative level of wealth
- [ ] very poor
- [ ] poor
- [x] average
- [ ] rich
- [ ] very rich

Level of mechanization
- [ ] manual work
- [ ] animal traction
- [ ] mechanized/ motorized

Sedentary or nomadic
- [ ] Sedentary
- [ ] Semi-nomadic
- [ ] Nomadic

Individuals or groups
- [x] individual/ household
- [ ] groups/ community
- [ ] cooperative
- [ ] employee (company, government)

Gender
- [ ] women
- [x] men

Age
- [ ] children
- [ ] youth
- [ ] middle-aged
- [ ] elderly

Area used per household
- [ ] < 0.5 ha
- [ ] 0.5-1 ha
- [ ] 1-2 ha
- [ ] 2-5 ha
- [x] 5-15 ha
- [ ] 15-50 ha
- [ ] 50-100 ha
- [ ] 100-500 ha
- [ ] 500-1,000 ha
- [ ] 1,000-10,000 ha

Scale
- [ ] small-scale
- [x] medium-scale
- [ ] large-scale

Land ownership
- [ ] state
- [ ] company
- [ ] communal/ village
- [ ] group
- [ ] individual, not titled
- [x] individual, titled

Land use rights
- [ ] open access (unorganized)
- [ ] communal (organized)
- [ ] leased
- [x] individual

Water use rights
- [ ] open access (unorganized)
- [x] communal (organized)
- [ ] leased
- [ ] individual

> 10,000 ha

Access to services and infrastructure

health	poor		✓		good
education	poor			✓	good
technical assistance	poor		✓		good
employment (e.g. off-farm)	poor	✓			good
markets	poor		✓		good
energy	poor		✓		good
roads and transport	poor	✓			good
drinking water and sanitation	poor		✓		good
financial services	poor	✓			good

IMPACTS

Socio-economic impacts

fodder production	decreased							✓	increased	
fodder quality	decreased							✓	increased	
animal production	decreased	✓							increased	during the first 10 years
wood production	decreased					✓			increased	
risk of production failure	increased		✓						decreased	30% failure rate
product diversity	decreased						✓		increased	
demand for irrigation water	increased				✓				decreased	
expenses on agricultural inputs	increased						✓		decreased	after at least 10 years
diversity of income sources	decreased							✓	increased	

Socio-cultural impacts

cultural opportunities (eg spiritual, aesthetic, others)	reduced						✓		improved	
recreational opportunities	reduced							✓	improved	agro-tourism opportunities
conflict mitigation	worsened					✓			improved	

Ecological impacts

surface runoff	increased					✓			decreased
soil moisture	decreased					✓			increased
soil cover	reduced						✓		improved
soil loss	increased						✓		decreased
nutrient cycling/ recharge	decreased						✓		increased
biomass/ above ground C	decreased					✓			increased
plant diversity	decreased							✓	increased
animal diversity	decreased						✓		increased
beneficial species (predators, earthworms, pollinators)	decreased							✓	increased
habitat diversity	decreased							✓	increased
pest/ disease control	decreased						✓		increased
fire risk	increased							✓	decreased
wind velocity	increased				✓				decreased

Off-site impacts

COST-BENEFIT ANALYSIS

Benefits compared with establishment costs

Short-term returns	very negative		✓						very positive
Long-term returns	very negative						✓		very positive

Benefits compared with maintenance costs

Short-term returns	very negative			✓					very positive
Long-term returns	very negative						✓		very positive

CLIMATE CHANGE

Other climate-related consequences

droughts / dry spells for the first 3 years	not well at all		✓				very well

ADOPTION AND ADAPTATION

Percentage of land users in the area who have adopted the Technology

- [ ] single cases/ experimental
- [ ] 1-10%
- [ ] 11-50%
- [ ] > 50%

Of all those who have adopted the Technology, how many have done so without receiving material incentives?

- [ ] 0-10%
- [ ] 11-50%
- [ ] 51-90%
- [x] 91-100%

Has the Technology been modified recently to adapt to changing conditions?

- [ ] Ja
- [ ] Nee

To which changing conditions?

- [ ] climatic change/ extremes
- [ ] changing markets
- [ ] labour availability (e.g. due to migration)

CONCLUSIONS AND LESSONS LEARNT

Strengths: land user's view

- Increased income through the provision of free fodder for the livestock.
- Restoration and protection of pastureland from further degradation.
- Provision of additional market opportunities to the land user.

Strengths: compiler's or other key resource person's view

- Restoration and protection of pastureland from further degradation.
- Provision of additional market opportunities to the land user.

Weaknesses/ disadvantages/ risks: land user's viewhow to overcome

- Decreased income though the reduction of livestock density (exclusion) for at least 10 years. Receive financial assistance (subsidies) per excluded animal. Voluntary contribution of local farmers to benefit from economies of scale (for unions).
- Decrease of vegetation under the tree canopy. Reduce carob tree density.

Weaknesses/ disadvantages/ risks: compiler's or other key resource person's viewhow to overcome

- Decreased income though the reduction of livestock density (exclusion) for at least 10 years. Receive financial assistance (subsidies) per excluded animal.
- Cannot implement in higher altitude pastureland due to the nature of the carob tree. Perform afforestation with Mulberries (Morus nigra)

REFERENCES

Compiler
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Editors

Reviewer
Deborah Niggli
Alexandra Gavilano

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Last update: Mei 6, 2019

Resource persons
Ioannis Daliakopoulos - SLM specialist
Ioannis Tsanis - SLM specialist

Full description in the WOCAT database
https://qcat.wocat.net/af/wocat/technologies/view/technologies_1600/

Linked SLM data
n.a.

Documentation was faciliated by

Institution

- Technical University of Crete (Technical University of Crete) - Greece

Project

- Catastrophic shifts in drylands (EU-CASCADE)

Bethlehem of Galilee Food Forest (Yuli Betzer)

Conversion of conventional monoculture farmland into a food forest (Israel)

Bethlehem of Galilee Food Forest

DESCRIPTION

Converting conventional monoculture farmland into a food forest-based agroforestry system restores soil health, increases vegetation cover, enhances biodiversity while diversifying production. The intervention improves soil organic matter and ecological resilience through multi-storey planting, reduced soil disturbance, and nature-based land management.

The development of a “food forest” was in response to visible soil degradation caused by years of wheat-based monoculture in Bethlehem of Galilee. The previous land use consisted of annual wheat production, tractor-powered deep ploughing, and routine use of herbicides and pesticides. Over time, these practices depleted soil organic matter, reduced microbial activity, and increased vulnerability to erosion, compaction, and moisture loss. The current food forest, covering approximately 1.5 acres (0.6 hectare), represents a transformative shift from this intensive, extractive system toward a sustainable, perennial, multi-strata agroforestry model.

The primary purpose of this site is research and education. It is not intended to be a commercial enterprise, but to demonstrate principles and practices of sustainable land management. The income generated is not from crops but from research grants, workshops and community activities.

The site has been under continuous restoration for approximately eight years, during which it has gradually developed into a multi-layered food forest. The upper canopy includes species such as ficus, tipa, mulberry, pecan, plane trees, and nitrogen-fixing “ice-cream bean” (Inga edulis), which together generate shade, biomass, and structural diversity. The productive mid-storey contains fruit-bearing species including lemon, plum, pomegranate, avocado, and additional deciduous trees. Beneath these layers, aromatic shrubs such as lavender and rosemary provide perennial cover, habitat complexity, and year-round biomass production. A dedicated lower layer supports seasonal vegetables: carrots, radishes, turnips, lettuces and other greens, interplanted within tree alleys and cultivated using organic methods.

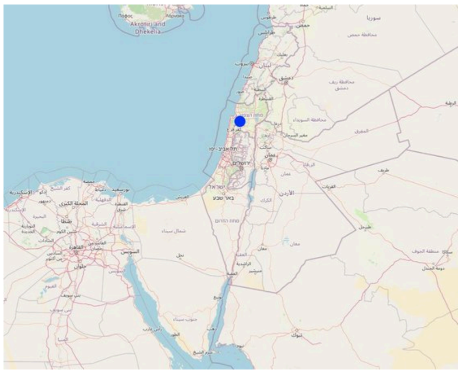
Production follows a diversified model typical of food forests. Tree crops currently yield modest but consistent quantities of lemons, plums, mulberries, pomegranates, and herbs, primarily for consumption by visitors, volunteers, and workers on site rather than large-scale commercial sale. The adjoining vegetable-growing area produces additional crops for small-scale marketing, providing a modest revenue stream while maintaining ecological integrity. As the system is still maturing, productive output is expected to increase over the coming years.

The project is privately managed by a couple in their thirties, who own and oversee all aspects of the site. Labour requirements were most intensive during the establishment phase of planting, mulching, earth-shaping, and infrastructure setup. As the food forest enters a more stable successional stage, labour demands have gradually decreased, with current activities centred on pruning, biomass recycling, vegetable cultivation, and occasional enrichment planting. No chemical inputs are applied at any stage.

Irrigation was originally supported by a drip system installed to establish young trees and early perennial layers. Today, irrigation needs have significantly decreased due to higher soil organic matter, increased shade, and improved microclimate regulation. Drip irrigation is now used only minimally and mainly within the annual vegetable plots, while most perennial components rely primarily on natural rainfall.

Overall, this food forest demonstrates a replicable nature-based solution for Mediterranean environments, showcasing how degraded wheat monoculture fields can be restored into resilient, biodiverse, and ecologically functional agroforestry systems. The long-term transition highlights substantial gains in soil health, water retention, and landscape diversity, while supporting small-scale production and community-oriented engagement.

LOCATION



Location: Bethlehem of Galilee, Galilee, Israel

No. of Technology sites analysed: single site

Geo-reference of selected sites

- 35.18589, 32.73255

Spread of the Technology: evenly spread over an area (0.01 km²)

In a permanently protected area?: No

Date of implementation: 2017; less than 10 years ago (recently)

Type of introduction

- [x] through land users' innovation
- [ ] as part of a traditional system (> 50 years)
- [x] during experiments/ research
- [x] through projects/ external interventions

Initial land preparation phase during the establishment of the food forest (Yuli Betzer)

The ecological pool constructed by the landowners as part of the food forest design (Yuli Betzer)

CLASSIFICATION OF THE TECHNOLOGY

Main purpose

- [ ] improve production
- [x] reduce, prevent, restore land degradation
- [x] conserve ecosystem
- [ ] protect a watershed/ downstream areas – in combination with other Technologies
- [x] preserve/ improve biodiversity
- [ ] reduce risk of disasters
- [x] adapt to climate change/ extremes and its impacts
- [ ] mitigate climate change and its impacts
- [ ] create beneficial economic impact
- [x] create beneficial social impact

Land use

Land use mixed within the same land unit: Yes - Agroforestry

Cropland

- Annual cropping: legumes and pulses - peas, medicinal/ aromatic/ pesticidal plants and herbs, vegetables - leafy vegetables (salads, cabbage, spinach, other), vegetables - root vegetables (carrots, onions, beet, other)
- Tree and shrub cropping: avocado, citrus, figs, pome fruits (apples, pears, quinces, etc.), stone fruits (peach, apricot, cherry, plum, etc), tree nuts (brazil nuts, pistachio, walnuts, almonds, etc.)

Number of growing seasons per year: 3
Is intercropping practiced? Yes
Is crop rotation practiced? Yes

Forest/ woodlands

- Tree plantation, afforestation: temperate continental forest plantation. Varieties: Mixed varieties

Tree types (mixed deciduous/ evergreen): n.a.
Products and services: Fruits and nuts, Other forest products, Nature conservation/ protection, Recreation/ tourism

Water supply

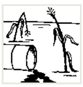
- [ ] rainfed
- [x] mixed rainfed-irrigated
- [ ] full irrigation

Purpose related to land degradation

- [ ] prevent land degradation
- [x] reduce land degradation
- [x] restore/ rehabilitate severely degraded land
- [ ] adapt to land degradation
- [ ] not applicable

Degradation addressed

soil erosion by water - Wt: loss of topsoil/ surface erosion



chemical soil deterioration - Cn: fertility decline and reduced organic matter content (not caused by erosion), Cs: salinization/ alkalinization

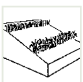
physical soil deterioration - Pc: compaction, Pi: soil sealing, Ps: subsidence of organic soils, settling of soil

biological degradation - Bc: reduction of vegetation cover, Bh: loss of habitats, Bq: quantity/ biomass decline, Bs: quality and species composition/ diversity decline

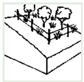
SLM group

- agroforestry
- improved ground/ vegetation cover
- minimal soil disturbance

SLM measures



vegetative measures - V1: Tree and shrub cover, V2: Grasses and perennial herbaceous plants

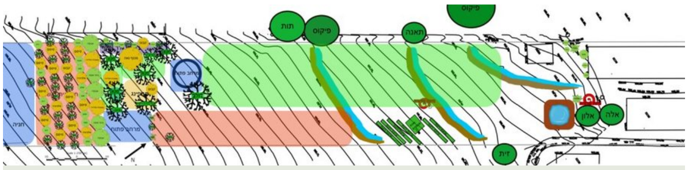


management measures - M1: Change of land use type, M2: Change of management/ intensity level, M5: Control/ change of species composition

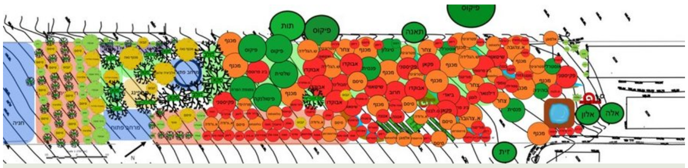
TECHNICAL DRAWING

Technical specifications

The general site plan (above) illustrates the full spatial organization of the food forest, structured into clearly defined functional zones that together create a balanced ecological and productive landscape (Note: original plan reproduced with captions in Hebrew). The outer perimeter consists of a protective tree belt designed to provide wind buffering, habitat continuity, and microclimate regulation. Inside this perimeter lies a series of densely planted clusters of mixed-species trees and support plants, forming the core forested zones of the design. These clusters contain a combination of canopy species, fruit trees, nitrogen-fixing support species, and understory elements arranged to promote ecological interactions and long-term resilience. Several open areas are intentionally integrated throughout the site, providing space for circulation, light penetration, future expansion, and community activities. The plan also includes a designated agricultural strip for annual vegetable production, strategically placed to benefit from the moderated microclimate created by the surrounding tree layers. Additional functional elements such as a compost area, shaded seating or gathering points, and access paths appear throughout the design, supporting both maintenance and educational use. Overall, the plan demonstrates a holistic integration of productive, ecological, and social spaces, emphasizing diversity, spatial layering, and regenerative land-use principles.
The planting plan (below) illustrates the full structural design of the food forest, showing a diverse mixture of perennial species arranged according to ecological function and spatial layout (Note: original plan reproduced with captions in Hebrew). Each color on the map represents a different botanical or functional category. The green circles indicate the major canopy and shade-providing trees that form the upper layer of the system. The red circles mark the fruit-bearing species distributed across the plot, including pomegranate, avocado, fig, loquat, mango, mulberry and others, representing the primary productive component of the mid-storey. The orange circles correspond to nitrogen-fixing trees and shrubs, strategically positioned to enrich soil fertility and support surrounding species through natural nutrient cycling. The yellow circles mark ornamental or habitat-supporting species that enhance biodiversity, microclimate regulation and ecological resilience. Together, these categories create a multi-layered mosaic in which canopy, fruit, support species and habitat elements interweave across the site. The design also includes designated open areas, compost space, perimeter rows and an agricultural strip for annual vegetables, demonstrating an intentional balance between ecological restoration, food production and functional zoning.



Author: Nitzan Betzer



Author: Nitzan Betzer

ESTABLISHMENT AND MAINTENANCE: ACTIVITIES, INPUTS AND COSTS

Calculation of inputs and costs

- Costs are calculated: per Technology area (size and area unit: **1.5 acres**; conversion factor to one hectare: **1 ha = 1 acre = 0.4 hectares**)
- Currency used for cost calculation: **USD**
- Exchange rate (to USD): 1 USD = n.a
- Average wage cost of hired labour per day: 158.2

Most important factors affecting the costs

The most significant cost factor, both during establishment and ongoing maintenance, is labour. All work is carried out manually using hand tools, and apart from the initial establishment phase, no heavy machinery is used

Establishment activities

1. Initial site assessment and mapping of soil condition and exposure (Timing/ frequency: Late winter / early spring)
2. Discontinuation of tillage and herbicide applications (Timing/ frequency: Immediately prior to establishment)
3. Soil preparation without deep tillage (light loosening, mulching base layer) (Timing/ frequency: Early spring)
4. Planting of trees in primary layout (skeleton layer) (Timing/ frequency: Spring)
5. Planting of shrubs and understory companion species (Timing/ frequency: Late spring / early summer)
6. Installation of organic mulch cover to protect soil and retain moisture (Timing/ frequency: After planting (early summer))
7. Enrichment planting / filling gaps with additional groundcover species (Timing/ frequency: Late summer / following spring)
8. Protection of young trees/shrubs if needed (guards, shading, temporary watering) (Timing/ frequency: First growing season)
9. Establishment of biomass cycling (chop-and-drop, composting on-site) (Timing/ frequency: After vegetation takes root)
10. Transition into maintenance phase (reduced intervention, natural succession) (Timing/ frequency: Once canopy begins forming)

Establishment inputs and costs (per 1.5 acres)

Specify input	Unit	Quantity	Costs per Unit (USD)	Total costs per input	% of costs borne by land

				(USD)	users
Labour					
Manual labour	Person-days	139.0	158.2	21989.8	100.0
Equipment					
Tools and maintenance equipment		1.0	5000.0	5000.0	100.0
Tractor (for construction)		1.0	7200.0	7200.0	100.0
Plant material					
Seedlings, cuttings, and seeds		1.0	14000.0	14000.0	100.0
Fertilizers and biocides					
Compost		1.0	10500.0	10500.0	100.0
Construction material					
Irrigation system		1.0	14500.0	14500.0	100.0
Pruned biomass mulch		1.0	6500.0	6500.0	100.0
Total costs for establishment of the Technology				**79'689.8**	
Total costs for establishment of the Technology in USD				*79'689.8*	

Maintenance activities

1. Mulching with organic biomass (leaf litter, pruning residues, woodchips, etc.) (Timing/ frequency: 2–3 times per year, mainly after rainy season and mid-summer)
2. Selective pruning of trees and shrubs to maintain structure and light balance (Timing/ frequency: Annually / as needed (late winter or autumn))
3. Enrichment planting and succession planting of understorey species (Timing/ frequency: Seasonally, as ecosystem matures or gaps appear)
4. Weeding by ecological suppression (groundcover strengthening) rather than removal (Timing/ frequency: Continuous, low-intensity maintenance)
5. Soil moisture conservation (biomass renewal / occasional supportive watering in drought years) (Timing/ frequency: Seasonally during dry periods (as needed))
6. Monitoring soil condition and vegetation health (Timing/ frequency: Ongoing, at least once per season)
7. Replacement of failed or weak young plants (Timing/ frequency: Annually during early growth seasons)
8. Maintenance of biodiversity guilds / companion planting structure (Timing/ frequency: Continuous, adaptive to natural succession)

Maintenance inputs and costs (per 1.5 acres)

Specify input	Unit	Quantity	Costs per Unit (USD)	Total costs per input (USD)	% of costs borne by land users
Labour					
Manual labour	Person-days	110.0	158.2	17402.0	100.0
Equipment					
Equipment renewal and maintenance		1.0	5000.0	5000.0	100.0
Plant material					
Cuttings and seeds		1.0	4000.0	4000.0	100.0
Other					
Water bills		1.0	5500.0	5500.0	100.0
Products selling kits		1.0	2000.0	2000.0	100.0
Total costs for maintenance of the Technology				**33'902.0**	
Total costs for maintenance of the Technology in USD				*33'902.0*	

NATURAL ENVIRONMENT

Average annual rainfall
- [ ] < 250 mm
- [ ] 251-500 mm
- [x] 501-750 mm
- [ ] 751-1,000 mm
- [ ] 1,001-1,500 mm
- [ ] 1,501-2,000 mm
- [ ] 2,001-3,000 mm
- [ ] 3,001-4,000 mm
- [ ] > 4,000 mm

Agro-climatic zone
- [ ] humid
- [x] sub-humid
- [ ] semi-arid
- [ ] arid

Specifications on climate
Name of the meteorological station: The climatic information for the food forest site was obtained from two sources: official data provided by the Israel Meteorological Service (IMS) and on-site measurements collected through a dedicated rain gauge installed as part of the research infrastructure. Together, these sources provide accurate local rainfall and climate monitoring for the plot.

Slope
- [ ] flat (0-2%)
- [ ] gentle (3-5%)
- [x] moderate (6-10%)
- [ ] rolling (11-15%)
- [ ] hilly (16-30%)
- [ ] steep (31-60%)
- [ ] very steep (>60%)

Landforms
- [ ] plateau/plains
- [ ] ridges
- [ ] mountain slopes
- [ ] hill slopes
- [x] footslopes
- [ ] valley floors

Altitude
- [ ] 0-100 m a.s.l.
- [x] 101-500 m a.s.l.
- [ ] 501-1,000 m a.s.l.
- [ ] 1,001-1,500 m a.s.l.
- [ ] 1,501-2,000 m a.s.l.
- [ ] 2,001-2,500 m a.s.l.
- [ ] 2,501-3,000 m a.s.l.
- [ ] 3,001-4,000 m a.s.l.
- [ ] > 4,000 m a.s.l.

Technology is applied in
- [ ] convex situations
- [ ] concave situations
- [x] not relevant

Soil depth
- very shallow (0-20 cm)
- shallow (21-50 cm)
- moderately deep (51-80 cm)
- ✓ deep (81-120 cm)
- very deep (> 120 cm)

Soil texture (topsoil)
- coarse/ light (sandy)
- ✓ medium (loamy, silty)
- fine/ heavy (clay)

Soil texture (> 20 cm below surface)
- coarse/ light (sandy)
- ✓ medium (loamy, silty)
- fine/ heavy (clay)

Topsoil organic matter content
- high (>3%)
- medium (1-3%)
- ✓ low (<1%)

Groundwater table
- on surface
- < 5 m
- ✓ 5-50 m
- > 50 m

Availability of surface water
- excess
- good
- medium
- ✓ poor/ none

Water quality (untreated)
- good drinking water
- poor drinking water (treatment required)
- ✓ for agricultural use only (irrigation)
- unusable

Water quality refers to: both ground and surface water

Is salinity a problem?
- Yes
- ✓ No

Occurrence of flooding
- Yes
- ✓ No

Species diversity
- high
- medium
- ✓ low

Habitat diversity
- high
- medium
- ✓ low

CHARACTERISTICS OF LAND USERS APPLYING THE TECHNOLOGY

Market orientation
- ✓ subsistence (self-supply)
- mixed (subsistence/ commercial)
- commercial/ market

Off-farm income
- less than 10% of all income
- 10-50% of all income
- ✓ > 50% of all income

Relative level of wealth
- very poor
- poor
- ✓ average
- rich
- very rich

Level of mechanization
- ✓ manual work
- animal traction
- mechanized/ motorized

Sedentary or nomadic
- ✓ Sedentary
- Semi-nomadic
- Nomadic

Individuals or groups
- ✓ individual/ household
- groups/ community
- cooperative
- employee (company, government)

Gender
- ✓ women
- ✓ men

Age
- children
- youth
- ✓ middle-aged
- elderly

Area used per household
- < 0.5 ha
- 0.5-1 ha
- 1-2 ha
- ✓ 2-5 ha
- 5-15 ha
- 15-50 ha
- 50-100 ha
- 100-500 ha
- 500-1,000 ha
- 1,000-10,000 ha
- > 10,000 ha

Scale
- ✓ small-scale
- medium-scale
- large-scale

Land ownership
- state
- company
- communal/ village
- group
- individual, not titled
- ✓ individual, titled

Land use rights
- open access (unorganized)
- communal (organized)
- leased
- ✓ individual

Water use rights
- open access (unorganized)
- communal (organized)
- leased
- ✓ individual

Access to services and infrastructure

health	poor			✓	good
education	poor			✓	good
technical assistance	poor		✓		good
employment (e.g. off-farm)	poor			✓	good
markets	poor		✓		good
energy	poor			✓	good
roads and transport	poor			✓	good
drinking water and sanitation	poor			✓	good
financial services	poor		✓		good

IMPACTS

Socio-economic impacts

expenses on agricultural inputs

increased					✓			decreased

Agricultural input expenses are very limited in this system. Since the site operates as a food forest rather than a conventional agricultural plot, nearly no external inputs are purchased. The management relies on ecological processes, on-site biomass, mulching, and manual care. Inputs are therefore minimal and do not reflect commercial-scale agricultural expenditure.

diversity of income sources

The plot was originally managed as a monoculture field that depended economically on agricultural production. Today, decreased ✓ increased

the food forest operates on a completely different model: its income is derived primarily from research activities, educational programs, workshops, and community engagement. Economic sustainability is no longer based on agricultural yield, as crop production is not the financial foundation of the site anymore.

Socio-cultural impacts

cultural opportunities (eg spiritual, aesthetic, others)

reduced ✓ improved

The food forest contributes significantly to cultural opportunities in the area. It serves as a community-oriented space that hosts educational events, workshops, volunteer activities, and gatherings focused on sustainability and ecological awareness. The site fosters cultural exchange, strengthens community cohesion, and provides a shared environment for learning, creativity, and connection to nature.

community institutions

weakened ✓ strengthened

Note: The food forest strengthens community institutions by collaborating with local educational programs, volunteer groups, and research initiatives. It provides a stable platform for schools, community organizations, and environmental groups to conduct activities, thereby reinforcing their role in community life and expanding their capacity for outreach and engagement.

SLM/ land degradation knowledge

reduced ✓ improved

The food forest contributes to improved SLM and land-degradation knowledge by serving as a living demonstration site where restoration practices can be observed, tested, and monitored over time. It provides real-world evidence on soil recovery, biodiversity enhancement, and regenerative management, supporting both scientific research and practical learning for land users, students, and professionals.

Ecological impacts

surface runoff

increased ✓ decreased

The food forest reduces surface runoff through continuous vegetative cover, increased soil organic matter, and improved infiltration. The multi-layered perennial structure slows water movement, stabilizes the soil, and enhances water absorption, thereby decreasing erosion risk and minimizing overland flow during rainfall events.

evaporation

increased ✓ decreased

The food forest reduces soil surface evaporation through dense vegetative cover, shading from the multi-layered canopy, and increased soil organic matter. Mulching and groundcover plants further protect the soil surface, lowering temperatures at ground level and limiting direct exposure to sun and wind, which significantly decreases soil surface evaporative water loss.

soil moisture

decreased ✓ increased

The food forest increases soil moisture by improving infiltration, enhancing organic matter content, and maintaining continuous groundcover. The multi-layered canopy moderates temperature and reduces evaporation, while mulch and living groundcovers retain water in the upper soil layers. Together, these features create a cooler, moister soil environment that supports long-term ecological function.

soil cover

reduced ✓ improved

The food forest improves ground cover through the establishment of multi-layered perennial vegetation, including trees, shrubs, and living groundcovers. Mulch application and natural leaf litter further protect the soil surface, ensuring year-round coverage that reduces erosion, enhances soil health, and supports ecological stability.

soil crusting/ sealing

increased ✓ reduced

The food forest reduces soil crusting and surface sealing by increasing organic matter, maintaining continuous vegetative cover, and enhancing biological activity in the upper soil layers. Leaf litter, mulch, and root penetration prevent the formation of hard surface layers, while improved soil structure allows better infiltration and aeration, minimizing the risk of crust development.

nutrient cycling/ recharge

decreased ✓ increased

The food forest enhances nutrient cycling and soil nutrient recharge through continuous biomass production, leaf litter accumulation, and root turnover. Nitrogen-fixing species, mulch, and on-site organic matter decomposition replenish soil nutrients naturally, while diverse plant strata promote active microbial communities that accelerate nutrient transformation and availability.

soil organic matter/ below ground C

decreased ✓ increased

The food forest increases soil organic matter and below-ground carbon through continuous inputs of leaf litter, root biomass, and decomposing mulch. The perennial, multi-layered vegetation system supports sustained carbon incorporation into the soil, while reduced disturbance and enhanced microbial activity further promote long-term carbon storage and soil organic matter accumulation.

vegetation cover

decreased ✓ increased

The food forest substantially increases vegetation cover by establishing multiple perennial layers - canopy trees, mid-storey species, shrubs, and groundcovers - that provide continuous, year-round biomass. This expanded plant cover protects the soil, supports ecological processes, and creates a more resilient and biodiverse landscape compared to the former monoculture field.

biomass/ above ground C

decreased ✓ increased

The food forest increases above-ground biomass and carbon storage through the establishment of diverse perennial vegetation, including canopy trees, fruit species, shrubs, and herbaceous layers. As these plants grow, they accumulate significant living biomass, sequester carbon, and contribute to long-term ecological stability through continuous organic matter production and structural complexity.

plant diversity

decreased ✓ increased

The food forest greatly increases plant diversity by integrating a wide range of tree species, fruit trees, nitrogen-fixing plants, shrubs, herbs, and groundcovers. This multi-strata design replaces the former single-crop system with a complex, species-rich community that enhances ecological resilience, supports wildlife, and promotes functional biodiversity across the site.

habitat diversity

decreased ✓ increased

The food forest increases habitat diversity by creating a multi-layered structure that supports varied ecological niches. The combination of canopy trees, understory species, shrubs, groundcovers, open areas, and water features provides habitats for a wide range of insects, birds, and small wildlife. This structural and functional diversity replaces the uniform habitat of the former monoculture and greatly enhances overall ecosystem complexity.

emission of carbon and greenhouse gases

increased ✓ decreased

The food forest helps reduce carbon and greenhouse gas emissions by minimizing external inputs, eliminating chemical fertilizers, and avoiding soil disturbance that would otherwise release stored carbon. The perennial vegetation continuously sequesters carbon in both biomass and soil, while the system's low-energy, regenerative management reduces emissions associated with conventional agricultural practices.

Off-site impacts

impact of greenhouse gases

Using IPCC Tier-1 methods (2006 Guidelines with the 2019 Refinement), we estimate annual removals from (i) mineral soil organic carbon (SOC) gains after conversion from tilled wheat to multistrata agroforestry, and (ii) incremental woody biomass growth. Mediterranean evidence suggests SOC increases on managed woody systems of ~0.2–1.0 t C increased ☐ ☐ ☐ ☐ ☐ ☐ ✓ reduced

ha⁻¹ yr⁻¹, while biomass increments in multistrata/silvo-arable agroforestry typically add ~0.8–2.5 t C ha^{-1} yr^{-1} in the establishment decades; together this yields ~1.0–3.5 t C ha^{-1} yr^{-1}, i.e., ≈ 3.7–13 tCO_2e ha^{-1} yr^{-1} (3.67 conversion). For reporting we adopt the conservative lower bound until our paired soil cores (baseline vs. years 2/5/8) and tree allometry—supported by Sentinel-2 time-series—finish quantifying site-specific change. Sources: IPCC 2006/2019 AFOLU guidance; AR6 WGIII (AFOLU); Mediterranean meta-analyses of SOC/biomass in woody systems and agroforestry.

COST-BENEFIT ANALYSIS

Benefits compared with establishment costs

Short-term returns: very negative ☐ ☐ ✓ ☐ ☐ ☐ ☐ very positive

Long-term returns: very negative ☐ ☐ ☐ ☐ ☐ ✓ ☐ very positive

Benefits compared with maintenance costs

Short-term returns: very negative ☐ ☐ ☐ ✓ ☐ ☐ ☐ very positive

Long-term returns: very negative ☐ ☐ ☐ ☐ ☐ ✓ ☐ very positive

The slightly negative short-term balance does not reflect external subsidies but rather the intentional design and purpose of the site. The food forest is not a commercial enterprise and was never intended to generate profit from agricultural production. Its primary function is research, education, and community engagement, and therefore its revenues come from workshops, collaborations, and research grants rather than crop sales. The short-term financial deficit simply reflects the fact that the landowners invest in a long-term ecological and educational project whose value is measured in environmental and social outcomes rather than immediate economic returns. It should not be interpreted as dependence on agricultural subsidies or market-based support.

CLIMATE CHANGE

Gradual climate change

annual temperature increase: not well at all ☐ ☐ ✓ ☐ ☐ very well

annual rainfall decrease: not well at all ☐ ☐ ☐ ✓ ☐ very well

Climate-related extremes (disasters)

local rainstorm: not well at all ☐ ☐ ✓ ☐ ☐ very well

heatwave: not well at all ☐ ☐ ☐ ✓ ☐ very well

drought: not well at all ☐ ☐ ☐ ✓ ☐ very well

ADOPTION AND ADAPTATION

Percentage of land users in the area who have adopted the Technology

- ☑ single cases/ experimental
- ☐ 1-10%
- ☐ 11-50%
- ☐ > 50%

Number of households and/ or area covered

One household: 1.5 acres

Of all those who have adopted the Technology, how many have done so without receiving material incentives?

- ☑ 0-10%
- ☐ 11-50%
- ☐ 51-90%
- ☐ 91-100%

Has the Technology been modified recently to adapt to changing conditions?

- ☑ Yes
- ☐ No

To which changing conditions?

- ☑ climatic change/ extremes
- ☐ changing markets
- ☐ labour availability (e.g. due to migration)

The design and composition of the food forest are continuously adapted as the system matures and as new insights emerge from ongoing learning by the landowners and collaborating researchers. Species selection, spatial arrangement, and management practices have been refined over time in response to observed ecological dynamics - such as canopy development, soil improvement, microclimatic changes, and species performance. Additional trees, shrubs, and groundcovers have been introduced to enhance diversity, strengthen ecological functions, and address emerging needs such as shade regulation, soil enrichment, or habitat creation. This adaptive approach reflects the core principle of the technology: the food forest is a living system that evolves through observation, experimentation, and evidence-based adjustments informed by both practical experience and scientific collaboration.

CONCLUSIONS AND LESSONS LEARNT

Strengths: land user's view

- Restores soil fertility and structure without relying on chemicals and reduces weed pressure naturally through permanent groundcover
- Improves moisture retention and reduces drought stress over time and supports biodiversity and creates a healthier farm ecosystem

Weaknesses/ disadvantages/ risks: land user's viewhow to overcome

- Slow establishment phase before benefits become visible Patience + phased planting; choose fast-growing pioneer species to accelerate canopy formation

- Transformational: turns degraded land into a productive long-term asset

Strengths: compiler's or other key resource person's view

- Demonstrates a replicable nature-based solution for restoring degraded agricultural soils in Mediterranean climates
- Increases soil organic matter and biological activity, improving long-term soil function and carbon sequestration
- Serves as a living demonstration site with high educational and upscaling potential for regenerative farming in the region

- Requires knowledge and ecological management skills Ongoing guidance from experts / capacity building / training
- Young plants vulnerable to drought during first summers Supplemental irrigation in the first years and thicker mulching to reduce evaporation

Weaknesses/ disadvantages/ risks: compiler's or other key resource person's viewhow to overcome

- Long ecological recovery timeline before system reaches full functionality Use succession planning and pioneer/perennial nurse species to accelerate canopy closure and soil regeneration
- Success depends on appropriate species selection for local microclimate and soil Improve site-specific design using adaptive planting trials, monitoring, and locally adapted cultivars
- Knowledge-intensive management compared to conventional systems Provide technical training, extension support, and farmer-to-farmer learning
- Restoration outcomes may vary with drought years and extreme heat events Increase biomass cover, soil shading, and water retention strategies in early establishment years

REFERENCES

Compiler
Tom Cohen

Editors

Reviewer
William Critchley
Rima Mekdaschi Studer

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Resource persons
Tom Cohen - SLM specialist
Anna Brook - SLM specialist
- land user

Full description in the WOCAT database
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Linked SLM data
n.a.

Documentation was faciliated by

Institution

- University of Haifa (uhaifa)

Project

- n.a.

Key references

- Zbedat, G., & Brook, A. (2025). Land Restoration Effectiveness Assessed by Satellite-Based Remote Sensing Technologies as A New Monitoring Approach. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 48, 149-155.: Google Scholar
- T. A. Cohen, A. Brook and G. Zbedat, "Long-Term Land Restoration Assessment Using Remote Sensing in Mediterranean Ecosystems," 2024 IEEE International Workshop on Metrology for Agriculture and Forestry (MetroAgriFor), Padua, Italy, 2024, pp. 179-183, doi: 10.1109/MetroAgriFor63043.2024.10948855.: Google Scholar

Links to relevant information which is available online

- React4Med site: https://react4med.eu
- Bethlehem of Galilee Food Forest Collection: https://haifa.primo.exlibrisgroup.com/discovery/collectionDiscovery?vid=972HAI_MAIN:HAU&inst=972HAI_MAIN&collectionId=81263109080002791

Organic table grape cultivation in the Province of Taranto, Italy (Pandi Zdruli)

Organic Farming of Table Grapes (Italy)

Agricoltura biologica nella coltivazione di uva da tavola

DESCRIPTION

Organic Farming (OF) of table grape production in Apulia region is estimated at 8.5% of the total area. The advantages of OF include an increase in soil organic matter, better water holding capacity and lower soil salinity.

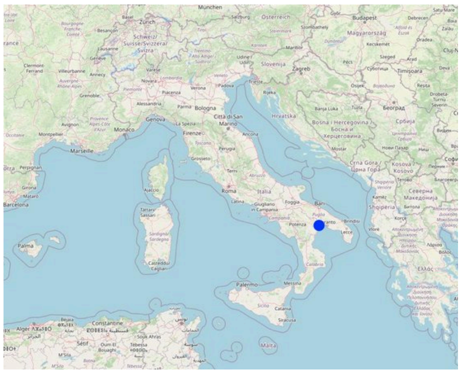
The EU Green Deal programme targets the conversion of 25% of agriculture into organic farming. Italy is close to 20% (as of 2024), and progress is being made towards the 25% target. Organic farming (OF) of fresh table grape production in Apulia region is estimated at about 8.5% of the total area of 35,000 ha. There are clear advantages of OF over conventional production methods in terms of soil heath. Soil organic matter is increased and water holding capacity is improved. Lower levels of soil salinity are also observed, principally due to the elimination of chemical fertilisers. Production is supported by modern, digitised, drip irrigation systems that increase water use efficiency.

Organic table grapes are produced at farm level. The main characteristics are based on the principles of organic farming, namely those of Health, Ecology, Fairness and Care. These principles guide the production system in (i) promoting soil, plant, animal, and human health, (ii) sustaining healthy ecological systems, (iii) ensuring fairness for all involved, and (iv) taking a precautionary and accountable approach to protect the environment for now and for future generations. Organic farming aims to produce food that sustains the health of the soil, plants, animals, humans, and thus the planet as an indivisible whole. This involves nurturing living systems rather than trying to control them, while promoting a strong and healthy environment.

The main purpose of organic table grape farming is to produce healthy grapes without hurting the environment, and in particular protecting soil and water from contamination. In the production system, inputs include organic manure to increase and maintain soil organic matter, and the encouragement of beneficial insects for pest control. The major benefits of farming this way are the production of better-quality grapes, while simultaneously improving soil health. Furthermore, the selling price of organic grapes attracts a premium of about 30%. This compensates for the lower yields that often occur as a result of eliminating synthetic chemical inputs.
Organic farming in Italy is regulated by the DECRETO LEGISLATIVO of 6 October 2023, no. 148 that sets out standards of production that are the basis of official certification.

However organic farming is not mainstream in fresh grape production, and many farmers remain reluctant to adopt it. This is mainly related to the need for biological means of pest and disease control that do not work effectively all the time, unlike synthetic chemical pesticides and fungicides that are not permitted under OF. This has consequences on yields and potentially on farmers' income.

LOCATION



Location: Dioemede Farm, Apulia Region, Taranto, Italy

No. of Technology sites analysed: 2-10 sites

Geo-reference of selected sites
- 16.84483, 40.47097

Spread of the Technology: evenly spread over an area (300.0 km^2)

In a permanently protected area?: No

Date of implementation: less than 10 years ago (recently)

Type of introduction
- [x] through land users' innovation
- [ ] as part of a traditional system (> 50 years)
- [ ] during experiments/ research
- [ ] through projects/ external interventions

A farmer describing organic farming of table grapes in relation to irrigation systems and selection of grape varieties (Enrico Perrino)

An irrigation system which delivers water at a depth of 20 cm close to rooting system to increase water use efficiency (Enrico Perrino)

CLASSIFICATION OF THE TECHNOLOGY

Main purpose

- [ ] improve production
- [x] reduce, prevent, restore land degradation
- [x] conserve ecosystem
- [ ] protect a watershed/ downstream areas – in combination with other Technologies
- [x] preserve/ improve biodiversity
- [ ] reduce risk of disasters
- [ ] adapt to climate change/ extremes and its impacts
- [ ] mitigate climate change and its impacts
- [x] create beneficial economic impact
- [x] create beneficial social impact

Land use

Land use mixed within the same land unit: No

Cropland

- Perennial (non-woody) cropping
- Grapes

Number of growing seasons per year: 1
Is intercropping practiced? No
Is crop rotation practiced? No

Other - Specify: Grapes vineyards
Remarks: Table grape production is widely spead in the Provinces of Bari and Taranto in Apulia Region

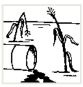
Water supply

- [ ] rainfed
- [ ] mixed rainfed-irrigated
- [x] full irrigation

Purpose related to land degradation

- [x] prevent land degradation
- [ ] reduce land degradation
- [ ] restore/ rehabilitate severely degraded land
- [ ] adapt to land degradation
- [ ] not applicable

Degradation addressed



chemical soil deterioration - Cn: fertility decline and reduced organic matter content (not caused by erosion), Cs: salinization/ alkalinization

physical soil deterioration - Pk: slaking and crusting, Pw: waterlogging

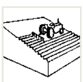
biological degradation - Bq: quantity/ biomass decline

water degradation - Ha: aridification, Hs: change in quantity of surface water, Hg: change in groundwater/aquifer level, Hp: decline of surface water quality, Hq: decline of groundwater quality

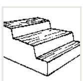
SLM group

- integrated soil fertility management
- integrated pest and disease management (incl. organic agriculture)
- irrigation management (incl. water supply, drainage)

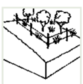
SLM measures



agronomic measures - A2: Organic matter/ soil fertility, A3: Soil surface treatment, A4: Subsurface treatment



structural measures - S3: Graded ditches, channels, waterways, S5: Dams, pans, ponds, S7: Water harvesting/ supply/ irrigation equipment

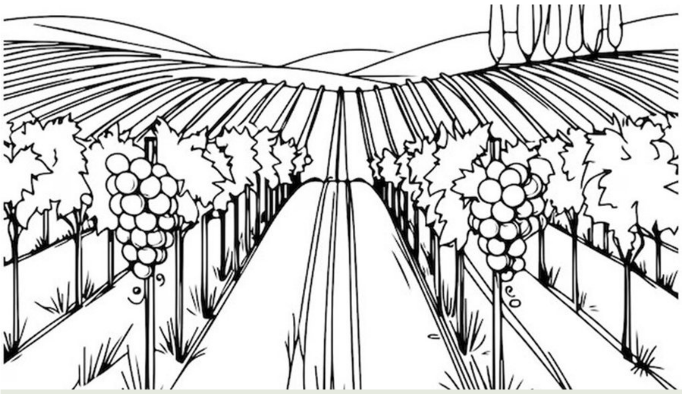


management measures - M2: Change of management/ intensity level, M3: Layout according to natural and human environment

TECHNICAL DRAWING

Technical specifications

The sketch gives an overview of an organically farmed table grape plantation. The grape rows are spaced at 2.5 metres apart, and the grape vines then pruned to reach 2.0 metres high (making management and harvesting easier). Drip irrigation pipes are situated alongside the rows of grapes - allowing precisely controlled and thus efficient application of water to each plant. Fertilizer is delivered in the irrigation water - thus it constitutes a "fertigation system".



Author: Pandi Zdruli

ESTABLISHMENT AND MAINTENANCE: ACTIVITIES, INPUTS AND COSTS

Calculation of inputs and costs

- Costs are calculated: per Technology area (size and area unit: **Hectare**)
- Currency used for cost calculation: **EUR**
- Exchange rate (to USD): 1 USD = 0.85 EUR
- Average wage cost of hired labour per day: 50

Most important factors affecting the costs

Raw materials, like rootstock, irrigation systems, tractors and labour costs

Establishment activities

1. Soil preparation (Timing/ frequency: Winter)
2. Location of cemented piles (Timing/ frequency: Winter)
3. Rootstock planting (Timing/ frequency: Winter)
4. Grafting (Timing/ frequency: Winter)
5. Establish irrigation and fertigation system (Timing/ frequency: Winter)
6. (Timing/ frequency: Fall)

Total establishment costs (estimation)

30000.0

Maintenance activities

1. Irrigation (Timing/ frequency: Every 10 days during the irrigation season)
2. Application of organic inputs (Timing/ frequency: Once per year in winter)
3. Weeding (Timing/ frequency: Frequently during the growing season)
4. Pruning (Timing/ frequency: Once a year)

Total maintenance costs (estimation)

10000.0

NATURAL ENVIRONMENT

Average annual rainfall

- [ ] < 250 mm
- [ ] 251-500 mm
- [x] 501-750 mm
- [ ] 751-1,000 mm
- [ ] 1,001-1,500 mm
- [ ] 1,501-2,000 mm
- [ ] 2,001-3,000 mm
- [ ] 3,001-4,000 mm
- [ ] > 4,000 mm

Agro-climatic zone

- [ ] humid
- [ ] sub-humid
- [x] semi-arid
- [ ] arid

Specifications on climate

Average annual rainfall in mm: 650.0

Typical Mediterranean climate with dry and hot summers and mild wet winters

Name of the meteorological station: Ginosa

Semi arid climate, with annual rainfall about 650 mm/year

Slope

- [x] flat (0-2%)
- [ ] gentle (3-5%)
- [ ] moderate (6-10%)
- [ ] rolling (11-15%)
- [ ] hilly (16-30%)
- [ ] steep (31-60%)
- [ ] very steep (>60%)

Landforms

- [x] plateau/plains
- [ ] ridges
- [ ] mountain slopes
- [ ] hill slopes
- [ ] footslopes
- [x] valley floors

Altitude

- [x] 0-100 m a.s.l.
- [ ] 101-500 m a.s.l.
- [ ] 501-1,000 m a.s.l.
- [ ] 1,001-1,500 m a.s.l.
- [ ] 1,501-2,000 m a.s.l.
- [ ] 2,001-2,500 m a.s.l.
- [ ] 2,501-3,000 m a.s.l.
- [ ] 3,001-4,000 m a.s.l.
- [ ] > 4,000 m a.s.l.

Technology is applied in

- [ ] convex situations
- [ ] concave situations
- [x] not relevant

Soil depth
- [ ] very shallow (0-20 cm)
- [ ] shallow (21-50 cm)
- [ ] moderately deep (51-80 cm)
- [ ] deep (81-120 cm)
- [x] very deep (> 120 cm)

Soil texture (topsoil)
- [ ] coarse/ light (sandy)
- [x] medium (loamy, silty)
- [ ] fine/ heavy (clay)

Soil texture (> 20 cm below surface)
- [ ] coarse/ light (sandy)
- [x] medium (loamy, silty)
- [ ] fine/ heavy (clay)

Topsoil organic matter content
- [ ] high (>3%)
- [ ] medium (1-3%)
- [x] low (<1%)

Groundwater table
- [ ] on surface
- [x] < 5 m
- [ ] 5-50 m
- [ ] > 50 m

Availability of surface water
- [ ] excess
- [ ] good
- [x] medium
- [ ] poor/ none

Water quality (untreated)
- [ ] good drinking water
- [ ] poor drinking water (treatment required)
- [x] for agricultural use only (irrigation)
- [ ] unusable

Water quality refers to: both ground and surface water

Is salinity a problem?
- [x] Yes
- [ ] No

Occurrence of flooding
- [x] Yes
- [ ] No

Species diversity
- [ ] high
- [x] medium
- [ ] low

Habitat diversity
- [ ] high
- [x] medium
- [ ] low

CHARACTERISTICS OF LAND USERS APPLYING THE TECHNOLOGY

Market orientation
- [ ] subsistence (self-supply)
- [ ] mixed (subsistence/ commercial)
- [x] commercial/ market

Off-farm income
- [x] less than 10% of all income
- [ ] 10-50% of all income
- [ ] > 50% of all income

Relative level of wealth
- [ ] very poor
- [ ] poor
- [ ] average
- [x] rich
- [ ] very rich

Level of mechanization
- [x] manual work
- [ ] animal traction
- [x] mechanized/ motorized

Sedentary or nomadic
- [x] Sedentary
- [ ] Semi-nomadic
- [ ] Nomadic

Individuals or groups
- [x] individual/ household
- [ ] groups/ community
- [x] cooperative
- [ ] employee (company, government)

Gender
- [x] women
- [x] men

Age
- [ ] children
- [ ] youth
- [x] middle-aged
- [ ] elderly

Area used per household
- [ ] < 0.5 ha
- [ ] 0.5-1 ha
- [ ] 1-2 ha
- [ ] 2-5 ha
- [ ] 5-15 ha
- [ ] 15-50 ha
- [ ] 50-100 ha
- [ ] 100-500 ha
- [ ] 500-1,000 ha
- [x] 1,000-10,000 ha
- [ ] > 10,000 ha

Scale
- [ ] small-scale
- [x] medium-scale
- [ ] large-scale

Land ownership
- [ ] state
- [x] company
- [ ] communal/ village
- [ ] group
- [ ] individual, not titled
- [x] individual, titled

Land use rights
- [ ] open access (unorganized)
- [ ] communal (organized)
- [ ] leased
- [x] individual

Water use rights
- [ ] open access (unorganized)
- [x] communal (organized)
- [ ] leased
- [ ] individual

Access to services and infrastructure

	poor				good
health	poor			✓	good
education	poor		✓		good
technical assistance	poor			✓	good
employment (e.g. off-farm)	poor		✓		good
markets	poor			✓	good
energy	poor			✓	good
roads and transport	poor			✓	good
drinking water and sanitation	poor			✓	good
financial services	poor		✓		good

IMPACTS

Socio-economic impacts

crop quality	decreased							✓	increased	Grapes are free of pesticide and fungicide residues
land management	hindered							✓	simplified	Minimum tillage makes field operations simpler and quicker
irrigation water availability	decreased						✓		increased	Infiltration and water holding capacity are increased, making more water available downstream for pumping
demand for irrigation water	increased			✓					decreased	Water demands are reduced because of efficient systems of irrigation

Impact	Scale		Comment
farm income	decreased	increased	A result of increased prices of grapes: value addition through organic farming

Socio-cultural impacts

Impact	Scale		Comment
SLM/ land degradation knowledge	reduced	improved	The major lever for conversion to OF is awareness among farmers that this form of farming brings economic soil health benefits.

Ecological impacts

Impact	Scale		Comment
groundwater table/ aquifer	lowered	recharge	Water infiltrates better under this system
evaporation	increased	decreased	Reduced by better ground cover
soil moisture	decreased	increased	Increased by better ground cover
soil cover	reduced	improved	Improved as a result of minimum tillage
soil loss	increased	decreased	Less erosion as ground cover improved
soil crusting/ sealing	increased	reduced	A positive result of minimum tillage
soil compaction	increased	reduced	A positive result of minimum tillage
nutrient cycling/ recharge	decreased	increased	The overall system supports and encourages this
salinity	increased	decreased	Less irrigation water used
soil organic matter/ below ground C	decreased	increased	The overall system supports and encourages this
pest/ disease control	decreased	increased	Fewer beneficial insects killed because of elimination of chemical pesticides
drought impacts	increased	decreased	The overall system supports and encourages irrigation water efficiency
emission of carbon and greenhouse gases	increased	decreased	A result of minimum tillage

Off-site impacts

Impact	Scale		Comment
water availability (groundwater, springs)	decreased	increased	Better infiltration of rainwater etc
reliable and stable stream flows in dry season (incl. low flows)	reduced	increased	Better infiltration of rainwater etc
downstream flooding (undesired)	increased	reduced	Better infiltration of rainwater etc

COST-BENEFIT ANALYSIS

Benefits compared with establishment costs

Short-term returns	very negative	very positive
Long-term returns	very negative	very positive

Benefits compared with maintenance costs

Short-term returns	very negative	very positive
Long-term returns	very negative	very positive

CLIMATE CHANGE

Gradual climate change

seasonal rainfall decrease	not well at all	very well	Season: summer

Climate-related extremes (disasters)

flash flood	not well at all	very well

ADOPTION AND ADAPTATION

Percentage of land users in the area who have adopted the Technology

- [ ] single cases/ experimental
- [ ] 1-10%
- [x] 11-50%
- [ ] > 50%

Number of households and/ or area covered

3000 hectares

Of all those who have adopted the Technology, how many have done so without receiving material incentives?

- [ ] 0-10%
- [x] 11-50%
- [ ] 51-90%
- [ ] 91-100%

Has the Technology been modified recently to adapt to changing conditions?

- [ ] Yes
- [x] No

To which changing conditions?

- [ ] climatic change/ extremes
- [ ] changing markets
- [ ] labour availability (e.g. due to migration)

CONCLUSIONS AND LESSONS LEARNT

Strengths: land user's view

- Organic Farming in fresh table grapes requires dedication from farmers and rigorous application of technology.
- Production may be lower in terms of quantity but the quality is better, translated into higher selling price
- This requires however, raising awareness of customers for such products and willingness to pay a higher price for a healthy product.

Strengths: compiler's or other key resource person's view

- Organic Farming has also benefits for soil health, biodiversity and overall environment

Weaknesses/ disadvantages/ risks: land user's viewhow to overcome

- Weaknesses are mostly related to the willingness of some farmers to change their methods of farming Spread the positive results, show concrete examples where the technology worked out well.

Weaknesses/ disadvantages/ risks: compiler's or other key resource person's viewhow to overcome

- Converting to OF is not easy and straightforward. Many farmers fear that they will lose income and will be subject to severe controls from the regional authorities and their product may not be certified, so they could lose the market. Correct application of the methodology.

REFERENCES

Compiler

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Editors

Reviewer

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Resource persons

Pandi Zdruli - SLM specialist

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n.a.

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Institution

- Centre International de Hautes Etudes Agronomiques Méditerranéennes, Istituto Agronomico Mediterraneo di Bari (CIHEAM IAMB)

Project

- REACT4MED

Key references

- Restoration, Indicators, and Participatory Solutions: Addressing Water Scarcity in Mediterranean Agriculture. Perrino, E.V.; Zdruli, P.; Piscitelli, L.; D'Agostino. 2025: Agronomy 2025, 15, 1517. https://doi.org/10.3390/agronomy15071517

Response of wheat to proline spraying under saline conditions in Tamia, Fayoum Governorate, Egypt (El Sayed El Habbasha, Ibrahim El–Metwally, Hani Saudy, Ahmed El-Shafie, Faten Ibrahim)

Wheat production in saline-affected soils (Egypt)

DESCRIPTION

This work demonstrates that the simple application of proline, a naturally occurring amino acid, can be a powerful strategy to protect wheat crops from the damaging effects of soil salinity. In arid regions, salt buildup in soil is a major threat to agriculture, stunting plant growth and drastically reducing yields.

The study investigated two Egyptian wheat cultivars (Misr-1 and Misr-3) grown in salty soil. The plants were sprayed with different concentrations of proline, and the results were clear and compelling:

1. Proline Acts as a Powerful Plant Protectant:

Under salt stress, plants experience physiological damage similar to "oxidative stress" in humans. Proline functions as a potent antioxidant and osmoprotectant. This means it:

Protects Cell Structures: It safeguards delicate cellular machinery, including chlorophyll (the pigment essential for photosynthesis), from salt-induced damage.

Maintains Water Balance: It helps plant cells retain water, countering the dehydrating effect of high salt concentrations in the soil.

2. Significant Improvements in Growth and Health:

Wheat plants treated with proline showed remarkable improvements compared to untreated plants:

Enhanced Growth: They were taller, had larger leaves, and produced more dry matter (biomass).

Better Photosynthesis: They maintained higher levels of chlorophyll, allowing them to produce more energy for growth even under stress.

Higher Internal Proline: The treatment boosted the plants' own natural proline production, enhancing their innate defense system.

3. Major Boosts in Yield and Grain Quality:

The most critical finding for farmers and food security was the impact on yield:

Increased Yield: The application of 150 ppm proline increased grain yield by up to 42.58% compared to untreated wheat.

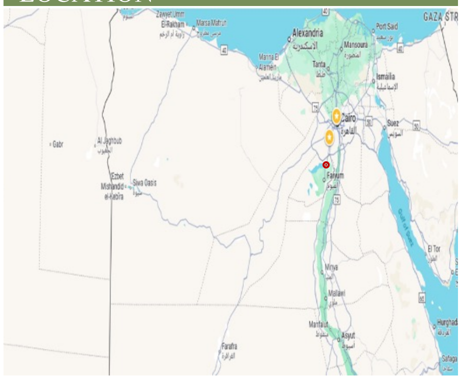
More Spikes and Heavier Grains: Treated plants produced more spikes per square meter and heavier individual grains.

Improved Grain Quality: The harvested grains from proline-treated plants had significantly higher protein and carbohydrate content, enhancing their nutritional value.

4. Cultivar Matters:

The study also found that the wheat cultivar Misr-3 was more responsive to proline and inherently more tolerant to salinity than Misr-1, highlighting the importance of selecting the right genetic material for challenging environments.

LOCATION



Location: Tamia, Fayoum Governorate, Egypt

No. of Technology sites analysed: 2-5 sites

Geo-reference of selected sites

- 29°30'53.4"N 30°58'07.8"E

Spread of the Technology: evenly spread over an area (105.0 km²)

In a permanently protected area?: No

Date of implementation: less than 10 years ago (recently)

Type of introduction

- [x] through land users' innovation
- [ ] as part of a traditional system (> 50 years)
- [ ] during experiments/ research
- [ ] through projects/ external interventions

During the spraying of wheat with the antioxidant (proline)

Examination of wheat spikes after treatment with proline (an antioxidant)

CLASSIFICATION OF THE TECHNOLOGY

Main purpose

- [ ] improve production
- [x] reduce, prevent, restore land degradation
- [x] conserve ecosystem
- [ ] protect a watershed/ downstream areas in combination with other Technologies
- [x] preserve/ improve biodiversity
- [ ] reduce risk of disasters
- [ ] adapt to climate change/ extremes and its impacts
- [ ] mitigate climate change and its impacts
- [x] create beneficial economic impact
- [x] create beneficial social impact

Land use

Land use mixed within the same land unit: No

Cropland
- Perennial (non-woody) cropping
- Wheat

Number of growing seasons per year: 1
Is intercropping practiced? No
Is crop rotation practiced? Yes

Other - Specify: Wheat cultivars (Misr-3 and Misr-1)
Remarks: Wheat production is widespread in the Tamia region and in most areas of the Fayoum Governorate.

Water supply

- [ ] rainfed
- [ ] mixed rainfed-irrigated
- [x] full irrigation

Purpose related to land degradation

- [x] prevent land degradation
- [ ] reduce land degradation
- [ ] restore/ rehabilitate severely degraded land
- [ ] adapt to land degradation
- [ ] not applicable

Degradation addressed

chemical soil deterioration - Cn: fertility decline and reduced organic matter content (not caused by erosion), Cs: salinization/ alkalinization

physical soil deterioration - Pk: slaking and crusting, Pw: waterlogging

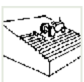
biological degradation - Bq: quantity/ biomass decline

water degradation - Ha: aridification, Hs: change in quantity of surface water, Hg: change in groundwater/aquifer level, Hp: decline of surface water quality, Hq: decline of groundwater quality

SLM group

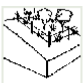
- integrated soil fertility management
- integrated pest and disease management (incl. organic agriculture)
- irrigation management (incl. water supply, drainage)

SLM measures



agronomic measures - A2: Organic matter/ soil fertility, A3: Soil surface treatment, A4: Subsurface treatment

structural measures - S3: Graded ditches, channels, waterways, S5: Dams, pans, ponds, S7: Water harvesting/ supply/ irrigation equipment

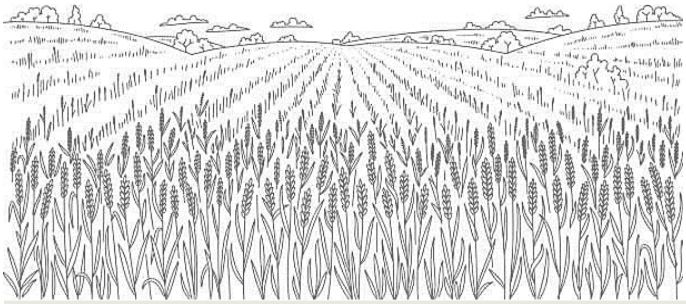


management measures - M2: Change of management/ intensity level, M3: Layout according to natural and human environment

TECHNICAL DRAWING

Technical specifications

This sketch demonstrates that foliar application of the antioxidant proline significantly enhances wheat tolerance to soil salinity.
In field experiments, two cultivars (Misr-1 and Misr-3) were treated with proline solutions. The proline acts as a powerful osmoprotectant, improving key physiological processes. This led to robust plant growth, higher chlorophyll levels, and increased proline accumulation. Consequently, proline-treated plants, especially the Misr-3 cultivar at 150 ppm, achieved superior grain and straw yields. The treatment also improved grain quality by boosting protein and carbohydrate content. This strategy offers an effective solution for sustaining wheat productivity in saline agricultural areas.



Author: El Sayed El Habbasha, Ibrahim El–Metwally, Hani Saudy, Ahmed El-Shafie, Faten Ibrahim

ESTABLISHMENT AND MAINTENANCE: ACTIVITIES, INPUTS AND COSTS

Calculation of inputs and costs

- Costs are calculated: per Technology area (size and area unit: Hectare)
- Currency used for cost calculation: EUR
- Exchange rate (to USD): 1 USD = 0.85 EUR
- Average wage cost of hired labour per day: 50

Most important factors affecting the costs

Raw materials, like rootstock, irrigation systems, tractors and labour costs

Agricultural activities

. Soil preparation (Timing/ frequency: Winter)
. Application of organic inputs (Timing/ frequency: winter)
. Adding fertilizers (Timing/ frequency: Winter)
. Planting (Timing/ frequency: Winter)
. Post-planting operations (Timing/ frequency: Winter)
. Irrigation and fertigation (Timing/ frequency: Winter)
. Irrigation (Timing/ frequency: Every 10 days during the irrigation season)
. Weeding (Timing/ frequency: Frequently during the growing season)
. Harvesting (Timing/ frequency: Summer)

Agricultural activities costs (estimation): 1800 EUR

NATURAL ENVIRONMENT

Average annual rainfall

- [x] < 250 mm
- [ ] 251-500 mm
- [ ] 501-750 mm
- [ ] 751-1,000 mm
- [ ] 1,001-1,500 mm
- [ ] 1,501-2,000 mm
- [ ] 2,001-3,000 mm
- [ ] 3,001-4,000 mm
- [ ] > 4,000 mm

Agro-climatic zone

- [ ] humid
- [ ] sub-humid
- [x] semi-arid
- [ ] arid

Specifications on climate

Average annual rainfall in mm: 7.2
Typical Mediterranean climate with dry and hot summers and mild wet winters
Name of the meteorological station: Tamia
Semi arid climate, with annual rainfall about 7.2 mm/year

Slope

- [x] flat (0-2%)
- [ ] gentle (3-5%)
- [ ] moderate (6-10%)
- [ ] rolling (11-15%)
- [ ] hilly (16-30%)
- [ ] steep (31-60%)
- [ ] very steep (>60%)

Landforms

- [x] plateau/plains
- [ ] ridges
- [ ] mountain slopes
- [ ] hill slopes
- [ ] footslopes
- [x] valley floors

Altitude

- [x] 0-100 m a.s.l.
- [ ] 101-500 m a.s.l.
- [ ] 501-1,000 m a.s.l.
- [ ] 1,001-1,500 m a.s.l.
- [ ] 1,501-2,000 m a.s.l.
- [ ] 2,001-2,500 m a.s.l.
- [ ] 2,501-3,000 m a.s.l.
- [ ] 3,001-4,000 m a.s.l.
- [ ] > 4,000 m a.s.l.

Technology is applied in

- [ ] convex situations
- [ ] concave situations
- [x] not relevant

Soil depth
- ☐ very shallow (0-20 cm)
- ☐ shallow (21-50 cm)
- ☐ moderately deep (51-80 cm)
- ☐ deep (81-120 cm)
- ☑ very deep (> 120 cm)

Soil texture (topsoil)
- ☐ coarse/ light (sandy)
- ☐ medium (loamy, silty)
- ☑ fine/ heavy (clay)

Soil texture (> 20 cm below surface)
- ☐ coarse/ light (sandy)
- ☐ medium (loamy, silty)
- ☑ fine/ heavy (clay)

Topsoil organic matter content
- ☐ high (>3%)
- ☐ medium (1-3%)
- ☑ low (<1%)

Groundwater table
- ☐ on surface
- ☑ < 5 m
- ☐ 5-50 m
- ☐ > 50 m

Availability of surface water
- ☐ excess
- ☐ good
- ☑ medium
- ☐ poor/ none

Water quality (untreated)
- ☐ good drinking water
- ☐ poor drinking water (treatment required)
- ☑ for agricultural use only (irrigation)
- ☐ unusable

Water quality refers to: both ground and surface water

Is salinity a problem?
- ☑ Yes
- ☐ No

Occurrence of flooding
- ☐ Yes
- ☑ No

Species diversity
- ☐ high
- ☑ medium
- ☐ low

Habitat diversity
- ☐ high
- ☑ medium
- ☐ low

CHARACTERISTICS OF LAND USERS APPLYING THE TECHNOLOGY

Market orientation
- ☐ subsistence (self-supply)
- ☐ mixed (subsistence/ commercial)
- ☑ commercial/ market

Off-farm income
- ☑ less than 10% of all income
- ☐ 10-50% of all income
- ☐ > 50% of all income

Relative level of wealth
- ☐ very poor
- ☑ **poor**
- ☐ average
- ☐ rich
- ☐ very rich

Level of mechanization
- ☑ manual work
- ☐ animal traction
- ☑ mechanized/ motorized

Sedentary or nomadic
- ☑ Sedentary
- ☐ Semi-nomadic
- ☐ Nomadic

Individuals or groups
- ☑ individual/ household
- ☐ groups/ community
- ☑ cooperative
- ☐ employee (company, government)

Gender
- ☑ women
- ☑ men

Age
- ☐ children
- ☐ youth
- ☑ middle-aged
- ☐ elderly

Area used per household
- ☑ < 0.5 ha
- ☐ 0.5-1 ha
- ☐ -2 ha
- ☐ -5 ha
- ☐ 5-15 ha
- ☐ 15-50 ha
- ☐ 50-100 ha
- ☐ 100-500 ha
- ☐ 500-1,000 ha
- ☐ 1,000-10,000 ha
- ☐ > 10,000 ha

Scale
- ☑ small-scale
- ☐ medium-scale
- ☐ large-scale

Land ownership
- ☐ state
- ☑ company
- ☐ communal/ village
- ☐ group
- ☐ individual, not titled
- ☑ individual, titled

Land use rights
- ☐ open access (unorganized)
- ☐ communal (organized)
- ☐ leased
- ☑ individual

Water use rights
- ☐ open access (unorganized)
- ☑ communal (organized)
- ☐ leased
- ☐ individual

Access to services and infrastructure

health	poor	☐	☐	☑	good
education	poor	☐	☑	☐	good
technical assistance	poor	☐	☐	☑	good
employment (e.g. off-farm)	poor	☐	☑	☐	good
markets	poor	☐	☐	☑	good
energy	poor	☐	☐	☑	good
roads and transport	poor	☐	☐	☑	good
drinking water and sanitation	poor	☐	☐	☑	good
financial services	poor	☐	☑	☐	good

IMPACTS

Socio-economic impacts

crop quality	decreased	☐	☐	☐	☐	☐	☐	☑	increased	Wheat seeds are free of pesticide and fungicide residues
land management	hindered	☐	☐	☐	☐	☐	☐	☑	simplified	Minimum tillage makes field operations simpler and quicker
irrigation water availability	decreased	☐	☐	☐	☐	☐	☑	☐	increased	Infiltration and water holding capacity are increased, making more water available downstream for pumping
demand for irrigation water	increased	☐	☐	☑	☐	☐	☐	☐	decreased	Water demands are reduced because of efficient systems of irrigation

farm income
decreased increased
As a result of rising wheat prices: adding value through the use of antioxidants

Socio-cultural impacts

SLM/ land degradation knowledge
reduced improved
The major lever for conversion to OF is awareness among farmers that this form of farming brings economic soil health benefits.

Ecological impacts

groundwater table/ aquifer
lowered recharge
Water infiltrates better under this system

evaporation
increased decreased
Reduced by better ground cover

soil moisture
decreased increased
Increased by better ground cover

soil cover
reduced improved
Improved as a result of minimum tillage

soil loss
increased decreased
Less erosion as ground cover improved

soil crusting/ sealing
increased reduced
A positive result of minimum tillage

soil compaction
increased reduced
A positive result of minimum tillage

nutrient cycling/ recharge
decreased increased
The overall system supports and encourages this

salinity
increased decreased
Less irrigation water used

soil organic matter/ below ground C
decreased increased
The overall system supports and encourages this

pest/ disease control
decreased increased
Fewer beneficial insects killed because of elimination of chemical pesticides

drought impacts
increased decreased
The overall system supports and encourages irrigation water efficiency

emission of carbon and greenhouse gases
increased decreased
A result of minimum tillage

Off-site impacts

water availability (groundwater, springs)
decreased increased
Better infiltration of rainwater etc

reliable and stable stream flows in dry season (incl. low flows)
reduced increased
Better infiltration of rainwater etc

downstream flooding (undesired)
increased reduced
Better infiltration of rainwater etc

COST-BENEFIT ANALYSIS

Benefits compared with establishment costs

Short-term returns
very negative very positive

Long-term returns
very negative very positive

Benefits compared with maintenance costs

Short-term returns
very negative very positive

Long-term returns
very negative very positive

CLIMATE CHANGE

Gradual climate change

seasonal rainfall decrease
not well at all very well
Season: winter

Climate-related extremes (disasters)

flash flood
not well at all very well

ADOPTION AND ADAPTATION

Percentage of land users in the area who have adopted the Technology

- [x] single cases/ experimental
- [ ] 1-10%
- [ ] 11-50%
- [ ] > 50%

Number of households and/ or area covered

10 hectares

Of all those who have adopted the Technology, how many have done so without receiving material incentives?

- [x] 0-10%
- [ ] 11-50%
- [ ] 51-90%
- [ ] 91-100%

Has the Technology been modified recently to adapt to changing conditions?

- [ ] Yes
- [x] No

To which changing conditions?

- [ ] climatic change/ extremes
- [ ] changing markets
- [ ] labour availability (e.g. due to migration)

CONCLUSIONS AND LESSONS LEARNT

Strengths: land user's view

Adopting proline treatment is a straightforward, low-cost strategy that integrates easily into existing wheat cultivation practices. While it requires precise application timing, it leads to a direct and significant increase in both grain yield and straw yield, even in saline soils. This results in higher and more stable farm income, providing a reliable return on investment by turning a problematic field into a productive asset.

Strengths: Compiler's or other key resource person's view

Scientifically, proline is a sustainable treatment that boosts wheat's innate salt tolerance. It enables cultivation in saline soils, enhances grain protein content, and secures yields in challenging environments.

Weaknesses/ disadvantages/ risks: land user's viewhow to overcome

Farmers may hesitate to adopt a new practice, fearing cost and complexity.

Overcome: Demonstrate proven yield increases and clear profitability through on-farm success stories.

Weaknesses/ disadvantages/ risks: compilers or other key resource persons viewhow to overcome

Improper application (wrong dose or timing) risks inconsistent results.

Overcome: Provide simple, clear guidelines for the 150 ppm concentration and critical 30/60-day spray schedule.

REFERENCES

Compiler
El Sayed El Habbasha
Ahmed El Shafie

Editors

Reviewer
William Critchley
Rima Mekdaschi Studer

Date of documentation: Oct. 5, 2025

Last update: Oct. 16, 2025

Resource persons

El Sayed El Habbasha - SLM specialist
Ahmed El Shafie

Full description in the WOCAT database

https://qcat.wocat.net/en/wocat/technologies/view/technologies_7648/

Linked SLM data

n.a.

Documentation was faciliated by

Institution

- PDS
- REACT4MED Project

Key references

- Restoration, Indicators, and Participatory Solutions: Addressing Water Scarcity in Mediterranean Agriculture. Perrino, E.V.; Zdruli, P.; Piscitelli, L.; DAgostino. 2025: Agronomy 2025, 15, 1517. https://doi.org/10.3390/agronomy15071517

Lentil crops on NTT extension plots (Ait Lhaj A.)

No-till technology (Morocco)

DESCRIPTION

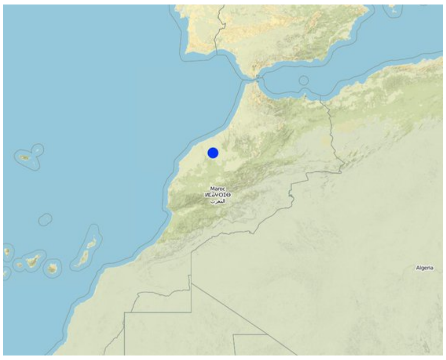
A no-till system with crop residue management for mediumscale wheat and barley farming.

This no-till technology (NTT) system, with direct seeding and crop residue management, was designed by the National Institute of Agricultural Research (INRA) in Settat, Morocco. A special no-till drill was developed to simultaneously seed and fertilize annual crops: the drill cuts through residue, opens a 20 cm wide slot which, after seed and N/P-fertilizers are dropped into it, is closed firmly to encourage contact between seed and soil. Seeding is earlier than in the case of conventional tillage – which requires seedbed preparation. Spacing between rows is adjusted according to crop type: 20 cm for wheat or barley, and 40 cm for lentils and chickpeas. Tillage depth is between 5–12 cm depending on soil workability and moisture content.

Establishment / maintenance activities and inputs: Crops, planted in rotation with a fallow period, are barley, wheat, legumes (lentils and chickpea) and also fodder species. Application of special herbicides replaces tillage for weed control, and enables the farmer to have an 18-month fallow period (a 'chemical fallow') after two crops have been taken over a 6-month period. Fallowing is essential for water conservation in this semi-arid area. NTT reduces passes with heavy machines to three times per year. Residue management involves maintaining the soil partially covered with stubble and straw. Overall, yields are higher and costs are lower than under conventional tillage. NTT reduces soil erosion and soil compaction while conserving water in the soil. Optimum use of scarce and low rainfall to stabilise/increase crop yields is essential in this area.

Natural / human environment: The use of the special no-till drill ensures both minimal working of the soils, and precise incorporation of phosphate fertilizer beneath seeds. Depending on the specific site, residue management is adjusted from low residue maintenance (stubble/controlled grazing) to medium surface cover (stubble/straw maintenance, forage crops and exclusion of grazing). Erosion and evaporation suppression/control are the main impacts of the system: runoff and concentrated flow in watersheds are reduced. Chemicals are applied for weed control, but this takes into account the environment, and can be reduced over time. Maintaining crop residues in the fields increases soil organic matter and thus the amount of carbon sequestered, as well as nutrient levels. Hence application of inorganic fertilizers can be reduced.

LOCATION



Location: Settat, Khourigba and Benslimane Provinces, Chaouia Ouardigha Region, Morocco, Morocco

No. of Technology sites analysed:

Geo-reference of selected sites
- -7.59, 32.94

Spread of the Technology: evenly spread over an area (20.0 km²)

In a permanently protected area?:

Date of implementation: less than 10 years ago (recently)

Type of introduction
- [ ] through land users' innovation
- [ ] as part of a traditional system (> 50 years)
- [x] during experiments/ research
- [ ] through projects/ external interventions

No-till barley seeding using the special drill, supervised by an extension agent; the photo was taken in the first year of NTT, thus the residue cover is still poor. (Ait Lhaj A.)

CLASSIFICATION OF THE TECHNOLOGY

Main purpose
- improve production
- ✓ reduce, prevent, restore land degradation
- conserve ecosystem
- protect a watershed/ downstream areas – in combination with other Technologies
- preserve/ improve biodiversity
- reduce risk of disasters
- adapt to climate change/ extremes and its impacts
- mitigate climate change and its impacts
- create beneficial economic impact
- create beneficial social impact

Land use

Cropland
- Annual cropping

Water supply
- rainfed
- mixed rainfed-irrigated
- full irrigation

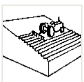
Purpose related to land degradation
- prevent land degradation
- ✓ reduce land degradation
- restore/ rehabilitate severely degraded land
- adapt to land degradation
- not applicable

Degradation addressed

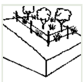
soil erosion by water - Wt: loss of topsoil/ surface erosion

SLM group
- improved ground/ vegetation cover
- minimal soil disturbance

SLM measures



agronomic measures - A3: Soil surface treatment (A 3.1: No tillage)



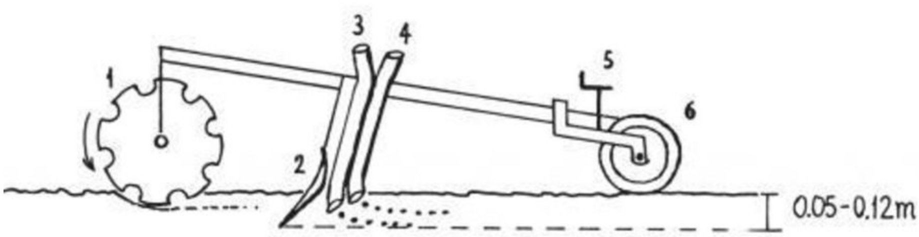
management measures - M2: Change of management/ intensity level

TECHNICAL DRAWING

Technical specifications
Schematic view of the specially designed no-till drill that simultaneously plants and applies fertilizer. Note the key components of the drill: 1) disc/opener, 2) hoe, 3) fertilizer tube, 4) seed tube, 5) seeding depth control, 6) wheel packer.

Main technical functions: control of raindrop splash, increase in organic matter, increase / maintain water stored in soil

Secondary technical functions: control of dispersed runoff: impede / retard, control of concentrated runoff: impede / retard, reduction in wind speed, increase in soil fertility, improvement of soil structure



ESTABLISHMENT AND MAINTENANCE: ACTIVITIES, INPUTS AND COSTS

Calculation of inputs and costs
- Costs are calculated:
- Currency used for cost calculation: **n.a.**
- Exchange rate (to USD): 1 USD = n.a
- Average wage cost of hired labour per day: n.a

Most important factors affecting the costs
Annual recurrent costs are calculated on a two years basis, including a 6-month cropping and 18-month fallow period, divided by two. The initial cost for the no-till drill is calculated – on a per hectare basis – for an average farm size of 10 ha. In this case a 'pilot' farmer's case is taken, where the drill is supplied free. As with conventional drills, a new no-till drill costs US$ 6,000 but it is subsidised by up to 50% by the Government. Thus farmers can buy it for US$ 3,000 (though 'pilot' farmers receive it free of charge – as noted above). They have no extra costs (compared to conventional tillage) and they can share the price of the drill between them if they wish. The price of certified seeds and fertilizers, energy and equipment are the main factors affecting the costs of no-till, when subsidies are cut after the pilot phase. However, the costs of NTT are lower than for conventional farming, even when the cost of the drill is included.

Establishment activities
n.a.

Establishment inputs and costs

Specify input	Unit	Quantity	Costs per Unit (n.a.)	Total costs per input (n.a.)	% of costs borne by land users
Equipment					
No-till drill	Unit	1.0	600.0	600.0	
Total costs for establishment of the Technology				**600.0**	
Total costs for establishment of the Technology in USD				*600.0*	

Maintenance activities
1. Stubble maintenance (no grazing, only partial straw removal after harvest). (Timing/ frequency: После уборки урожая/ежегодно)
2. Direct seeding/fertilizer (N/P) banding using no-till drill (early November). (Timing/ frequency: В начале ноября ежегодно)
3. Chemical weed control (December/January). (Timing/ frequency: Дек/янв ежегодно)
4. Nitrogen fertilization (March). (Timing/ frequency: Март ежегодно)
5. Harvest (May: after 6 months crop period). (Timing/ frequency: Май, после 6-месячного периода / ежегодно)
6. Leave fields to fallow for 18 months; apply herbicides if needed. (Timing/ frequency: None)

Maintenance inputs and costs

Specify input	Unit	Quantity	Costs per Unit (n.a.)	Total costs per input (n.a.)	% of costs borne by land users
Labour					
Seeding, maintenance, harvesting	unit	1.0	160.0	160.0	100.0
Equipment					
Machine use	unit	1.0	110.0	110.0	
Plant material					
Seeds	unit	1.0	60.0	60.0	
Fertilizers and biocides					
Fertilizer	unit	1.0	30.0	30.0	
Biocides	unit	1.0	40.0	40.0	
Total costs for maintenance of the Technology				**400.0**	
Total costs for maintenance of the Technology in USD				*400.0*	

NATURAL ENVIRONMENT

Average annual rainfall
- ✓ < 250 mm
- ✓ 251-500 mm
- 501-750 mm
- 751-1,000 mm
- 1,001-1,500 mm
- 1,501-2,000 mm
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- > 4,000 mm

Agro-climatic zone
- humid
- sub-humid
- semi-arid
- arid

Specifications on climate
n.a.

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- gentle (3-5%)
- ✓ moderate (6-10%)
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- hilly (16-30%)
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- very steep (>60%)

Landforms
- ✓ plateau/plains
- ridges
- ✓ mountain slopes
- hill slopes
- footslopes
- valley floors

Altitude
- 0-100 m a.s.l.
- ✓ 101-500 m a.s.l.
- ✓ 501-1,000 m a.s.l.
- 1,001-1,500 m a.s.l.
- 1,501-2,000 m a.s.l.
- 2,001-2,500 m a.s.l.
- 2,501-3,000 m a.s.l.

Technology is applied in
- convex situations
- concave situations
- not relevant

☐ 3,001-4,000 m a.s.l.
☐ > 4,000 m a.s.l.

Soil depth
- ✓ very shallow (0-20 cm)
- ☐ shallow (21-50 cm)
- ☐ moderately deep (51-80 cm)
- ✓ deep (81-120 cm)
- ☐ very deep (> 120 cm)

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- ✓ fine/ heavy (clay)

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- ☐ good
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- ☐ poor/ none

Water quality (untreated)
- ☐ good drinking water
- ☐ poor drinking water (treatment required)
- ☐ for agricultural use only (irrigation)
- ☐ unusable

Is salinity a problem?
- ☐ Yes
- ☐ No

Occurrence of flooding
- ☐ Yes
- ☐ No

Species diversity
- ☐ high
- ☐ medium
- ☐ low

Habitat diversity
- ☐ high
- ☐ medium
- ☐ low

CHARACTERISTICS OF LAND USERS APPLYING THE TECHNOLOGY

Market orientation
- ☐ subsistence (self-supply)
- ✓ mixed (subsistence/ commercial)
- ☐ commercial/ market

Off-farm income
- ☐ less than 10% of all income
- ☐ 10-50% of all income
- ☐ > 50% of all income

Relative level of wealth
- ☐ very poor
- ☐ poor
- ☐ average
- ☐ rich
- ☐ very rich

Level of mechanization
- ☐ manual work
- ☐ animal traction
- ✓ mechanized/ motorized

Sedentary or nomadic
- ☐ Sedentary
- ☐ Semi-nomadic
- ☐ Nomadic

Individuals or groups
- ☐ individual/ household
- ☐ groups/ community
- ☐ cooperative
- ☐ employee (company, government)

Gender
- ☐ women
- ☐ men

Age
- ☐ children
- ☐ youth
- ☐ middle-aged
- ☐ elderly

Area used per household
- ☐ < 0.5 ha
- ☐ 0.5-1 ha
- ☐ 1-2 ha
- ☐ 2-5 ha
- ✓ 5-15 ha
- ☐ 15-50 ha
- ☐ 50-100 ha
- ☐ 100-500 ha
- ☐ 500-1,000 ha
- ☐ 1,000-10,000 ha
- ☐ > 10,000 ha

Scale
- ☐ small-scale
- ☐ medium-scale
- ☐ large-scale

Land ownership
- ☐ state
- ☐ company
- ☐ communal/ village
- ☐ group
- ☐ individual, not titled
- ✓ individual, titled

Land use rights
- ☐ open access (unorganized)
- ☐ communal (organized)
- ☐ leased
- ☐ individual

Water use rights
- ☐ open access (unorganized)
- ☐ communal (organized)
- ☐ leased
- ☐ individual

Access to services and infrastructure

IMPACTS

Socio-economic impacts

Impact		1	2	3	4	5	6	7		Comment
Crop production	decreased							✓	increased	
fodder production	decreased							✓	increased	
expenses on agricultural inputs	increased						✓		decreased	
farm income	decreased							✓	increased	
workload	increased						✓		decreased	
flexible labour inputs	reduced							✓	improved	seeding is independent of rain onset
timeliness	reduced							✓	improved	
costs	increased		✓						decreased	fewer tractor passes in field
Initial costs	increased		✓						decreased	For special drill/tractor

Socio-cultural impacts

Impact		1	2	3	4	5	6	7		Comment
national institutions	weakened						✓		strengthened	
SLM/ land degradation knowledge	reduced						✓		improved	
conflict mitigation	worsened		✓						improved	stubble grazing by neighbours can cause socio-cultural conflicts (it is no longer allowed)
economic inequity	increased			✓					decreased	

Ecological impacts

excess water drainage	reduced						✓		improved
soil moisture	decreased							✓	increased
soil loss	increased							✓	decreased
soil organic matter/ below ground C	decreased							✓	increased
biomass/ above ground C	decreased						✓		increased
biodiversity	diminished						✓		enhanced
soil fertility	decreased							✓	increased

Off-site impacts

reliable and stable stream flows in dry season (incl. low flows)	reduced						✓		increased
downstream flooding (undesired)	increased						✓		reduced
groundwater/ river pollution	increased							✓	reduced

COST-BENEFIT ANALYSIS

Benefits compared with establishment costs

Benefits compared with maintenance costs

Short-term returns	very negative					✓			very positive
Long-term returns	very negative							✓	very positive

Pilot farmers receive the no-till drill fully financed by the project (thus no benefits under investment costs' above). Farmers who purchase the drill on their own (with a 50% subsidy) will recover its cost in less than two years.

CLIMATE CHANGE

-

ADOPTION AND ADAPTATION

Percentage of land users in the area who have adopted the Technology

- ☐ single cases/ experimental
- ✓ 1-10%
- ☐ 11-50%
- ☐ > 50%

Of all those who have adopted the Technology, how many have done so without receiving material incentives?

- ✓ 0-10%
- ☐ 11-50%
- ☐ 51-90%
- ☐ 91-100%

Number of households and/ or area covered

14 households in an area of 20 km2

Has the Technology been modified recently to adapt to changing conditions?

- ☐ Yes
- ☐ No

To which changing conditions?

- ☐ climatic change/ extremes
- ☐ changing markets
- ☐ labour availability (e.g. due to migration)

CONCLUSIONS AND LESSONS LEARNT

Strengths: land user's view

- More flexibility in planting, early land access and easier management
  of soils

  How can they be sustained / enhanced? Continue to cover soils with residues at planting/seeding to
  ensure sufficient soil moisture.
- Reduced energy, labour and cost: in NTT the tillage and seedbed preparation
  operations are eliminated; the no-till drill applies P and N fertilizers
  with the seed

  How can they be sustained / enhanced? Stress the use of appropriate equipment and inputs.

Strengths: compiler's or other key resource person's view

- Erosion control

  How can they be sustained / enhanced? Maintaining sufficient soil cover.
- Soil quality improvement

Weaknesses/ disadvantages/ risks: land user's view → how to overcome

- Costly machinery (drills, tractor, sprayer) required
  → Subsidies, purchase
  of equipment by groups of farmers.
- Weed control in NTT is critical: weed infestation if not well managed;
  high cost of herbicides → Apply environment-friendly herbicides, crop diversification; hand weeding.
- Socio-economic constraints of Moroccan farmers
  → Technology needs a long-term approach for full acceptance and implementation.

Weaknesses/ disadvantages/ risks: compiler's or other key resource person's view → how to overcome

- High level of management is required → Training of land users.
- Sensitive to nitrogen level management → Soil tests/apply N according
  to needs of crops under NTT.
- High disease and pest prevalence if crop residues are not well managed → Resistant varieties and early seeding of diverse crops.

How can they be sustained / enhanced? Controlled biomass exportation and grazing;
on-time seeding.

- Efficient use of soil water: increased infiltration, water loss reduced,
  increased water availability for plants

  How can they be sustained / enhanced? Fallowing, maintaining sufficient
  soil cover.
- Increased crop production and yield stability

  How can they be sustained / enhanced? Promote productive and
  pest-resistant crop varieties and early seeding in order to cover soils and
  protect them from rainfall impact.
- Improved land use and diversified cropping systems with higher yields
  than in conventional system

  How can they be sustained / enhanced? Refine the integrated crop management
  and pest control system.

- Reduced availability of straw (fodder) → Optimise crop/livestock integration: straw production under NTT is higher but farmers have to be convinced to remove only part it; use fodder crops in rotation.
- Unforeseen environmental risks: eg soil or ground water contamination
  with herbicides/phosphate → Training, video presentations etc.

REFERENCES

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Full description in the WOCAT database
https://qcat.wocat.net/en/wocat/technologies/view/technologies_1253/

Linked SLM data
Approaches: Applied research and knowledge transfer https://qcat.wocat.net/en/wocat/approaches/view/approaches_2355/

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Institution
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Project
- Book project: where the land is greener - Case Studies and Analysis of Soil and Water Conservation Initiatives Worldwide (where the land is greener)

No-till field day in Benahmed region. The sign says: Trial with barley, direct seeding

Applied research and knowledge transfer (Morocco)

DESCRIPTION

Innovative, cross-disciplinary community-based approach for development and transfer of no-till technology at the farm level.

Aims / objectives: After 15 years of on-station research at the National Institute of Agricultural Research (INRA), testing and evaluation of no-till technology (NTT) at farm level started in 1997 with three pilot farmers. Recently two new projects were established to promote the introduction and adoption of NTT, in collaboration with the regional council and extension service of the Ministry of Agriculture (MoA). Fourteen pilot farmers are now involved in NTT. The overall purpose is to promote no-till technology to restore soils, improve production, mitigate drought, increase wealth and strengthen farmers??? organisations. NTT has been shown to be socially, economically and ecologically adapted to the local conditions. The approach has three stages: (1) Initiation: this includes basic research, strategic research and applied research; (2) Consolidation: planning is followed by detailed evaluation of technology adoption on farmers' fields; (3) Maturity: this involves the acceptance/spread of NTT with an increased number of farmers in the future.

Methods: INRA carries out research, information dissemination, gives training to technicians and farmers, and provides both technical assistance and monitoring. The regional council was convinced by the technology and now financially supports research activities, drill manufacture and extension of NTT. It also facilitates contacts with decision makers and farmers, and carries out evaluations. MoA development and extension services provide financial support, advice, technical assistance, and logistical support to farmers: they help to make the drills available. NGOs are engaged in the development of local/regional networks and farmers associations, as well as in funding and providing incentives. Farmers themselves are involved in the implementation, evaluation and dissemination of NTT. Participation, cross-discipline and bottom-up planning are key elements of the approach. Methods for implementation include long-term community on-farm trials, on-site training and information exchange, participation of stakeholders, information dissemination tools, and multi-directional knowledge flow. These are supplemented by intensive measurement/monitoring schemes, establishment of local/regional networks and farmers' association creation. On-the-job training is also provided.

LOCATION

Location: Chaouia/Ouardigha, Morocco

Geo-reference of selected sites

- -7.606, 32.959

Initiation date: 1997

Year of termination: n.a.

Type of Approach

- ☐ traditional/ indigenous
- ☐ recent local initiative/ innovative
- ☑ project/ programme based

No-till field day in Benahmed region. The sign says: Trial with barley, direct seeding

Barley samples from on-farm plots at Khourigba, showing improved growth under no-till technology compared with conventional farming.

APPROACH AIMS AND ENABLING ENVIRONMENT

Main aims / objectives of the approach
The Approach focused mainly on SLM with other activities

- spread the no-till technology: thereby enhancing soil productivity and reducing susceptibility to land degradation. - develop the production of no-till drill machinery. - generally: to ameliorate the living conditions of rural people through enhancing expertise, capacities and knowledge of farmers in managing their soils and crops

The SLM Approach addressed the following problems: - previous absence of an integrated research and extension programme. - lack of technical options in a harsh and risky environment. - underlying problems of land degradation and drought periods

Conditions enabling the implementation of the Technology/ ies applied under the Approach

Conditions hindering the implementation of the Technology/ ies applied under the Approach
- **Social/ cultural/ religious norms and values**: Over-reliance on traditions in soil management; attitudes of farmers towards conventional tillage need challenging through information about alternatives. Treatment through the SLM Approach: Training, video conferences, travelling workshops, etc.
- **Availability/ access to financial resources and services**: Lack of specific funds, credit, loans for investment in new machinery Treatment through the SLM Approach: Prioritise funds for no-tillage development
- **Institutional setting**: Extension service are not well incorporated in the approach due to lack of knowledge/information on no-tillage Treatment through the SLM Approach: Special Training program; change of institutional thinking upon no-tillage systems
- **Legal framework (land tenure, land and water use rights)**: lack of SWC-relatedl laws Treatment through the SLM Approach: Recommendations on laws to cover SWC technologies. The existing land ownership, land use rights / water rights moderately hindered the approach implementation small size of field requires integration of farmers for using no-till drill and other equipment
- **Knowledge about SLM, access to technical support**: Lack of adapted machinery Treatment through the SLM Approach: Promotion of no-till drill industry in Morocco

PARTICIPATION AND ROLES OF STAKEHOLDERS INVOLVED

Stakeholders involved in the Approach and their roles

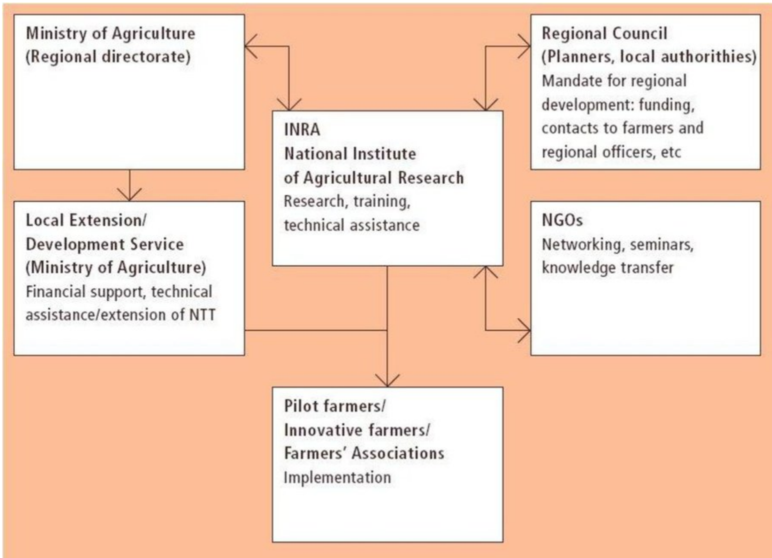
What stakeholders / implementing bodies were involved in the Approach?	Specify stakeholders	Describe roles of stakeholders
local land users/ local communities		
community-based organizations	Existing groups of land users	
SLM specialists/ agricultural advisers		
national government (planners, decision-makers)	INRA	

Involvement of local land users/ local communities in the different phases of the Approach

	none	passive	external support	interactive	self-mobilization	
initiation/ motivation		✓				Mainly:public meetings; partly: workshops/seminars; open days
planning			✓			Mainly: workshops/seminars; partly: public meetings
implementation			✓			Mainly: responsibility for minor steps; partly: casual labour
monitoring/ evaluation			✓			Mainly: interviews/questionnaires; partly: measurements/observations; field observations
Research				✓		on-farm; demonstration plots

Flow chart

Institutional framework: Stakeholders and their roles: cross-disciplinary linkages between INRA, collaborating institutions and farmers.



Decision-making on the selection of SLM Technology

Decisions were taken by
- ☐ land users alone (self-initiative)
- ☐ mainly land users, supported by SLM specialists
- ☐ all relevant actors, as part of a participatory approach
- ☑ mainly SLM specialists, following consultation with land users
- ☐ SLM specialists alone
- ☐ politicians/ leaders

Decisions were made based on
- ☐ evaluation of well-documented SLM knowledge (evidence-based decision-making)
- ☐ research findings
- ☐ personal experience and opinions (undocumented)

TECHNICAL SUPPORT, CAPACITY BUILDING, AND KNOWLEDGE MANAGEMENT

The following activities or services have been part of the approach
- ☑ Capacity building/ training
- ☑ Advisory service
- ☑ Institution strengthening (organizational development)
- ☑ Monitoring and evaluation
- ☑ Research

Capacity building/ training

Training was provided to the following stakeholders
- ☑ land users
- ☐ field staff/ advisers
- ☑ extensionists/trainers, politicians/decision makers, planners

Form of training
- ☑ on-the-job
- ☐ farmer-to-farmer
- ☑ demonstration areas
- ☑ public meetings
- ☐ courses

Subjects covered

no-tillage system, weed control, machinery, cropping systems, crop variety

Advisory service

Advisory service was provided
- ☑ on land users' fields
- ☐ at permanent centres

Key elements: Participation of extension agents and farmers / observations (on the crop, weeds, disease, seeding condition, yield components), On-job training / open days (field days to make farmers and extension discuss questions / remarks regarding no till technology, Monitoring/Participatory; 1) Advisory service was carried out through: government's existing extension system 2) Advisory service was carried out through: government's existing extension system; Extension staff: mainly government employees 3) Target groups for extension: land users; Activities: demonstration, field days, traveling workshops

Advisory service is inadequate to ensure the continuation of land conservation activities; Extension Agents need training

Institution strengthening

Institutions have been strengthened / established
- no
- yes, a little
- ✓ yes, moderately
- yes, greatly

at the following level
- ✓ local
- regional
- national

Describe institution, roles and responsibilities, members, etc.

Type of support
- ✓ financial
- ✓ capacity building/ training
- equipment

Further details

Monitoring and evaluation
Bio-physical aspects were regular monitored by 0 through measurements Technical aspects were regular monitored by 0 through measurements Socio-cultural aspects were ad hoc monitored by 0 through observations Economic / production aspects were regular monitored by 0 through measurements; Area treated aspects were ad hoc monitored by 0 through observations No. of land users involved aspects were regular monitored by 0 through measurements Management of Approach aspects were ad hoc monitored by 0 through observations; There were no changes in the Approach as a result of monitoring and evaluation: The evaluation is still in process: thus too early to state what changes are likely.

Research
Research treated the following topics
- ✓ sociology
- economics / marketing
- ecology
- ✓ technology
- ✓ agronomy

crop performance, soil analysis, no-till drill design and evaluation, socio-economic indexes of NTT.

Research was carried out both on station and on-farm

FINANCING AND EXTERNAL MATERIAL SUPPORT

Annual budget in USD for the SLM component
- < 2,000
- 2,000-10,000
- 10,000-100,000
- ✓ 100,000-1,000,000
- > 1,000,000

Precise annual budget: n.a.

Approach costs were met by the following donors: government (national - INRA/Ministry): 80.0%; local community / land user(s) (Regional Council): 20.0%

The following services or incentives have been provided to land users
- ✓ Financial/ material support provided to land users
- ✓ Subsidies for specific inputs
- ✓ Credit
- Other incentives or instruments

Financial/ material support provided to land users

	partly financed	fully financed
equipment: machinery		✓
agricultural: seeds		✓
agricultural: seeds: fertilizers		✓
biocides		✓

Labour by land users was
- ✓ voluntary
- food-for-work
- paid in cash
- rewarded with other material support

Credit

Conditions: repayment conditions: To promote the acceptance of the technology, farmers receive a 50% subsidy on the purchase price of the no-till drill (as is the general case for all types of drills)..
Credit providers: n.a.
Credit receivers: n.a.

IMPACT ANALYSIS AND CONCLUDING STATEMENTS

Impacts of the Approach

	No	Yes, little	Yes, moderately	Yes, greatly
Did the Approach help land users to implement and maintain SLM Technologies? Better use of the rainwater stored in the soil by crops leads to improvement of soil and water management: increase in soil organic matter has multiple benefits.			✓	

Did the Approach improve issues of land tenure/ user rights that hindered implementation of SLM Technologies?
The land is a private property and can not be affected by no-tillage but with no-tillage farmers can rent or buy new lands for adoption of more no-tillage.

Did other land users / projects adopt the Approach?
This no-till system can now be considered for several different agroecological situations where a similar approach can be applied (e.g. flood control project, agro-forestry program, soil restoration project, etc.).

Main motivation of land users to implement SLM
- [x] n.a.

Sustainability of Approach activities
Can the land users sustain what hat been implemented through the Approach (without external support)?
- [ ] no
- [x] yes
- [ ] uncertain

Progress can continue to be made, assuming that training, subsidised drills, and the creation of farmers' organisations all persist.

CONCLUSIONS AND LESSONS LEARNT

Strengths: land user's view
- Adaptability to farmers needs/constraints (How to sustain/ enhance this strength: Include integration of livestock and crops. This should be helpful to pursue in the approach)
- Farmer's decisions, opinions, critics (How to sustain/ enhance this strength: Bottom-up maintained (gradually))
- Incentives make it possible for land users to experiment with a new cultivation system (How to sustain/ enhance this strength: Diversification of incentives: eg reduction in seed prices and herbicides for NTT farmers; award - NTT best producers; reduction in interest rates for NTT farmers (for credits or loans); special NTT training courses.)

Strengths: compiler's or other key resource person's view
- The NTT project has integrated several institutions -which is unique in Morocco. Now research, extension, community and farmers are working together towards the same objective (How to sustain/ enhance this strength: Further develop, refine and spread NTT)
- NGOs development: the association of NTT farmers and environmental clubs are important for spreading NTT and for re-enforcing the importance of NTT amongst government officers and decision makers (How to sustain/ enhance this strength: special NGOs should be encouraged to respect soils, nature, environment)
- Cross-discipline: involving land users, research and extension agents has helped in building up an approach suitable for the local conditions. (How to sustain/ enhance this strength: The working teams received also incentives and recognictions)
- research connected to extension (How to sustain/ enhance this strength: research should be developed to get continuous measurements/information and to search new indexes and means)
- Progressive implementation of a 'bottom-up' approach; integration of farmers' decisions, opinions and criticisms (How to sustain/ enhance this strength: Farmers and their association are involved gradually in the approach and their critics, comments, feedbacks respected)

Weaknesses/ disadvantages/ risks: land user's view → how to overcome
- Information availability: up to now information and communication on NTT is scarce → intensify training of trainees
- In some situations (farmers with very low incomes), the need for external inputs such as herbicides, seeds, fertilizers and drills may retard implementation of NTT → Incentives should be maintained for a short period and supplemented by credit systems.

Weaknesses/ disadvantages/ risks: compiler's or other key resource person's view → how to overcome
- Direct incentives: there is always a risk that when eliminating these incentives, farmers will abandon NTT → Eliminate incentives gradually and replace with loans and credits.
- The programme's duration is currently too short to overcome resistance (to new technology adoption) and to address economic constraints of farmers → A long term programme is needed to increase acceptance among farmers.

REFERENCES

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Linked SLM data
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Morocco

Project

- Book project: where the land is greener - Case Studies and Analysis of Soil and Water Conservation Initiatives Worldwide (where the land is greener)

Key references

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-

Chipped branches (Spain)

DESCRIPTION

Chipped branch application on bare soil in order to prevent soil erosion, reduces overland flow, and increase the soil organic matter.

In a Persimmon crop area from Valencia (south-east Spain), the research team of the University of Valencia set up an experiment in order to test the effect of chipped branches lying on soil surface to avoid soil water erosion and improve soil properties.

Purpose of the Technology: The increase in ground cover will decrease soil erosion by reducing raindrop impact over the bare soil. Runoff amount also decrease by increasing water surface storage, decrease of runoff velocity, and increase infiltration. Its application must to be done after the pruning season and before Mediterranean high-storm events; namely end summer to early autumn, in order to protect raindrop impact and detached by bare

Establishment / maintenance activities and inputs: Chipped branches will be obtained after pruning and harvesting.

Natural / human environment: The persimmon production in the area has been implemented in recent dates due to the market prices. There has been a quick land use change from citrus orchards to persimmon orchards. The landscape reflects the long history of management where several constructions related with wine production depicted its importance on this region. Since the late 1960´s, chemical agriculture with use of fertilizers and herbicides, and new orchards plantations as Persimmon, lead to a seasonally bare soil surface, triggering huge erosion rates.

LOCATION

Location: Valencia, Spain, Spain

No. of Technology sites analysed:

Geo-reference of selected sites
- -0.6193, 38.95261

Spread of the Technology:

Date of implementation:

Type of introduction
- ☐ through land users' innovation
- ☐ as part of a traditional system (> 50 years)
- ☐ during experiments/ research
- ☐ through projects/ external interventions

CLASSIFICATION OF THE TECHNOLOGY

Main purpose

- [ ] improve production
- [x] reduce, prevent, restore land degradation
- [ ] conserve ecosystem
- [ ] protect a watershed/ downstream areas – in combination with other Technologies
- [ ] preserve/ improve biodiversity
- [ ] reduce risk of disasters
- [ ] adapt to climate change/ extremes and its impacts
- [ ] mitigate climate change and its impacts
- [ ] create beneficial economic impact
- [ ] create beneficial social impact

Land use

Cropland - Tree and shrub cropping
Main crops (cash and food crops): persimmon, citrus

Water supply

- [ ] rainfed
- [x] mixed rainfed-irrigated
- [ ] full irrigation

Number of growing seasons per year: 1
Land use before implementation of the Technology: n.a.
Livestock density: n.a.

Purpose related to land degradation

- [x] prevent land degradation
- [ ] reduce land degradation
- [ ] restore/ rehabilitate severely degraded land
- [ ] adapt to land degradation
- [ ] not applicable

Degradation addressed

soil erosion by water - Wt: loss of topsoil/ surface erosion

SLM group

- improved ground/ vegetation cover

SLM measures

agronomic measures - A1: Vegetation/ soil cover, A2: Organic matter/ soil fertility

vegetative measures - V1: Tree and shrub cover

management measures - M2: Change of management/ intensity level

TECHNICAL DRAWING

Technical specifications

Author: Artemio Cerdà, University of Valencia. Dept. of Geography
Chipped branches must be spread homogeneously in bare soil areas between trees lines in order to keep as much as possible the soil covered.

Location: Valencia. Spain

Date: 09/03/2015

Main technical functions: control of raindrop splash, control of dispersed runoff: retain / trap, improvement of ground cover, increase of surface roughness, increase in organic matter, sediment retention / trapping, sediment harvesting
Secondary technical functions: control of dispersed runoff: impede / retard, control of concentrated runoff: retain / trap, control of concentrated runoff: impede / retard, control of concentrated runoff: drain / divert, reduction of slope angle, reduction of slope length, improvement of surface structure (crusting, sealing), improvement of topsoil structure (compaction), improvement of subsoil structure (hardpan), stabilisation of soil (eg by tree roots against land slides), increase in nutrient availability (supply, recycling,…), increase of infiltration, increase / maintain water stored in soil, increase of groundwater level / recharge of groundwater, water harvesting / increase water supply, water spreading, improvement of water quality, buffering / filtering water, reduction in wind speed, increase of biomass (quantity), promotion of vegetation species and varieties (quality, eg palatable fodder), control of fires, reduction of dry material (fuel for wildfires), spatial arrangement and diversification of land use

Change of land use practices / intensity level: New practices must be implemented through the application on the chipped branches on bare soil areas.

ESTABLISHMENT AND MAINTENANCE: ACTIVITIES, INPUTS AND COSTS

Calculation of inputs and costs
- Costs are calculated:
- Currency used for cost calculation: **n.a.**
- Exchange rate (to USD): 1 USD = n.a
- Average wage cost of hired labour per day: n.a

Most important factors affecting the costs
n.a.

Establishment activities
n.a.

Maintenance activities
n.a.

NATURAL ENVIRONMENT

Average annual rainfall
- [ ] < 250 mm
- [x] 251-500 mm
- [x] 501-750 mm
- [ ] 751-1,000 mm
- [ ] 1,001-1,500 mm
- [ ] 1,501-2,000 mm
- [ ] 2,001-3,000 mm
- [ ] 3,001-4,000 mm
- [ ] > 4,000 mm

Agro-climatic zone
- [ ] humid
- [x] sub-humid
- [x] semi-arid
- [ ] arid

Specifications on climate
Mediterranean climate with concentred precipitation in february-may and september-december months. Drought from june to september
Thermal climate class: temperate (Transition zone between semiarid and subhumid)

Slope
- [ ] flat (0-2%)
- [x] gentle (3-5%)
- [ ] moderate (6-10%)
- [ ] rolling (11-15%)
- [ ] hilly (16-30%)
- [ ] steep (31-60%)
- [ ] very steep (>60%)

Landforms
- [x] plateau/plains
- [ ] ridges
- [ ] mountain slopes
- [ ] hill slopes
- [ ] footslopes
- [x] valley floors

Altitude
- [ ] 0-100 m a.s.l.
- [x] 101-500 m a.s.l.
- [ ] 501-1,000 m a.s.l.
- [ ] 1,001-1,500 m a.s.l.
- [ ] 1,501-2,000 m a.s.l.
- [ ] 2,001-2,500 m a.s.l.
- [ ] 2,501-3,000 m a.s.l.
- [ ] 3,001-4,000 m a.s.l.
- [ ] > 4,000 m a.s.l.

Technology is applied in
- [ ] convex situations
- [ ] concave situations
- [ ] not relevant

Soil depth
- [ ] very shallow (0-20 cm)
- [x] shallow (21-50 cm)
- [x] moderately deep (51-80 cm)
- [ ] deep (81-120 cm)
- [ ] very deep (> 120 cm)

Soil texture (topsoil)
- [ ] coarse/ light (sandy)
- [x] medium (loamy, silty)
- [ ] fine/ heavy (clay)

Soil texture (> 20 cm below surface)
- [ ] coarse/ light (sandy)
- [ ] medium (loamy, silty)
- [ ] fine/ heavy (clay)

Topsoil organic matter content
- [ ] high (>3%)
- [x] medium (1-3%)
- [ ] low (<1%)

Groundwater table
- [ ] on surface
- [ ] < 5 m
- [x] 5-50 m
- [ ] > 50 m

Availability of surface water
- [ ] excess
- [ ] good
- [ ] medium
- [x] poor/ none

Water quality (untreated)
- [ ] good drinking water
- [ ] poor drinking water (treatment required)
- [x] for agricultural use only (irrigation)
- [ ] unusable

Is salinity a problem?
- [ ] Yes
- [ ] No

Occurrence of flooding
- [ ] Yes
- [ ] No

Species diversity
- [ ] high
- [x] medium
- [ ] low

Habitat diversity
- [ ] high
- [ ] medium
- [ ] low

CHARACTERISTICS OF LAND USERS APPLYING THE TECHNOLOGY

Market orientation

Off-farm income

Relative level of wealth

Level of mechanization

- [ ] subsistence (self-supply)
- [ ] mixed (subsistence/ commercial
- [ ] commercial/ market

- [ ] less than 10% of all income
- [ ] 10-50% of all income
- [ ] > 50% of all income

- [ ] very poor
- [ ] poor
- [x] average
- [ ] rich
- [ ] very rich

- [ ] manual work
- [ ] animal traction
- [ ] mechanized/ motorized

Sedentary or nomadic
- [ ] Sedentary
- [ ] Semi-nomadic
- [ ] Nomadic

Individuals or groups
- [ ] individual/ household
- [ ] groups/ community
- [ ] cooperative
- [ ] employee (company, government)

Gender
- [ ] women
- [ ] men

Age
- [ ] children
- [ ] youth
- [ ] middle-aged
- [ ] elderly

Area used per household
- [x] < 0.5 ha
- [x] 0.5-1 ha
- [ ] 1-2 ha
- [ ] 2-5 ha
- [ ] 5-15 ha
- [ ] 15-50 ha
- [ ] 50-100 ha
- [ ] 100-500 ha
- [ ] 500-1,000 ha
- [ ] 1,000-10,000 ha
- [ ] > 10,000 ha

Scale
- [ ] small-scale
- [ ] medium-scale
- [ ] large-scale

Land ownership
- [ ] state
- [ ] company
- [ ] communal/ village
- [ ] group
- [ ] individual, not titled
- [ ] individual, titled

Land use rights
- [ ] open access (unorganized)
- [ ] communal (organized)
- [ ] leased
- [ ] individual

Water use rights
- [ ] open access (unorganized)
- [ ] communal (organized)
- [ ] leased
- [ ] individual

Access to services and infrastructure

		1	2	3	
health	poor		✓		good
education	poor			✓	good
technical assistance	poor		✓		good
employment (e.g. off-farm)	poor		✓		good
markets	poor		✓		good
energy	poor		✓		good
roads and transport	poor			✓	good
drinking water and sanitation	poor			✓	good
financial services	poor		✓		good

IMPACTS

Socio-economic impacts

Socio-cultural impacts

		1	2	3	4	5	6	7	
SLM/ land degradation knowledge	reduced					✓			improved

Ecological impacts

		1	2	3	4	5	6	7	
surface runoff	increased					✓			decreased
soil moisture	decreased					✓			increased
soil cover	reduced					✓			improved
soil loss	increased						✓		decreased
soil crusting/ sealing	increased				✓				reduced
soil compaction	increased				✓				reduced
soil organic matter/ below ground C	decreased				✓				increased

Off-site impacts

		1	2	3	4	5	6	7	
downstream flooding (undesired)	increased				✓				reduced
downstream siltation	increased				✓				decreased
wind transported sediments	increased				✓				reduced

COST-BENEFIT ANALYSIS

Benefits compared with establishment costs

Benefits compared with maintenance costs

CLIMATE CHANGE

Gradual climate change

		1	2	3	4	5		
annual temperature increase	not well at all						very well	Answer: not known

Climate-related extremes (disasters)

		1	2	3	4	5		
local rainstorm	not well at all				✓		very well	
local windstorm	not well at all						very well	Answer: not known
drought	not well at all		✓				very well	
general (river) flood	not well at all						very well	Answer: not known

Other climate-related consequences
reduced growing period — not well at all / very well — Answer: not known

ADOPTION AND ADAPTATION

Percentage of land users in the area who have adopted the Technology
- single cases/ experimental
- 1-10%
- 10-50%
- more than 50%

Of all those who have adopted the Technology, how many have done so without receiving material incentives?
- 0-10%
- 10-50%
- 50-90%
- 90-100%

Has the Technology been modified recently to adapt to changing conditions?
- Yes
- No

To which changing conditions?
- climatic change/ extremes
- changing markets
- labour availability (e.g. due to migration)

CONCLUSIONS AND LESSONS LEARNT

Strengths: land user's view
- Use of the chipped branches as a treatment to cover soil and decrease erosion. It also keep higher soil moisture levels.

Strengths: compiler's or other key resource person's view
- It is a technology very easy to apply, with low failure possibilities and a strong soil erosion control and local soil properties improvement.
- It will prevent sediment movement and accumulation over roads and down slope properties and values at risk.

Weaknesses/ disadvantages/ risks: land user's viewhow to overcome
- The use of specific machinery to produce chipped branches.

Weaknesses/ disadvantages/ risks: compiler's or other key resource person's viewhow to overcome
- A low application rate must be enough to decrease erosion. Testing different application rates to decrease soil-water erosion.

REFERENCES

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Editors

Reviewer
Fabian Ottiger
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Full description in the WOCAT database
https://qcat.wocat.net/en/wocat/technologies/view/technologies_1269/

Linked SLM data
n.a.

Documentation was faciliated by

Institution
- Universidad de Valencia (Universidad de Valencia) - Spain

Project
- n.a.

Fact Sheet for Restoration Action for Practitioners

Relevant categories and questions have been selected from the WOCAT questionnaire to categorize the restoration action.

Target audience: practitioners (farmers, farm owners, farm advisers)

Purpose: Inform practitioners on context, implementation details and benefits of implementation

<u>Remarks on filling in the questionnaire:</u>

1) *Regarding multiple choice questions (tick boxes ❑),* ***delete any answers that does not fit your restoration action.***
   e.g.
   Is/ are the technology site(s) located in a permanently protected area?
   ❑ Yes ❑ No
   If No is true, delete <u>all</u> unsuitable answers, *in the above case ❑ Yes*

2) *When you completed an answer,* ***delete the directions in red and italics***.

3) ***Delete all Q&As that do not apply*** *to your restoration action.*

1. Description of restoration action

1.1 Name of restoration action:

1.2 Contact details of person involved in assessment and documentation:

Name: Rachid Moussadek & Fatiha Bentata

Work address: INRA/ICARDA Rabat

E-Mail: rachidmoussadek@yahoo.fr; fatiha.bentata@inra.ma

1.3 Description of restoration action (short):

Current climatic conditions in Morocco influence the management of water and soil fertility in agriculture and are increasingly significant for lands undergoing degradation or degraded. Hence the interest in the extension of direct seeding through the national agricultural program Green Generation 2020-2030.

1.4 Description of restoration action (detailed):

This extension aims to improve crop productivity and the quality of natural resources.

it requires:

- regular and sustainable monitoring with farmers
- delimitations using location tools (e.g., GPS)
- equipment for rapid analysis of soil and crop productivity
- Adapted direct seeding equipment
- training initiated by institutions such as INRA, ICARDA and agricultural offices

In Morocco, the development of direct seeding has become more established in the regions of Zaer, Gharb, Saiss and Chaouia. Several research studies by Moroccan experts have already highlighted the interest of this system at this stage and are proof of the reliability of this extension.

the benefits of this technique:

- increase in farmer's profits (Social, economic and environment)
- improvement of the quality of natural resources and productivity.
- sustainability of soil biological activity
- Time saving and work efficiency

the main limitation is to find an effective solution relating to crop residues as soil cover to align livestock breeding with the direct seeding system.

1.5 Country/ region/ locations where the Technology has been applied and which are covered by this assessment

Country: ....Morocco................. Region/ State/Province: ....Zaer...

Further specification of location (e.g. municipality, town, etc.), if relevant: ....

Number of sites considered/ analysed in the documentation of this Technology:

	Single site	x	**2-10 sites**		10-100 sites
	100-1,000 sites		>1,000 sites		

Specify the spread of the Technology:

❑ evenly spread over an area

If the Technology is evenly spread over an area, specify area covered (in km²): It is for reaching 1 Million hectares in Morocco and 200.000 in the region by 2030.

(1 ha = 10'000m²; 1 km² = 100 ha)

Is/ are the technology site(s) located in a permanently protected area?

❑ Yes ❑ No

1.6 Date of implementation

Indicate year of implementation:

If precise year is not known, indicate approximate date:

❑ less than 10 years ago (recent) ❑ 10-50 years ago

1.7 Introduction of the Technology

Specify how the Technology was introduced. Several answers possible.

	indicate with x	
as part of a traditional system		Comments (type of project, etc.) The national strategy 'Green Generation 2020 -2030' program includes a roadmap for the relevant development of direct seeding through a set of conventions.
through recent land users' innovation	x	
during experiments/ research	x	
through projects/ external interventions	x	
other (specify): … to replace the conventional tillage system	x	

1.8 Photos of the Technology

Provide photos showing an overview and details of the Technology.

photo	Caption, explanation of photo	Date	Location	Name of photographer
	Photo of Direct seeding operation in Zaer Region	Dec.2022	Zaer region	Rachid Moussadek
	Photo of crop diversification to promote agroecology	Feb.2023	Brachouia site	Rachid Moussadek

2 Classification of the SLM Technology

2.1 Main purpose(s) of the Technology

- ❑ improve production (crop, fodder, wood/ fibre, water, energy)
- ❑ prevent (avoid) or reduce land degradation; restore/rehabilitate land (reverse land degradation) (soil, water, vegetation)
- ❑ preserve/ improve biodiversity
- ❑ create beneficial economic impact (e.g. increase income/ employment opportunities)
- ❑ adapt to climate change/ extremes and its impacts (e.g. resilience to droughts, storms)

2.1 Water supply

Water supply for the land on which the Technology is applied:

❑ rainfed

Comments: In Morocco agriculture is relied mainly on rainwater

for a long time

2.2 SLM group to which the Technology belongs

Assign the described Technology to one of the following SLM groups (see explanations below). If this is not possible, select several (max. 3) groups to represent the Technology:

❑ area closure (stop use, support restoration)
❑ rotational system (crop rotation, fallows, shifting cultivation)
❑ minimal soil disturbance
❑ integrated soil fertility management
❑ improved plant varieties/ animal breeds
❑ irrigation management (incl. water supply, drainage)
❑ groundwater management
❑ waste management/ waste water management
❑ energy efficiency

2.3 SLM measures comprising the Technology

Select SLM measure	Select one or more subcategories/ codes (see definitions below), and fill in the specifications where required
❑ agronomic measures	……Area closure, rotational system, minimal soil disturbance ………… Subcategories: A1 to A6………………………..
❑ vegetative measures	……Rotational system, improved plant varieties/ animal breeds, …… Subcategories: S7, S8 and S10 ……………………………..
❑ structural measures	………… Integrated soil fertility management, waste management/ waste water management, improved plant varieties/ animal breeds, … Subcategories: M1 to M6…………………………..

❑ management measures ………… integrated soil fertility management, improved plant varieties/ animal breeds, irrigation management, groundwater management, waste management/ waste water management ……………..……………………….

Specify tillage system (if relevant):

❑ no tillage

Specify residue management (if relevant): ❑ retained

Comments/ remarks: grazing is one of the limits, especially for farmers combining agriculture and livestock. the national direct seeding program aims to find plausible solutions to satisfy these two sides......

Subcategories:

Type of measure	Subcategories	Examples
Agronomic measures • are usually associated with annual crops • are repeated routinely each season or in a rotational sequence • are of short duration and not permanent • do not lead to changes in slope profile • are normally independent of slope	A1: Vegetation soil cover A2: Organic matter/soil fertility A3: Soil surface treatment A4: Subsurface treatment A5: Seed management, improved varieties A6: Residue management A7: Others	A1: Mixed cropping, intercropping, relay cropping, cover cropping A2: Conservation agriculture, production and application of compost/ manure, mulching, trash lines, green manure, crop rotation A3: Zero tillage (no-till), minimum tillage, contour tillage Differentiate tillage systems: No tillage, reduced tillage (>30% soil cover), full tillage (<30% soil cover) A4: Breaking compacted subsoil (hard pans), deep ripping, double digging A5: Production of seeds and seedlings, seed selection, seed banks, development/ production of improved varieties A6: Specification required: burned, grazed, collected, retained
Vegetative measures • involve the use of perennial • grasses, shrubs, or trees are of long duration • often lead to a change in slope profile • are often aligned along the contour or against the prevailing wind direction • are often spaced according to slope	S1: Terraces S2: Bunds, banks S3: graded ditches, channels, waterways S4: Level ditches, pits S5: Dams, pans, ponds, S6: Walls, barriers, palisades, fences S7: Water harvesting/ supply/ irrigation equipment S8: Sanitation/ waste water structures S9: Shelters for plants and animals S10: Energy saving measures	S1: Bench terraces (slope of terrace bed <6%); Forward sloping terraces (slope of terrace bed >6%) S2: Earth bunds, stone bunds (along the contour or graded), semi-circular bunds ("demi-lunes") S3: Diversion/ drainage ditch, waterways to drain and convey water S4: Retention / infiltration ditches, planting holes, microcatchments S5: Dams for flood control, dams for irrigation, sand dams S6: Sand dune stabilization, rotational grazing(using fences), area closure, gully plugs (check dams) S7: Rooftop water harvesting, water intakes, pipes, tanks, etc. S8: Compost toilet, septic tanks, constructed treatment wetlands S9: Greenhouses, stables, shelters for plant nurseries S10: Wood-saving stoves, insulation of buildings, renewable

	S11: others	energy sources (solar, biogas, wind, hydropower) S11: Compost production pits; reshaping of surface (slope reduction)
Management measures • Involve a fundamental change in land use • Usually involve no agronomic and structural measure • Often result in improved vegetative cover • Often reduce the intensity of use	M1: Change in land use type M2: change in management/ intensity level M3: Layout according to natural and human environment M4: Major change in timing of activities M5: Control/ change in species composition (if annually or in a rotational sequence as done e.g. on cropland → A1) M6: Waste management M7: others	M1: Area closure/ resting, protection, change from cropland to grazing land, from forest to agroforestry, afforestation M2: Change from grazing to cutting (for stall feeding), farm enterprise selection (degree of mechanization, inputs, commercialization), vegetable production in greenhouses, irrigation; from monocropping to rotational cropping; from continuous cropping to managed fallow; from open access to controlled access (grazing land, forests); from herding to fencing, adjusting stocking rates, rotational grazing M3: Exclusion of natural waterways and hazardous areas, separation of grazing types, distribution of water points, salt licks, livestock pens, dips (grazing land); increase in landscape diversity, forest aisle M4: Land preparation, planting, cutting of vegetation M5: Reduction of invasive species, selective clearing, encouragement of desired/ introduction of new species, controlled burning (e.g. prescribed fires in forests/ on grazing land)/ residue burning M6: Includes both artificial and natural methods for waste Management
other measures • comprise any measures that do not fit into the above categories		Beekeeping, small stock farming (e.g. poultry, rabbits), fish ponds; food storage and processing (including post-harvest loss reduction)
Combinations: • Occur where different measures complement each other and thus enhance each other's effectiveness • May comprise any two or more of the above measures		Terrace (S1) + Grass strips and trees along riser (V2, V1) + Contour tillage (A3) Zero grazing/ stall feeding (M2) + Construction of stables and fence (S10) + Compost/ manure production pits (S12) + Application of manure and compost on cropland (A2)

2.4 Prevention, reduction, or restoration of land degradation

Specify the goal of the Technology with regard to land degradation:

❑ to reduce land degradation

❑ to restore/ rehabilitate severely degraded land / reverse land degradation

Comments/ remarks:

Research carried out at the INRA/ICARDA's station at Marchouch zone (Zaer region) after more than 20 years of direct seeding in a semi-arid zone has approved the conservation of the environment in all its characteristics over the years. They also show ecological and economic profitability and leave room for the development of biological activity without being disturbed.

3 Natural environment

Give details of the natural (biophysical) conditions where the Technology is applied. Make specific reference to the sites where the documented Technology has been assessed and analysed. Use comment sections to specify your answers and provide additional information.

Note: Some of the environmental conditions (e.g. slope angle, soil characteristics, water quality/ availability, etc.) may change as a result of the Technology. However, **you are requested to describe the conditions as they were without any impact of sustainable land management**. In exceptional cases, certain questions might not be relevant for the Technology. In such cases, skip the question but use the comment sections to explain why you are skipping it. Use the definitions given in this document, even if they deviate from your own/ national definitions (e.g. slope, soil depth, etc.).

The Zaer region is characterized by a Mediterranean location with an arid to semi-arid annotation. it is an area currently impacted by unstable temperature and precipitation. The environments currently concerned by the study are mostly characterized by clayey soils. This area includes one of the oldest INRA/ICARDA stations under direct seeding at which the positive interest of direct seeding for the sustainability of biological activity was raised, notably the development of soil glasses, fungus etc. It should be noted that the objectivity is also to be able to adapt direct seeding to several types of soil.

3.1 Climate

Tick no more than two answers per question.

Annual rainfall

❑ < 250 mm
❑ 251-500 mm

[1]Agro-climatic zone

❑ semi-arid
❑ arid

[1]Agro-climatic zone
Humid: length of growing period (LGP) > 270 days
Sub-humid: LGP 180-269 days
Semi-arid: LGP 75-179 days
Arid: LGP < 74 days

Length of growing period (LGP) is defined as the period during which precipitation is more than half the potential evapotranspiration (PET) and the temperature is higher than 6.5° C.

Specify average annual rainfall (if known): .... mm

Specifications/ comments on rainfall distribution, seasonality (e.g. monsoon, winter/ summer rains), number/ length/ months of rainy seasons, occurrence of heavy rains, length of dry periods:

.........................Unstable precipitations..

....

Indicate the name of the reference meteorological station considered:

.........................INRA's Station..

....

Specifications/ comments on climate (e.g. mean annual temperature): ......

.... Unstable and disturbing climate during this past five years ....

....

3.2 Topography

Tick no more than two answers per question.

Slopes on average[1]

❑ moderate (6-10%)

Landforms[2]

❑ plateau/ plains

Altitudinal zone (in m a.s.l.)

❑ 101-500

Indicate if the Technology is specifically applied in ❑ concave situations (depression – conversion of water flow)

Comments and further specifications on toporaphy (e.g. exact altitude and slope angles of the evluated sites):

The territory of Zaer is made up of **a plateau**, known as the "zaer plateau". It is watered by the Bouregreg river and its tributary the Grou river; These rivers make the Zaer as an areas suitable for cereals. But in some slopy zones, soil erosion needs to be controlled through adoption of anti-erosion practices.

3.3 Soils

The following parameters are based on FAO standards. Tick no more than two answers per question.

Soil depth on average[1]

❑ moderately deep (51-80 cm)

❑ deep (81-120 cm)

Soil texture (topsoil)

❑ fine/ heavy (clay)

Soil texture (> 20 cm below surface)

❑ fine/ heavy (clay)

Topsoil organic matter

❑ medium (1-3%)

If available, attach full soil description or specify the available information, e.g. soil type, soil PH/ acidity, Cation Exchange Capacity, nitrogen, salinity etc.:

The soil is a vertisol with possible external drainage, hydromorphic (Aquic Chromoxerert).

pH(Water)	pH(KCl 1 N)	OM (%)	P_2O_5(ppm)	K_2O(ppm)	EC(mS/Cm)
7.5	6.5	2.2	30.0	265.1	0.2

[1] ***Soil depth on average**: Distance from top to parent material. 2 m*

3.4 Water availability and quality

One answer per question.

Availability of surface water

❑ poor/ none

Water quality (untreated)

❑ for agricultural use only

Water quality refers to: ❑ both ground and surface water

Is water salinity a problem? ❑ Yes ❑ No

Does flooding of the area occur? ❑ Yes ❑ No

3.5 Biodiversity

Indicate the state of biodiversity in the analysed sites relative to your region/ country standards. One answer per question.

Species diversity[1]	**Habitat diversity**[2]
❑ medium	❑ medium

Comments and further specifications on biodiversity:

The direct seeding strategic plan brings together habitat, agricultural productivity and sustainability of resources by ensuring conservative soils in the long term.

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Policies can help to apply successful strategies to control soil and water losses. The case of chipped pruned branches (CPB) in Mediterranean citrus plantations

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ABSTRACT

There is a need to devise management strategies that control soil and water losses in agriculture land to allow the design of proper policies to achieve sustainability. It is the responsibility of scientists to work with other actors to co-construct strategies that will lead to sustainable land-use policies. Using chipped pruned branches (CPB) as mulch can be a viable option because they represent local (in situ) organic material that can restore soil nutrients and organic matter. This research assesses: i) the perception of farmers towards different types of management strategies and CPB's costs; ii) the biomass yield of citrus branches and the impact of CPB on soil properties; iii) how CPB affects soil erosion and runoff generation in citrus plantations; and, iv) a discussion about how to favour the use of CPB thought successful policies. To achieve those goals we carried out: i) one-hundred interviews to assess the perception of farmers and twelve interviews to assess the economic balance of twelve land owners; ii) soil was sampled at 0–2 and 4–6 cm depths; iii) pruned material was surveyed for 40 trees; and iv) forty rainfall simulation experiments (55 mm h^{-1}) were carried out in two citrus plantations at paired sites (Control versus CPB), in La Costera District in Eastern Spain. Forty circular (0.25 m^2) plots were installed in four rows (4 × 5 = 20 plots) in control (CON) and CPB plots (20 + 20 = 40 plots) to perform the rainfall simulations over one hour. The cost of chipping ranged from 102 to 253 € ha^{-1}, and was related to the size of the farm. The soil quality, runoff and erosion assessment showed that CPB is a suitable strategy. CPB increased organic matter from 1.3% to 2.9% after 10 years in the 0–2 cm depth layer, while the 4–6 cm layer was largely not affected (OM moved from 1.1 to 1.3% after 10 years), and soil bulk density showed a similar trend: a decrease from 1.36 to 1.16 g cm^{-3} in the surface layer with no change in the subsurface layer. The hydrological and erosional responses were different between CON and CPB. The CON plots initiated ponding (40 s) and runoff (107 s) earlier than the CPB plots (169 and 254 s, respectively); and runoff discharge was 60% in CON vs 43% in CPB plots. Sediment concentration was four times larger in the CON plots than in the CPB (11.3 g l^{-1} vs 3 g l^{-1}), and soil erosion was 3.8 Mg ha^{-1} h^{-1} vs 0.7 Mg ha^{-1} h^{-1}. CPB mulches were effective at controlling soil and water losses in Mediterranean citrus plantations as they showed the relationship between vegetation/litter cover and soil erosion rates. However, the farmer's perception survey showed that the use of CPB was not welcomed nor accepted by the farmers. Policies that aim to promote CPB as soil conservation mulch need to be promoted by

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subsidies as the farmers requested, and by education to demonstrate the positive effects of CPB to of the farming community.

1. Introduction

Preserving soil is essential for sustainability, it provides vital functions. Soils produce food, biomass and raw materials, provide a habitat for flora and fauna, gene pools, sequester carbon, and manage water, minerals and biologic cycles. Climate change, desertification, and lack of water resources or food supply can be eventually successfully addressed only if soil sustainability issues are solved. The United Nations and European Union have highlighted soil protection as a key land-use policy issue (van Meijl et al., 2006; Keesstra et al., 2016a; Paleari, 2017). There is a need to design proper policies to achieve sustainability, and for this, the scientific community should produce information in collaboration with land managers and other actors, which will guide policy makers to implement the most efficient managements and strategies. Land degradation processes are a consequence of human misuse and mismanagement of natural resources due to economic activities that result in overgrazing (Gutiérrez et al., 2011; Schnabel et al., 2013), excessive tillage (Biddoccu et al., 2016; Novara et al., 2011), forest disturbances (Keesstra et al., 2016c; Navalho et al., 2017), high sediment yield due to mining (Brown et al., 2014) or as a consequence of the construction of road and road embankments (Jordán and Martínez-Zavala, 2008; Jordán et al., 2009) and abuse of herbicides (Taguas et al., 2015).

Soil erosion is a major threat to sustainability due to the immediate damage it causes to the soil system (Rodrigo-Comino and Cerdà, 2018). Many agricultural areas are highly prone to soil erosion due to the lack of vegetation cover, intense tillage, soil compaction due to heavy traffic and the use of biocides that reduce biologic activity such as plant growth; consequently soil forming processes can be impeded (Brevik et al., 2002; Brevik and Fenton, 2012). Non-suitable land management strategies and actions threaten the sustainable use of agricultural soils (Mhazo et al., 2016; Salomé et al., 2016) damaging soil quality (Bogunović et al., 2016; Khaledian et al., 2016). The impact of millennia old tillage on soils has reduced soil organic matter and aggregate stability in many regions worldwide (Rodrigo-Comino et al., 2018). Tillage has produced a long-term increase in soil bulk density, although each ploughing cycle reduces soil compaction temporally and removes the soil crust to induce higher infiltration rates (Rodrigo-Comino et al., 2016a; Rodrigo-Comino et al., 2017a). The use of herbicides and tillage result in a similar trend without any positive feedback and, as a result, soil degradation is faster with higher erosion rates (Cerdà et al., 2017a). Moreover, herbicides lead to the progressive compaction of soil due to the lack of tillage and organic matter, and therefore increase runoff rates and sediment yield (García-Díaz et al., 2017). Some researchers have already highlighted this impact of herbicide use, which makes agricultural land highly vulnerable to degradation (Keesstra et al., 2016b), and also it is relevant the impact of the plantation works (Rodrigo-Comino et al., 2017b).

The need to develop new sustainable management practices in agriculture is widely accepted (Araya et al., 2010; Marques et al., 2015; Mekonnen et al., 2015; Sastre et al., 2016; Cerdà et al., 2017b). However, there are three key points that need to be prioritized: i) the construction of new strategies in collaboration with farmers and policy-makers to achieve sustainability; ii) the acceptance of these new strategies by farmers; and, iii) development of policies that will make the new strategies suitable for farmers. The importance of well-designed and implemented policies for sustainable land management is well accepted in both agricultural and forest ecosystems (Muñoz-Rojas et al., 2015).

Citrus plantations in Spain were originally located in the bottoms of valleys, on fluvial terraces and deltas where flood irrigation is possible. During the last century there was an expansion of Mediterranean citrus plantations due to market growth in Northern Europe and technical and energy production improvements that allowed water to be pumped to higher altitudes, first by steam power (1860s) and later by electricity (1930s). Over the last 30 years, the expansion of citrus plantations reached ever-higher terrain as a result of the introduction of drip irrigation, which allows irrigation on sloping landscapes. This resulted in a new agricultural system where unsustainable soil erosion rates are taking place due to intensive ploughing and the excessive use of herbicides (Cerdà et al., 2009). This is not a unique or special situation; it has also been found with other crops such as persimmon (Cerdà et al., 2016), apricot (Keesstra et al., 2016c) olive (Gómez et al., 2014; Taguas et al., 2015), vineyards (Rodrigo-Comino et al., 2016b), and avocado (Bravo-Espinosa et al., 2014) plantations. This clearly shows that there is a need to develop sustainable management strategies to avoid high soil losses in several types of crops. The most effective option known to date is to use local materials such as rock fragments, living ground cover (Zhang and Chen, 2017), or pruned branches. Pruned branches need to be chipped to produce proper mulch that covers the soil and allows machinery and people in the orchards to move around. Chipping also accelerates decomposition of the branches which contributes to soil fertility and biomass turnover and helps to create a mulch (CPB) that protects the soil from the impact of raindrops, supplies organic matter, and increases biological activity (Walmsley and Cerdà, 2017). Our hypothesis is that CPB soil cover affects soil quality over the long-term following decomposition, therefore inducing an improvement of the soil through the addition of organic matter, which also improves soil hydraulic conductivity and reduces runoff and sediment delivery (Saxton and Rawls, 2006). Furthermore, it leads to an immediate reduction in soil erosion because the use of mulches (Prosdocimi et al., 2016a) also contributes to improved soil quality over a longer time span (Barreiro et al., 2016; Parras-Alcántara et al., 2016; Masvaya et al., 2017).

Therefore, the aim of this research was to assess the effects of chipped pruned branches on soil and water losses after a decade of CPB cover in citrus orchards. This paper evaluates the use of CPB as a mulch to control soil and water losses based on a paired-plot sampling strategy, and considers the perception of farmers in the area in order to find the right strategy to implement policies for agricultural land that are sustainable from a biophysical, social and economic point of view. Mediterranean type ecosystems are characterized by contrasting climate seasons, sloping terrain, and a millennia old human use and abuse that triggers soil erosion rates that must be reduced to achieve sustainability, and chipped pruned branches can be a suitable and sustainable strategy.

2. Material and methods

2.1. Study area

The Soil Erosion and Degradation Research Group (SEDER) at the Universidad de Valencia (Spain) established the Montesa Experimental Station in 2005. The Montesa Station is located in the southwest part of Valencia province in Eastern Spain (altitude 200 m.a.s.l), within La Costera district. This research station is devoted to studying the impact of citrus plantations on soil degradation and restoration, and is composed of six 300 m^2 soil erosion plots, a meteorological station and sampling fields to determine the impact of agricultural management on soil erosion, runoff generation, soil degradation, soil quality and crop production. Mean annual rainfall and temperature are 550 mm and 15.5 °C, respectively. The soils are classified as Xerorthents (Soil Survey Staff, 2014) with an average grain size distribution of 30% clay, 33% silt, and 34% sand with 4.3% gravel content. The field used in this study is located in the "Camí del Riu" within the municipality of Montesa, an area where parent material is colluvium coming from the nearby Limestones, and with an average slope of 2% as the land was levelled to allow flood irrigation in the 1940′s, although for the last twenty years the irrigation has been performed through dripping.

Two paired-neighbouring plots with a total area of 5000 m^2 were selected, both of them planted with citrus (Ortanique variety 25 year-old trees, see Fig. 1). The planting pattern is a 5 × 4 m grid. Herbicide treatments (Glyphosate (N-(phosphonomethyl glycine) are applied 4 times per year and the fields are chemically fertilized with 0.8 Mg ha^{-1} yr^{-1} of NPK 15% applied in parallel with the drip irrigation. Farmers maintain the field bare of plant cover the whole year to avoid any herbaceous competition for the crop, and also because the tradition in this area is to plough as a widespread strategy to control weeds. Keeping the soil free of weeds is important for the local reputation of the farmers, as rainfed crops were widespread until 1990.

2.2. Soil sampling points

In July 2013, twenty control (CON) plots and twenty chipped pruned branches (CPB) points were established along eight rows, each row with five sampling points (every 5 meters) for the CON and CPB plots (see Fig. 2). The CON plot used conventional (chemical) farming practices to manage the trees, with the pruned branches being transported out of the plot and burned. Since 2003, the pruned branches were chipped and spread in the rows between trees such that they covered the soil surface in the CPB plots. Pruning was done yearly in April. At each sampling plot, soil and water losses were measured with a rainfall simulator and a sample was collected to determine soil water content (SWC), bulk density (BK), organic matter and grain size with a 100 cm^3 cylinder. The soil samples were collected from 0 to 2 and 4 to 6 cm depths. Vegetation cover was determined as the percentage of soil covered by plants using a 1 cm^2 grid. Soil organic matter (SOM) was determined using the Walkley and Black (1934) methodology, and soil moisture was measured after drying the samples for 24 h at 105 °C.

2.3. Farmer perception survey and economic cost calculation

A survey was conducted to evaluate farmers' perception of soil management in the region. The survey was designed to gain insights into their perception of the use of herbicides, tillage, cash crops, weeds, geotextiles, grass strips, rock fragment mulch, modern terraces, straw and branch mulches. One-hundred farmers responded to six questions: i) is this strategy financially viable?; ii) is it an efficient way to reduce soil losses?; iii) is it easy to apply?; iv) should it be subsidised?; v) is it socially accepted?; and, vi) does it add value to the land? The data obtained are shown in Table 1, where the positive responses are given as a percentage of the total number of famers interviewed. The cost of the individual management practices was then calculated (Table 1) for both chipped branches and burned branches after asking twelve farmers for input cost information. The twelve farmers were selected to provide representation from the various sizes of farms that were surveyed, as this information is relevant to understand management costs per ha and if those costs are different for different sized farms. The twelve farmers represented the small (< 3 ha), medium (3–10) and large (> 10 ha) farms that were surveyed.

2.4. Rainfall simulation experiments

Plant, litter and rock fragment covers were determined prior to the rainfall simulation experiments by measuring their presence (1) or absence (0) at 100 regularly distributed points in each 0.25 m^2 plot. Forty rainfall simulation experiments (4 rows × 5 plots × 2 managements) were carried out at 55 mm h^{-1} rainfall intensity for one hour on circular paired plots (0.55 m in diameter, 0.25 m^2). Natural rainfall events with intensities of 55 mm h^{-1} have a return period of 5 years in this area (Elías Castillo and Ruiz Beltrán, 1979). In order to overcome the effects of inter-annual variability in soil moisture and allow

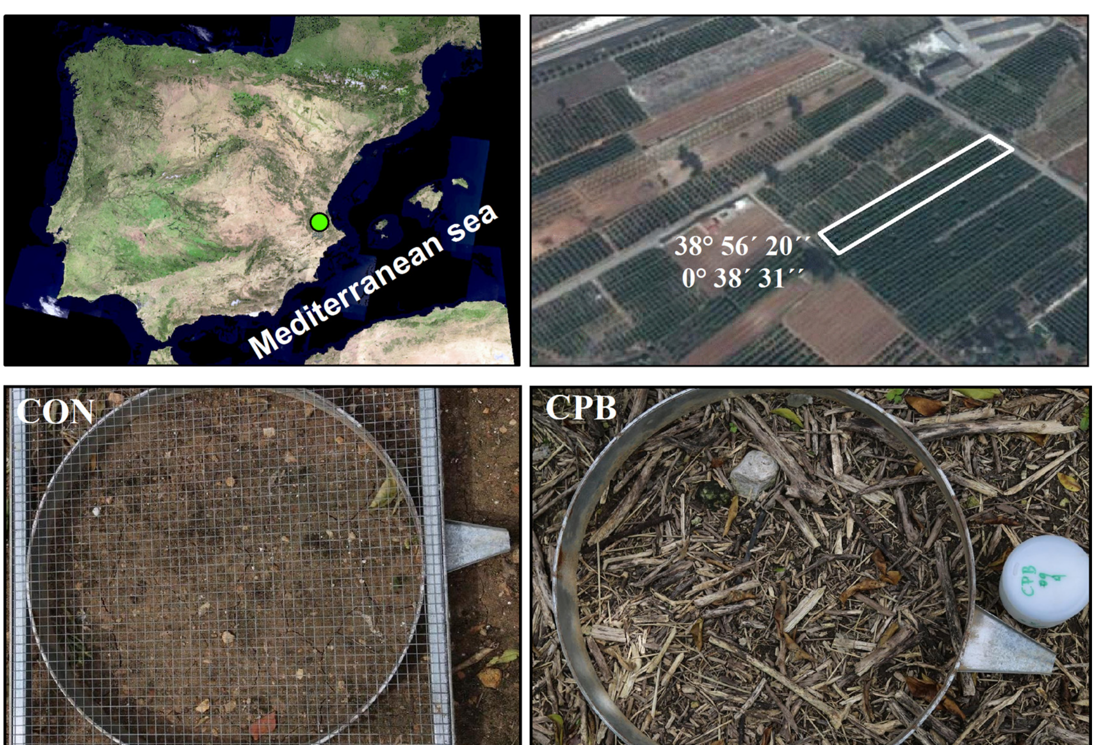

Fig. 1. Study area and example of the type of covers. CON: Control plots; CPB: Chipped pruned branches plots.

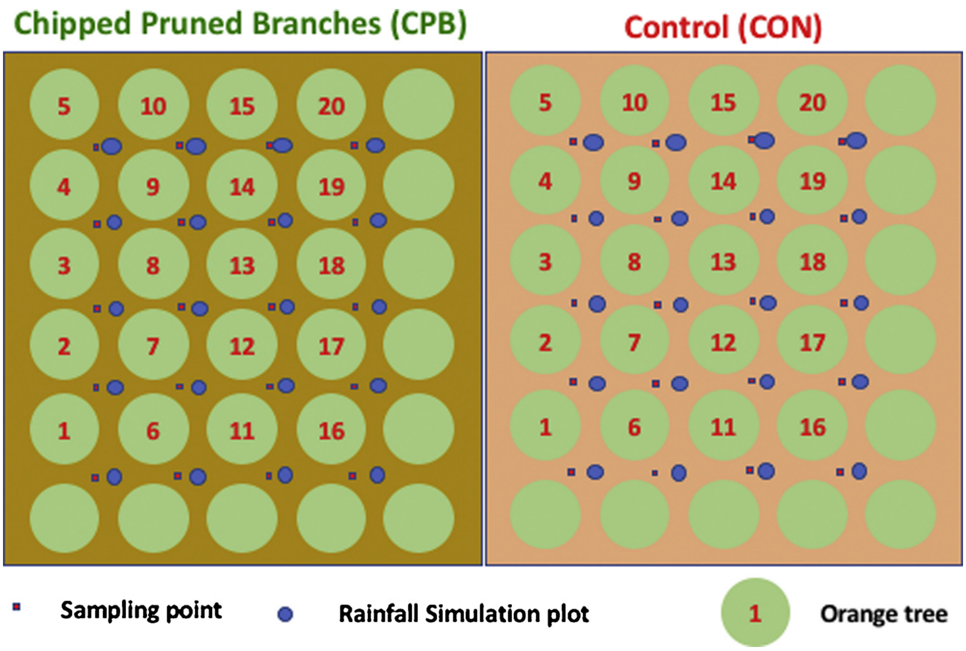

Fig. 2. Soil sampling and rainfall simulation experiments strategy. CON: Control plots; CPB: Chipped pruned branches plots. The rainfall simulation plot diameter is 55 cm.

Table 1
Farmer's opinion about the type of management (%).

Questions (n = 100[a])	Cost[b]	Efficiency[c]	Applied[d]	Subsidised[e]	Social[f]	Add value[g]	Average points
Herbicides	**67**	30	**93**	**94**	**95**	3	63.7
Tillage	54	**87**	59	**89**	**97**	6	65.3
Catch crops	12	65	1	67	68	12	37.5
Weeds	15	32	7	45	41	1	23.5
Geotextiles	3	35	1	62	34	14	24.8
Grass strips	3	4	0	23	35	5	11.7
Rock fragment mulch	56	2	0	5	6	2	11.8
Modern terraces	10	30	5	43	17	24	21.5
Traditional terraces	4	34	23	**78**	**98**	**89**	54.3
Straw mulch	14	68	2	59	53	21	36.2
Chipped branches mulch	12	2	18	57	23	14	21.0

Bold values signifies the highest % of positive replies.
[a] Only it was counted the positive answer.
[b] Is the cost affordable by the farmer?
[c] Is efficient this type of management?
[d] Is easy to apply?
[e] Should be subsidesed?
[f] Is social accepted?
[g] Does add value to the land?

comparisons between study sites, all experiments were carried out when the soil moisture levels were low, during the last week of July 2013, after no rainfall events had happened during the summer. Information on the characteristics of the rainfall in the region and the rainfall simulator are available in Cerdà (1997) and Prosdocimi et al. (2016b). At each plot, runoff flow was collected at 1-min intervals and the water volume was measured. The runoff coefficient was calculated as the percentage of rainfall water running out the circular plot. Runoff samples were desiccated (105 °C for 24 h) and sediment yield calculated on a weight basis in order to calculate soil loss per area and time ($Mg\,ha^{-1}\,h^{-1}$). During the rainfall simulation experiments, time to ponding (time required for 40% of the surface to be ponded; Tp, s), time to runoff initiation (Tr, s) and time required for runoff to reach the outlet (Tro, s) were recorded. Tr-Tp and Tro-Tr were calculated as indicators of how the ponding is transformed into runoff, and how much time the runoff on the soil surface needs to reach the plot outlet, respectively. These data sets show runoff initiation and how rainfall is transformed into runoff.

2.5. Statistical analysis

Runoff, sediment yield and sediment concentration were represented in the form of box plot graphics including median, averages and outliers. Runoff characteristics related to the time of generation and time to ponding were expressed in tables with averages, standard deviation (±), and maximum and minimum values. To be able to compare the results obtained in both paired plots a one-way ANOVA test was performed with Sigma Plot 12.0 (Systat Software Inc.). However, the results did not show a normal distribution (only bulk density at 4–6 cm depth) after testing for normality with Saphiro-Wilk and equal variance tests. Therefore, a Tukey test was carried out, where significant differences at the $P < 0.001$ level were assessed. Lineal regressions analysis showed correlations between the soil erosion results and the vegetation and litter covers.

3. Results

3.1. Farmer's perception and economic cost

The results of the farmer surveys on opinions about different types of soil management from La Costera District are shown in Table 1 for the 100 interviewees set. Farmers indicated that the most affordable management was the use of herbicides (67%), rock fragments mulches (56%) and tillage (54%). In relation to efficiency, farmers agreed that tillage was the most efficient management option (87%), although cash crops (65%) and straw mulch (68%) also had a high number of positive answers. Undoubtedly, famers find the use of herbicides the easiest management strategy in citrus plantations (93%) and think that it should be subsidized (94%), with tillage (89%) and traditional terraces (78%) as their second and third best options, respectively. The most accepted management options were also the use of herbicides (95%), tillage (97%) and traditional terraces (98%). Most farmers agreed that traditional terraces (89%) add the most value to the land. Overall, we found that tillage, herbicides and traditional terraces had the highest acceptance rates with averages of 65.3%, 63.7% and 54.3%, respectively, for the 100 interviewed farmers. The farmers' perception of CPB was generally negative (Table 1). One of the reasons given by the farmers was that chipping branches requires new and expensive machinery, and that they feel comfortable with the tradition of burning branches after pruning. The average cost to chip pruned branches was 176 € ha^{-1} while burning them cost 127 € ha^{-1} (Table 2).

3.2. Soil analysis and total pruned biomass

Soil properties for all test plots are compared in Table 3. Stone fragment cover had values of about 5–6%. Differences between SOM in the surface levels were found, ranging from 1.2% in CON and 2.9% in CPB with maximum values of 4%. However, no differences in SOM were found in the subsurface layers (1.1% in CON and 1.3% in CPB). Soil bulk density had higher values in the CON plots in the surface (1.36 g cm^{-3}) and subsurface (1.47 g cm^{-3}) layers than the soil with pruned branches (1.16 g cm^{-3} and 1.44 g cm^{-3}, respectively). Soil water content (SWC) was also higher in the plots with pruned branches (surface = 8.3%; subsurface = 10.7%) as compared to the control plot (surface = 5.9%; subsurface = 9%). Following a Tukey test after failing the normality test, almost all paired soil sampling results showed that the differences in the mean values among the treatment groups were greater than would be expected by chance, therefore giving statistically significant differences ($p < 0.001$). The only exception was for BD at the 4–6 cm depth, where no significant differences were found ($p < 0.356$). Finally, total pruned biomass in CON and CPB were quantified (Table 4), and similar branch biomass was found in both plots (CON: 171 g m^{-2} and CPB: 159 g m^{-2}). No statistically significant differences were found.

3.3. Water and soil losses

The results of the rainfall simulations are shown in Fig. 3 and Tables 5 and 6. In the CON plots, the average runoff value was 8.3 ± 1 l m^{-2} h^{-1} with a range of 6 l m^{-2} h^{-1} to 10 l m^{-2} h^{-1}, an average runoff coefficient of 60.1 ± 7.5%, and an average Tp of 39.3 ± 6.9 s. Tr and Tro were 107.7 ± 16.6 and 227.3 ± 19.4 s, respectively. The CPB plots had a lower mean runoff of 6 ± 1.1 l m^{-2} h^{-1} with a range of 4–8 l m^{-2} h^{-1}. The mean runoff coefficient was 16.8% lower than in the CON plots, which delayed runoff generation. Tp (169.2 ± 59.1 s), Tr (253.9 ± 69.3) and Tro (428.3 ± 87.2 s) values were also higher in CPB than in CON.

Soil losses were significantly different between the CPB and CON plots. Soil erosion in the CON plots averaged 376.5 ± 101.2 g m^{-2} h^{-1} (3.8 ± 1 Mg ha^{-1} h^{-1}) with maximum values of 566 g m^{-2} h^{-1}. CON sediment concentrations averaged 11.3 ± 2.2 g l^{-1} with a range of 8.56 g l^{-1}–15.59 g l^{-1}. In the CPB plots soil loss averaged 74 g m^{-2} h^{-1} (0.7 ± 0.4 Mg ha^{-1} h^{-1}), which was 5 times lower than in the CON plots. Sediment concentrations were also lower, averaging only 3 ± 1 g l^{-1} with a range from 1.57 g l^{-1} to 5.28 g l^{-1}, which was 3.8 times lower than in the CON plots. The data failed the normality test in all paired rainfall simulations. Results from the Tukey test showed that the differences in the mean values between the treatment groups were greater than would be expected randomly, meaning the differences were statistically significant ($p < 0.001$).

4. Discussion

Some strategies that can be utilized to avoid herbicides and tillage are already well known and widely tested. The use of weeds as a cover is positive from an economic point of view as there is no cost to establish the vegetation cover and it is efficient at reducing soil and water losses and enhancing the development of a litter layer to protect the soil against raindrop impact, just as other mulches and vegetation covers do (Benvenuti and Bretzel, 2017; Keesstra et al., 2016b; Prosdocimi et al., 2016b; Mekonnen et al., 2017; Tanveer et al., 2017). However, farmers in eastern Spain do not accept weeds in their fields for social, cultural and moral reasons as tradition requires a tidy orchard, which is essential to maintain a farmer's reputation as a good land manager (Marques et al., 2015; Sastre et al., 2016; Cerdà et al., 2017b). Weeds can also deplete soil water resources and reduce crop yields, and this has become even more relevant for soil management due to climate change (Lovelli et al., 2012). The use of geotextiles has been shown to be profitable as they reduce soil losses, although they can increase

Table 2
Cost of the individual management practices for both chipped branches and burnt branches after asking twelve owners. The average does not count the surface of the plots. CON: Control plot; CPB: plot with pruned brunches.

Owners	ha	CON €	CPB €	CON € ha^{-1}	CPB € ha^{-1}	CPB-CON €	CPB-CON € ha^{-1}	CPB-CON (%)
1	3.2	387.2	532.12	121.00	166.29	45.29	14.15	37.4
2	4.6	438.9	678.3	95.41	147.46	52.04	11.31	54.6
3	17.5	1899.2	2342.3	108.53	133.85	25.32	1.45	23.3
4	3.1	432.3	632.1	139.45	203.90	64.45	20.79	46.2
5	2.8	325.3	435.2	116.18	155.43	39.25	14.02	33.8
6	13.2	1987.23	2543.34	150.55	192.68	42.13	3.19	28
7	1.4	200.2	354.65	143.00	253.32	110.32	78.80	77.2
8	2.6	432.32	623.2	166.28	239.69	73.42	28.24	44.2
9	22.5	3010.2	3654.3	133.79	162.41	28.63	1.27	21.4
10	250	23331.2	25542.4	93.32	102.17	8.84	0.04	9.5
11	176.2	17823.3	19823.1	101.15	112.50	11.35	0.06	11.2
12	78.2	8922.12	9987.3	114.09	127.71	13.62	0.17	11.9
Total/Mean	320.9	32444.05	37337.91	126.75	175.72	48.97	0.15	38.6

Table 3
Soil properties. CON: Control plot; CPB: Pruned branches plot; $\overline{x}\pm$: Average and standard deviation; Max.: maximum values; Min.: minimum values; SOM: Soil organic matter; BD: Bulk density.

Variables	Stone cover (%)		SOM (%)				BD (g cm^{-3})				SWC (%)			
Depth	0-2 cm		0-2 cm		4-6 cm		0-2 cm		4-6 cm		0-2 cm		4-6 cm	
Management	CON	CPB	CON	CPB	CON	CPB	CON	CPB	CON	CPB	CON	CPB	CON	CPB
$\overline{x}\pm$	5.9 ± - 1.7	5.2 ± 1.8	1.2 ± 0.2	2.9 ± 0.6	1.1 ± 0.1	1.3 ± 0.2	1.36 ± 0.1	1.16 ± 0.1	1.47 ± 0.1	1.44 ± 0.1	5.9 ± 1	8.3 ± 1.1	9 ± 0.6	10.7 ± 1.2
Max.	9	9	1.8	3.9	1.5	1.8	1.6	1.3	1.7	1.7	8	10.2	10.9	12.9
Min.	3	1	0.9	1.9	0.9	1	1.2	1	1.3	1.2	3.9	6.3	8	8.9

Table 4
Total fresh and dry pruned biomass. CON: Control plots; CPB: Chipped pruned branches plots;$\overline{x}\pm$: Average and standard deviation; Max.: maximum values; Min.: minimum values; FPB: fresh pruned biomass.

Plots	FPB (g)		Moisture (%)		Dry biomass (%)		Dry biomass (g)		FPB (g m^{-2})		Dry biomass (g m^{-2})	
n = 20	CON	CPB	CON	CPB	CON	CPB	CON	CPB	CON	CPB	CON	CPB
$\overline{x}\pm$	14,138 ± 230-9.1	14033.9 ± 2692.4	72.6 ± 4	74.6 ± 4.4	27.4 ± 4	25.43 ± 4.4	3868.7 ± 863.3	3604.9 ± 1009.1	706.9 ± 115.5	701.7 ± 134.6	171.1 ± 74.9	159.4 ± 78.1
Max.	18976	19823	79	79	33	36	5842	6296	949	991	292	315
Min.	10976	10324	67	64	21	21	2537	2267	549	516	0	0

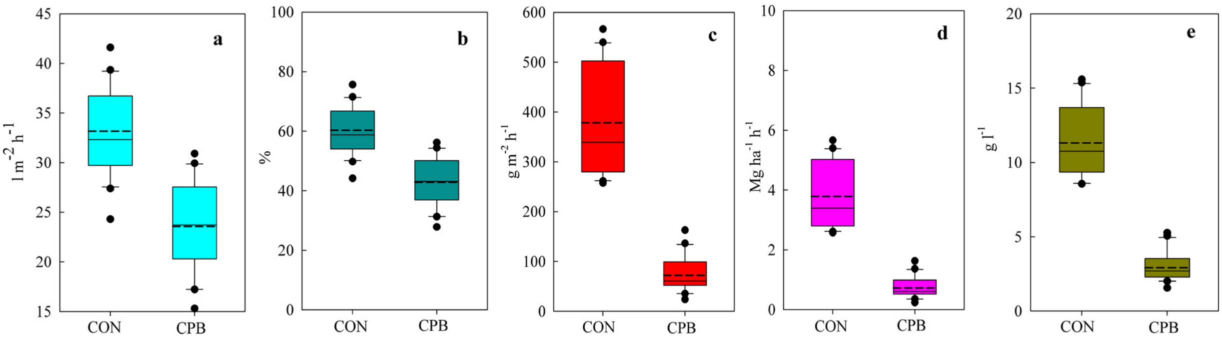

Fig. 3. Runoff, soil erosion and sediment concentration measured by mean of rainfall simulation experiments. CON: Control plots; CPB: Chipped pruned branches plots. a: Runoff; b: Runoff coefficient; c: sediment yield; d: soil erosion; and, e: sediment concentration. Trees are planted at 5 × 4 m, rainfall simulation plots are 0.24 m^2 in size and the sampling took place in a 10 × 10 cm square plot.

Table 5
Soil erosion results on the control plot and with branches. CON: Control plot; CPB: Pruned branches plot; $\overline{x}\pm$: Average and standard deviation; Max.: maximum values; Min.: minimum values; Rc: Runoff coefficient; Sc: Sediment concentration; Tr: Total runoff; Sy: Sediment yield; Se1: Soil erosion in g m^2 h^{-1}; Se2: Soil erosion: Soil erosion in Mg ha^{-1} h^{-1}.

Plots	Rc (%)		Sc (g l^{-1})		Tr (l)		Sy (g)		Se1 (g m^2 h^{-1})		Se2 (Mg ha^{-1} h^{-1})	
n = 20	CON	CPB	CON	CPB	CON	CPB	CON	CPB	CON	CPB	CON	CPB
$\overline{x}\pm$	60.1 ± - 7.5	43.3 ± 7.9	11.3 ± 2.2	3 ± 1	8.3 ± 1	6 ± 1.1	94.1 ± 25.3	18.5 ± 8.9	376.5 ± 101.2	74.0 ± 35.7	3.8 ± 1	0.7 ± 0.4
Max.	76	56	16	5	10	8	142	41	566	163	6	2
Min.	44	28	9	2	6	4	64	6	258	24	3	0

Table 6
Times to runoff characterization on the control plot and with branches. CON: Control plot; CPB: Pruned branches plot; $\overline{x}\pm$: Average and standard deviation; Max.: maximum values; Min.: minimum values; Tp: Time to ponding; Tr: time to runoff; Tro: time to runoff in outlet.

Plots	Tp (s)		Tr (s)		Tp-Tr (s)		Tro (s)		Tr-Tro (s)	
n = 20	CON	CPB	CON	CPB	CON	CPB	CON	CPB	CON	CPB
$\overline{x}\pm$	39.3 ± - 6.9	169.2 ± 59.1	107.7 ± 16.6	253.9 ± 69.3	68.5 ± 17.6	84.8 ± 25.2	227.3 ± 19.4	428 ± 87.2	119.6 ± 18.7	174.1 ± 26.4
Max.	58	312	135	410	103	160	251	605	156	235
Min.	27	95	69	178	32	44	185	325	80	138

runoff if the material has a hydrophobic response (Giménez-Morera et al., 2010). Moreover, geotextiles are expensive and not all farmers can access these types of materials. The use of straw mulch has also proved to be positive and efficient on agricultural land (Prosdocimi et al., 2016a; Cerdà et al., 2017b). But the acceptance by farmers is poor, as the straw and its application are costly and farmers see the straw mulch as a source of pests and as being unsightly on their farm. However, the farmer's perception of CPB is that they would use it if it is subsidized. The desires of the stakeholders are important when making such decisions, or at least they should be, and there is a need for a framework that will integrate biophysical and economic land use and management issues (Bouman et al., 1999; Hondebrink et al., 2017) that also incorporates stakeholder's opinions (Bouma and Kamp-Roelands, 2000; Brevik et al., 2016).

4.1. Biophysical benefits of CPB

The use of CPB is very efficient to lower soil erosion rates, as was demonstrated in this study, and CPB can be the decisive factor controlling soil surface properties in citrus orchards. Confirmation of our hypothesis that the CPB would efficiently control soil losses was demonstrated through the relationships between litter cover and soil erosion as shown in Fig. 4. This relationship demonstrates the importance of the chipped branches mulch in two ways: i) the CON plots delivered more sediment than the CPB plots did; and, ii) the relationship within the CPB plots between litter cover and soil erosion is negative. Soil erosion decreased when litter cover increased. Litter cover from the CPB also contributed to increased organic matter in the surface layer, potentially resulting in improved infiltration rates and

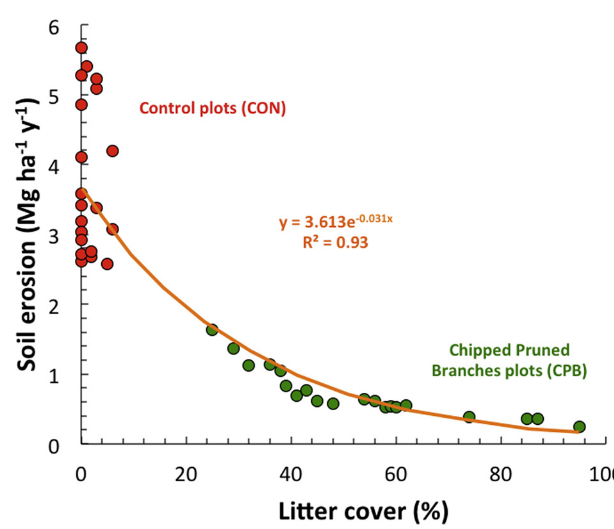

Fig. 4. Relationship between soil loss and vegetation/litter cover. CON: Control plots; CPB: Chipped pruned branches plots.

reduced surface flow and soil erosion. Fig. 5 clearly shows this relationship. It also demonstrated that the chipped branches increased soil organic matter when CON and CPB plots were compared and that within the CPB there was an increase in soil organic matter with increasing CPB cover.

The relationship between the runoff coefficient and sediment concentration showed the importance of CPB in changing the hydrologic properties of the soils. Fig. 6 shows that the CON plots produced more runoff and sediment load than the CPB plots and that the increase in runoff also resulted in an increase in soil erodibility as shown by the sediment concentration. The implication of this finding is that once a soil is covered with CPB the runoff discharge decreased due to the increase in organic matter and infiltration. However, there was a second positive effect, and this was that the sediment concentration in the runoff was reduced by the cover of chipped pruned branches that protected the soil surface from direct raindrop impact. Therefore, chipped pruned branches offered two major benefits: i) they reduced runoff discharge; and, ii) they reduced soil erodibility. Both changes contributed to an immediate and efficient reduction of the soil erosion rates.

4.2. Farmer's perception and economic constraints

Farmer's perceptions about the use of pruned branches in the study area are that they are not a viable solution for crop management. The following reasons were given: i) it is more expensive than removing and burning the branches; ii) the soil is not as clean as they wish (a tidy farm is important for the farmers' good reputations); and, iii) this is not part of the tradition in terms of land management in this region. This is not a new response by farmers in the area, who tend to base their farm management decisions on traditions, as demonstrated by Green and Heffernan (1987). The tradition in this region is to use the branches as forage or burn them. This tradition was established in 1960s, as before that time all the pruned branches were used for forage or fuel. Therefore, the opinion of the farmers is based on a fairly recent perception of the issue.

An important issue that should be taken into account when addressing the implementation of management strategies is the perception of farmers towards specific strategies, because if farmers are not willing to adopt a management strategy it will fail (Critchley et al., 1994; Hellin and Haigh, 2002). In this sense, it is important to indicate that the effectiveness of a management strategy from a soil biophysical point of view is not the only relevant issue. Whether a policy measure for land management will become successful will depend to a large extent on the perception of the farmers who must implement it. Gould et al. (1989) found that farmers' views on conservation tillage as a way to reduce soil erosion was not as positive as expected. Napier et al. (1988) confirmed that the willingness of land operators to participate in soil erosion control programs was often low, and Osterman and Hicks (1988) found that farmers often do not perceive soil erosion as a problem in its own right in a study in Washington, USA. Ervin and Ervin (1982) found that the opinion and support of the farmers was important for the successful implementation of conservation practices and policies; Okoba and de Graaff (2005) reported similar findings in the Central Highlands of Kenya, where the perception and knowledge of the farmers was the most important issue determining the success of the policies. Research carried out in different parts of Africa demonstrates that the success of land use policies is related to the knowledge and perception of the farmers (Okoye, 1998; Visser et al., 2003; Zegeye et al., 2010). We found a similar response from the farmers in eastern Spain, which means there is a worldwide need to find better ways to engage these stakeholders in the implementation of better soil management techniques.

Several issues hamper the adoption of chipped pruned braches by farmers in eastern Spain as protective mulch to reduce runoff and erosion. First, and probably most important, is the economic issue. Burning the branches, as farmers currently do, is less expensive than applying CPB. Therefore, farmers need to receive subsidies to promote the use of CPB to compensate them for their increased costs. The economic survey demonstrated that chipping the branches in orange plantation is costlier at small farms (Fig. 7) and that the increase in cost to switch from burning the branches to chipping them is related to the size of the farm (Fig. 8). Therefore, subsidies or incentives need to take farm size into account to effectively influence the management practices of smallholder farmers.

The research presented here is new for the Mediterranean belt. Rainfall simulation experiments have frequently been used to determine the sustainability of agriculture management practices, but this has not previously been done in combination with a stakeholder perception analysis. European agricultural policies that seek to achieve better land management (Glæsner et al., 2014) and reduce soil erosion rates (Boellstorff and Benito, 2005) or increase biodiversity (van Buskirk and Willi, 2004) have achieved success in Belgium (van Rompaey et al., 2001) and Iceland (Arnalds and Barkarson, 2003). However, examples of such success are not found in other regions, as Berger et al. (2006) highlighted, due to the characteristics of voluntary agri-environmental measures at a regional scale. This is because each region in Europe has different environmental, social and economic conditions. Andersen et al. (2007) showed that farm management and typologies must be relevant before farmers will apply the set-aside programs, making it necessary to change the policy environment in Europe such that it recognizes these differences and can adjust to them. Bourgeon et al. (1995) already identified the need for appropriate incentives to achieve the target of sustainable agricultural management in Europe. Lahmar (2010) states that there is still no scientific documentation of the long-term socio-economic and ecological impact of reduced tillage, such as he found in Norway and Germany, which are well subsidized by the national governments. In the Mediterranean, recent European Union policy that sustains less favoured areas and supports intense terracing in vineyards supports techniques that may actually result in a worsening of slope instability phenomena (Martínez-Casasnovas and Concepcion Ramos, 2009; Stanchi et al. 2012). This is a consequence of incentives to expand crops that negatively affect soil and water conservation management, either in developed or developing countries (Barbier, 1997; Barbier and Bishop, 1995; Lundekvam et al., 2003). The impact of policies on biodiversity (van Buskirk and Willi, 2004) and how policy environments affect agricultural land use (van Meijl et al., 2006) are also clear examples of the impacts of the interaction of policy development and biophysical changes in agricultural land.

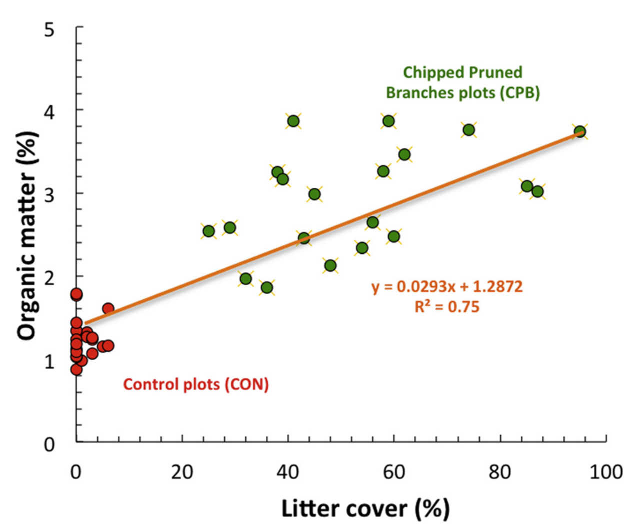

Fig. 5. Relationship between litter cover and organic matter. CON: Control plots; CPB: Chipped pruned branches plots.

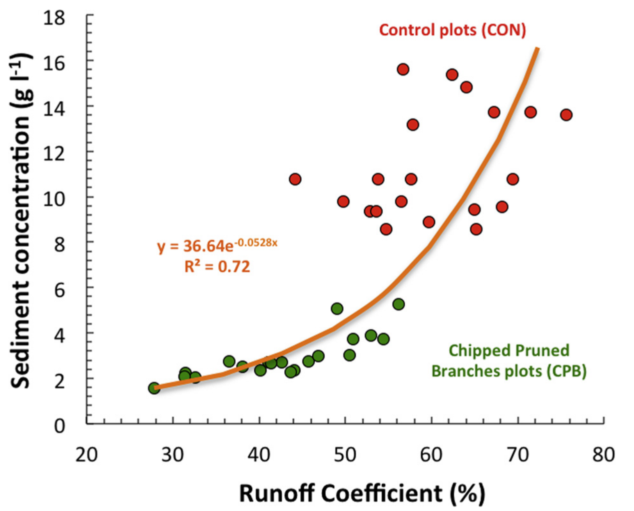

Fig. 6. Linear correlation between runoff coefficient and sediment concentration. CON: Control plots; CPB: Chipped pruned branches plots.

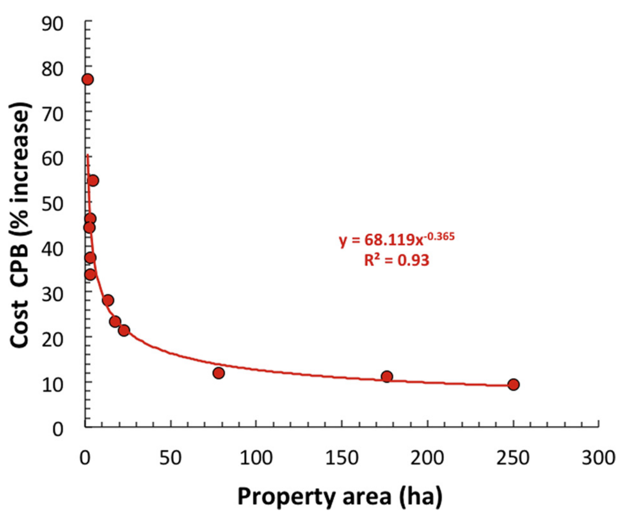

Fig. 7. Relationship between the cost of CPB and property area. CPB: Chipped pruned branches plots.

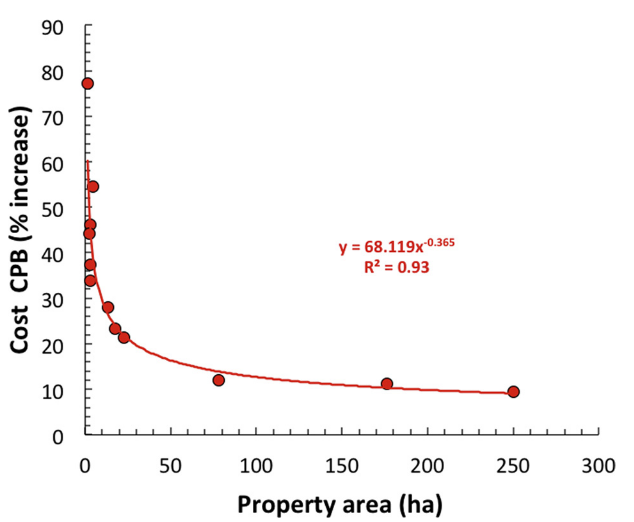

Fig. 8. Relationship between the increase (% increase relative to CON) of the cost of CPB to the traditional burning of branches and property area. CPB: Chipped pruned branches plots.

Our research in citrus plantations shows that there is a need to develop different policies for different types of farms. For the large farms in the study area, applying CPB strategies would result in a 10% increase in expenses compared to removing the branches and burning them. However, for medium size owners (10–30 ha) the increased expenses would be between 20 and 30%, and for the small farms (< 10 ha) expenses may increase as much 80% for the very small operations (< 2 ha), especially the farms that have multiple small fields at different locations within the same municipality. EU policies do not currently adapt their subsidies and incentives to address these contingencies, and thus end up supporting only large farms, leaving the small operations with a lack of opportunity to update their machinery or to apply new technologies. However, small farmers are the ones that most effectively promote biodiversity and landscape diversity due to their diversity in crops and in the borders between farms that are frequently occupied by hedgerows, irrigation, or drainage boundaries (Lin et al., 2009).

4.3. Ways ahead

The issues described above demonstrate the need for new types of policies that are adapted to regional socioeconomic and cultural conditions. Panagos et al. (2012) presented the European Soil Data Centre, which is a key database to support success in European agricultural and soil policies. However, information in this data set is not accurate or detailed enough to facilitate a sound understanding of the behaviour of farmers and their requirements at a regional level in order to achieve a more sustainable agriculture. De Graaff and Eppink (1999) identified weak points in EU subsidies that made it difficult to achieve a green policy for olive production. Such policies can sometimes even increase environmental problems instead of reducing them (Boardman et al., 2003). A good example for this is the implementation of drip irrigated citrus orchards on sloping terrain, which drives very high erosion rates (Cerdà et al., 2009). In addition, there is a need to educate farmers about how they can contribute to more sustainable land-use management options. Subsidies and financial incentives help to achieve these goals as Marques et al. (2015) found, but the knowledge of the farmers and their contribution as citizens is relevant as well. In a study in Peru, Swinton (2000) found that social capital is important to reduce soil erosion. Therefore, we need to ask ourselves if Europe is investing enough in the social and cultural capital of rural areas. Are we building a European policy merely based on subsidies? The research carried out in the La Costera district says yes.

As mentioned before a second important issue is the farmers' tradition of keeping their fields tidy. In general, farmers in this region prefer their soil clean of any cover such as growing vegetation, straw, or chipped branches. This is not a unique situation as other regions within the Mediterranean show similar farmer behaviours. Our research in the citrus plantations in Eastern Spain indicates the importance of conservation techniques in reducing runoff and soil loss, therefore confirming the findings of Prats et al., (2014) and demonstrating that CPB can act as mulch. This confirms previous findings by Fernández and Vega (2014) in fire-affected land and by Ruiz-Colmenero et al. (2013) in vineyards where vegetation cover reduced soil erosion and enhanced organic carbon in soils of Central Spain. However, there is a major constraint to successfully using those strategies in citrus orchards as farmers dislike them and consider them an imposition by policy makers who know little about practical farming needs and care little about farmers' perceptions.

The third important obstacle in the road to implementing CPB is the lack of knowledge by farmers about the negative effects of their current practices and the benefits that sustainable new strategies such as CPB can have for their soils. There is therefore a lag in the system for educating farmers that could be covered by policies that lead to an improvement in farmers' education. In other words, farmers need to be encouraged to be lifelong learners, just as other professionals are encouraged to be lifelong learners (Jarvis, 1987; Ballou et al., 1999; Westover, 2009). The European Union, National, and Regional fund offices are actively subsidizing the use of chipped branches, but there is a lack of farmer education about the benefits this strategy brings to the soil and to the economic situation of the farmers. Even though it is well accepted that soil conservation management strategies contribute to a healthier environment, there is a need to better translate the scientific knowledge into socially-acceptable environmental policies, and each region is different in this issue (Bouma and Droogers, 2007). There is a need to co-construct, in cooperation and collaboration with farmers and other stakeholders, an environmental policy strategy for Europe.

We propose here that European policies should be more realistic, better adapted to unique regional needs, developed from the bottom-up, designed for the farmers and with the farmers. We must co-construct the agricultural fate of Europe based on the knowledge and opinions of farmers, scientists, policy makers and citizens. Soil environmental quality is a key issue for the future of European agriculture and also for European sustainability (Bouma, 1997), and we need to take action as scientists, as citizens and as consultants for the policy-makers. The key mistake over the last 20 years of European agricultural policy was to develop subsidies that seek to have immediate success and can therefore be evaluated over the short-term. In Mediterranean areas there is a need to reorganize, rebuild and co-construct new policies and strategies to achieve sustainable agriculture, and should be based in nature-base solutions (Keesstra et al., 2018). Over the long term, success can only reached if education programs for farmers accompany the subsidies. The CPB survey conducted in the La Costera District for this study is a good example of this need. Farmers did not find the CPB technique attractive unless there was financial support from public entities. European policies must make soil conservation and building management practices attractive from more than the short-term economical point of view, they should also be socially and environmentally suitable (Bouma et al., 2012).

5. Conclusions

CPB are very efficient at improving soil quality, although their effect is restricted to the soil´s surface at least over the time period covered by this study. CPB controls soil and water losses in chemically managed citrus plantations where vegetation cover is absent due to the tradition of farmers to keep their fields "clean" and "tidy", resulting in a bare soil surface. After ten years of CPB mulch use, we found increased organic matter and reduced bulk density at the soil surface (0–2 cm) level. This resulted in decreased sediment concentration (11.3 $g\,l^{-1}$–3 $g\,l^{-1}$) and soil erosion (3.8 $Mg\,ha^{-1}\,h^{-1}$ vs 0.7 $Mg\,ha^{-1}\,h^{-1}$). However, the use of CPB is not popular within the farmers' community and there is a need to subsidize (or incentivize) this technique for it to be accepted as a viable management option that offers an alternative to removing the pruned branches. There is a need for European agriculture policies will be based not only on subsidies, but also on the education of farmers that will provide farmers with a holistic perspective of how their management choices impact the land they manage and make them feel that they are part of a larger society effort, and not merely servants of subsidies or policymakers. This is especially relevant in the Mediterranean context where farmers have the perception that they do not matter to the European policy makers. There is a need to incentivize a new sustainable (societally, environmentally and economically) agriculture that will include cooperating with farmers and having them work closely with scientists, policy-makers, and other relevant members of society.

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Effects of soil management techniques on soil water erosion in apricot orchards

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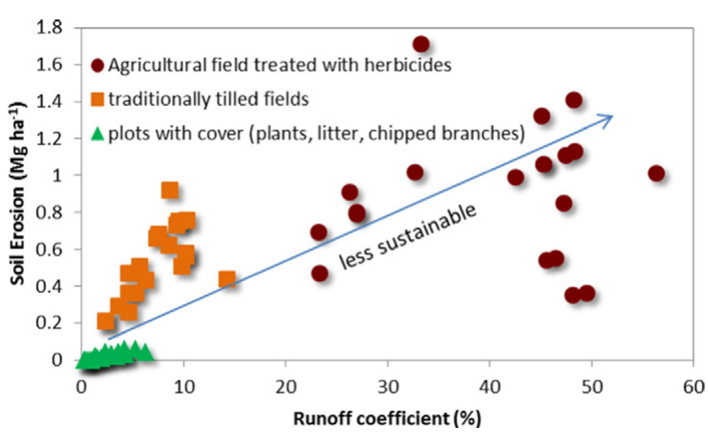
HIGHLIGHTS

- Prevailing management (tillage and herbicide treatment) keeps soil bare and prone to erosion
- Assessment of runoff and erosion for three management types (tillage, herbicide and covered)
- Herbicide treatment causes 1.8 and 45.5 times more erosion than tillage and covered respectively
- 60 rainfall simulation experiments showed tenfold lower erosion rates with covered soil
- Soil erosion was extremely high in herbicide treated orchards, even higher than in tilled orchards

GRAPHICAL ABSTRACT



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ABSTRACT

Soil erosion is extreme in Mediterranean orchards due to management impact, high rainfall intensities, steep slopes and erodible parent material. Vall d'Albaida is a traditional fruit production area which, due to the Mediterranean climate and marly soils, produces sweet fruits. However, these highly productive soils are left bare under the prevailing land management and marly soils are vulnerable to soil water erosion when left bare. In this paper we study the impact of different agricultural land management strategies on soil properties (bulk density, soil organic matter, soil moisture), soil water erosion and runoff, by means of simulated rainfall experiments and soil analyses. Three representative land managements (tillage/herbicide/covered with vegetation) were selected, where 20 paired plots (60 plots) were established to determine soil losses and runoff. The simulated rainfall was carried out at 55 mm h^{-1} in the summer of 2013 (<8% soil moisture) for one hour on 0.25 m^2 circular plots. The results showed that vegetation cover, soil moisture and organic matter were significantly higher in covered plots than in tilled and herbicide treated plots. However, runoff coefficient, total runoff,

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Agriculture land management
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sediment yield and soil erosion were significantly higher in herbicide treated plots compared to the others. Runoff sediment concentration was significantly higher in tilled plots. The lowest values were identified in covered plots. Overall, tillage, but especially herbicide treatment, decreased vegetation cover, soil moisture, soil organic matter, and increased bulk density, runoff coefficient, total runoff, sediment yield and soil erosion. Soil erosion was extremely high in herbicide plots with 0.91 Mg ha^{-1} h^{-1} of soil lost; in the tilled fields erosion rates were lower with 0.51 Mg ha^{-1} h^{-1}. Covered soil showed an erosion rate of 0.02 Mg ha^{-1} h^{-1}. These results showed that agricultural management influenced water and sediment dynamics and that tillage and herbicide treatment should be avoided.

1. Introduction

Acceleration of soil erosion rates is the main cause of land degradation and, as a consequence, leads to loss of soil fertility and decrease in agricultural production and farmers income, which results in unsustainable agriculture (Colazo and Buschiazzo, 2015; Novara et al., 2015; Yan and Cai, 2015). Acceleration of soil erosion rates is the result of increased runoff on soil surfaces that are vulnerable to soil detachment (Van Oost et al., 2009). If a soil has characteristics (Stanchi et al., 2015) that prohibit infiltration of water (e.g. crusting, slacking, lack of macro pores) the runoff coefficient will be higher (Liu et al., 2014). However, if the soil has a rough surface (Gao et al., 2015), runoff will be delayed by ponding water, allowing water to infiltrate and reducing the soil erosion on such sites. But in the case where the soil is covered by vegetation infiltration rates are generally higher as a result of better soil structure, and the soil is protected against sediment detachment, which reduces the vulnerability to soil erosion (Seutloali and Beckedahl, 2015).

Agriculture is the main cause of soil losses and runoff (Cerdà et al., 2009a, 2009b; Novara et al., 2011; Laudicina et al., 2015) and orchards under rainfed agriculture have some of the highest soil erosion losses due to the lack of land levelling, terraces, intense tillage, compaction due to heavy machinery and herbicide application (Bisantino et al., 2015; Prosdocimi et al., 2016). Tillage has been part of the Mediterranean agricultural practices for millennia. Farmers have used this as a tool to avoid the competition for water with the crops, to enhance the infiltration by creating a rough and permeable surface. In addition the tillage breaks the capillary routes for the water to evaporate after a rain event. In Vall d'Albaida the tradition of an intense ploughing was used also to produce “dust” that protect the plant against insects (farmers personal communication). Because of the long tradition of Mediterranean farmers to keep their fields clean of weeds, farmers continue to do this, even when from a sustainability or productivity point of view this is no longer necessary and this is now a key point in the education for a better soil management (Keesstra et al., 2016a, 2016b). In Vall d'Albaida the ploughing use to take place 3 to 4 times per year, but many farmers over-tillage because this tradition of produce “dust” and avoid any weed. In Fig. 1B can be seen how farmers plough already bare orchards.

High erosion rates have been observed in avocado (Atucha et al., 2013) and olive orchards (Gómez et al., 2003; Vanwalleghem et al., 2010), new citrus plantations (Cerdà et al., 2009b; Li et al., 2015) and vineyards (Novara et al., 2013; Tarolli et al., 2015). Almond (Faulkner, 1995), persimmon (Cerdà et al., 2015), and apricot (Abrisqueta et al., 2007) orchards have also shown high erosion rates, but little research has been carried out comparing agriculture land management in fruit orchards. Also no research has been reported in other orchards such as apples, cherries or pears even though the worldwide land area devoted to fruit production is growing due to demand for fresh fruits and juices (Jackson et al., 2011). Until recently, most of the research in soil erosion has been done in areas occupied by cereals. These annual crops show high erosion rates due to intense tillage and a lack of vegetative cover (Cerdà et al., 2009a, 2009b; Stevens et al., 2009; Rodríguez-Blanco et al., 2013; Ligonja and Shrestha, 2015). High erosion rates result in the loss of soil, and with that the loss of services soils provide for society (Brevik, 2009; Keesstra et al., 2012; Berendse et al., 2015; Brevik et al., 2015; van Leeuwen et al., 2015).

Apricot (*Prunus armeniaca*) production in Spain was 119.400 Mg in 2013, which is 3% of the total world production (FAO, 2015). In Spain, 25 to 50% of the total apricot production is exported to European

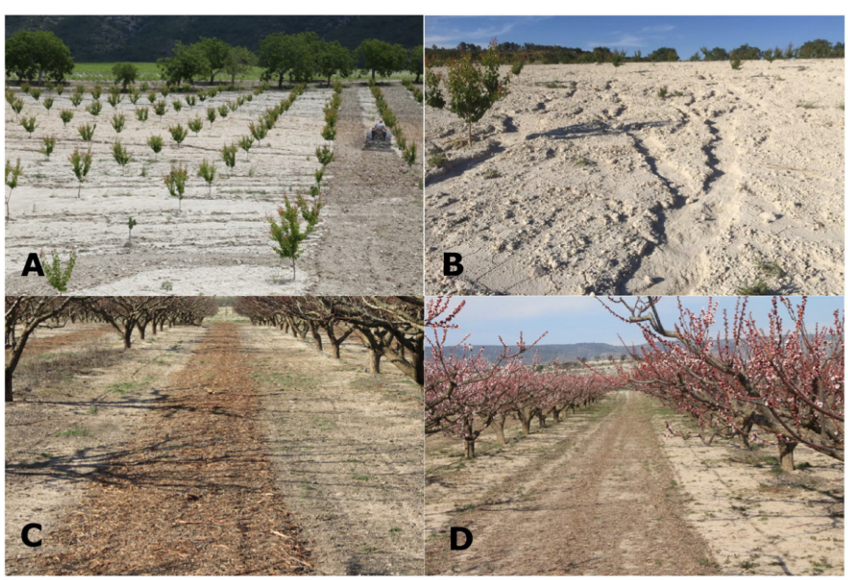

Fig. 1. Views of apricot orchards in the province of Valencia. Pictures A and B show evidence of high erosion rates after a thunderstorm that dropped 40 mm of rain in 30 min on 2-year old apricot orchards. Pictures C and D show chipped branches spread over the soil between the trees in mature apricot orchards in winter.

markets making Spain and France the largest exporters of apricots in the world (Siddiq et al., 2012). The Spanish production of apricots is centred in the provinces of Murcia and Valencia. The orchards are modern plantations managed to produce apricots of high quality for the international market. Most of the apricot production is based on farms that keep the soil bare using intense tillage and herbicides, and that use pesticides to control the plagues (Fig. 1). Some farmers manage their orchards without herbicides (organic farming) and tillage, allowing vegetative cover that is sown three times per year to cover the soil between trees, although this is very rare (1% of the apricot production) because most farmers believe apricots cannot be produced without the use of chemicals (source: RECARE project stakeholders participation: http://www.recare-project.eu/, personal interviews with the farmers).

This paper aims to assess water and soil losses in apricot orchards under the three main management strategies used in La Vall d'Albaida: tillage, no-tillage with herbicides, and no-tillage with sowing of vegetative cover and chipped branches. We assessed the main factors that determine soil losses and runoff: vegetation cover, organic matter, soil moisture and bulk density.

2. Materials and methods

2.1. Study site

The experimental area was selected in the northern Albaida river basin, south of Valencia province in Eastern Spain, in the municipality of Aielo de Malferit (38°52 N, 0°35'W) where apricot production under rainfed conditions is traditional. Parent materials in the area's apricot fields are Cretaceous limestone and Tertiary deposits of marls. The soils are typical for this area, a Typic Xerorthent (Soil survey Staff, 2010; Cerdà and Doerr, 2007), with a soil organic matter (SOM) content of about 1%, basic (pH 8) and with a loamy texture, developed on Miocene Marls. The climate is Mediterranean with 3–5 months of summer drought, with mean annual rainfall at the study site of 620 mm. On average there are 48 days of rain per year. Rainfall shows a maximum peak of rain intensity and volume during the autumn. The mean annual temperature is 13.9 °C while the hottest month (August) has an average temperature of 24 °C. The field sites were selected close to each other, to assure that all differences measured are only the result of the management treatments and not because of differences in slope, aspect or parent material. The selected fields were neighbouring fields on the same hillslope with the same slope and in the same physiographic characteristics. Fig. 1 shows an overview of the landscape and the orchards.

2.2. Field experiments and laboratory analyses

A 30-year old apricot orchard was selected to measure soil losses on no-till bare management (herbicide treatments, called "herbicide"), on tilled fields (tillage treatment, called "tillage"), and on fields where the soil was covered by vegetation (sowing treatment, called "covered"). In the herbicides plots, herbicides were applied every time the farmer saw some seedlings, all vegetative cover was prevented, and pruning residuals were burnt after removal from the field. The tillage plots were tilled three or four times per year depending on the amount of rain and weed cover, and the pruning residuals were removed from the field and burned. Tillage has an average depth of 20 cm. The tilled and herbicide plots had both been under these treatments for 30 years. The covered fields were characterised by vegetative cover and chipped pruning residuals and had been so managed for 20 years. Over that time the covered field have regenerated to a state in which the average vegetative cover in the covered field are 87% during the winter and 56% in summer due to the Mediterranean drought and passes of machinery. In these fields representative plots were selected to perform rainfall simulations between the tree lines (10 m between the lines of trees) of the apricots at 5 m distance from earch other. In each line of apricot trees four plots were selected. In total this covered a surface of 1000 m^2 in each management type. In total sixty rainfall simulation experiments were carried out at 55 mm h^{-1} rainfall intensity for one hour on circular paired plots of 0.25 m^2. The intensity chosen for this experiment represents a high intensity, low frequency storm as occurs in the Mediterranean climate prevailing in this area with a return period of 10 years (Castillo and Beltran, 1977; Pereira et al., 2015). The experimental trial took place in July 2013, when soil moisture was the lowest of the year. In the tillage plots the ploughing was done one week prior to the experiments, and as no rainfall occurred prior to the measurements, no crusts had formed. In the covered plots, the sites with representative

Table 1
Vegetation cover (%), soil moisture (%) at 0–1 cm depth. Soil organic matter content at 0–1 cm depth. And bulk density at 0–5 cm depth for 60 samples collected at the Herbicide, Tillage and Covered plots in the Vall d'Albaida research sites on apricot production. Different letters represent significant differences at a $p < 0.05$.

Plots	Vegetation (%)			Soil moisture (%)			Organic Matter (%)			Bulk density (g cm^{-3})		
n = 60	Herbicide	Tillage	Covered	Herbicides	Tillage	Covered	Herbicides	Tillage	Covered	Herbicides	Tillage	Covered
1	3	0	49	3.25	2.65	3.48	0.98	0.98	1.50	1.32	1.23	1.10
2	2	0	21	2.26	2.48	6.25	1.02	0.97	0.98	1.45	1.26	1.21
3	1	0	75	2.45	3.47	3.48	0.98	0.98	2.32	1.23	1.24	1.03
4	3	1	37	2.69	3.52	4.65	0.89	1.02	1.23	1.65	1.19	1.08
5	2	0	56	3.54	3.14	5.96	1.03	1.32	1.06	1.25	1.35	1.15
6	5	1	45	3.42	3.68	5.78	1.06	1.59	1.45	1.42	1.26	1.12
7	2	0	33	3.61	3.57	5.02	1.25	1.23	1.33	1.32	1.24	1.18
8	0	2	15	2.98	3.42	5.15	1.24	1.25	1.20	1.65	1.35	1.35
9	2	1	69	2.78	3.56	2.35	1.32	1.00	2.01	1.32	1.38	1.10
10	6	0	33	5.10	3.02	4.35	1.21	1.02	1.80	1.41	1.24	1.06
11	5	0	28	2.78	3.14	5.65	1.06	1.36	1.06	1.52	1.21	1.15
12	0	1	78	3.64	3.26	3.25	1.04	1.02	3.02	1.48	1.23	1.02
13	3	2	62	3.25	3.75	4.85	0.98	1.02	1.68	1.47	1.38	1.03
14	1	2	45	4.26	3.68	5.24	0.97	0.89	1.55	1.64	1.25	1.24
15	2	1	97	5.15	3.95	3.65	0.96	0.87	2.78	1.54	1.24	0.99
16	0	0	84	2.35	4.65	3.47	0.98	0.89	2.64	1.61	1.26	0.98
17	2	4	81	3.87	5.86	1.69	0.87	0.96	2.06	1.36	1.27	1.02
18	5	2	54	4.02	3.25	5.98	0.89	0.98	1.75	1.44	1.29	1.09
19	0	0	61	4.65	2.45	3.54	0.98	0.95	1.56	1.33	1.33	1.06
20	2	1	65	4.01	2.96	4.98	1.03	0.96	2.03	1.60	1.24	1.10
Average	2.30b	0.90b	54.40a	3.50b	3.47b	4.44a	1.04b	1.06b	1.75a	1.45a	1.27b	1.10c
Max	6	4	97	5.15	5.86	6.25	1.32	1.59	3.02	1.65	1.38	1.35
Min	0	0	15	2.26	2.45	1.69	0.87	0.87	0.98	1.23	1.19	0.98
Std	1.81	1.07	22.48	0.86	0.76	1.27	0.12	0.19	0.59	0.13	0.06	0.09

plant and litter cover were chosen. These measurements were representative of interill or pedon scale soil erosion processes and inform on the detachment of material under different agricultural management practices. Detailed information on the characteristics of the rainfall in the region and the rainfall simulator can be found in Cerdà (1997) and Cerdà and Jurgensen (2011). Overland flow from the plot area was measured at 1-min intervals and every five minutes a one-minute runoff sample was collected for laboratory analysis in order to determine sediment concentration and calculate the erosion rates. The runoff rates and sediment concentration measurements were used to calculate the sediment yield, total runoff, runoff coefficient (percentage of discharged rainfall), and erosion rates. Vegetative cover was determined with 100 pins measurement in each 0.25 m^2 plot, and soil moisture was measured by drying 100 cm^3 ring samples, collected from the surface to 5 cm of depth before the rainfall experiments, at a temperature of 105 °C for 24 h. Sediment concentration in the runoff was calculated after the desiccation of the samples in the laboratory. Soil bulk density was measure by means of the ring method (Cerdà, 1999) and soil organic matter after Walkley and Black (1934). The experiments were carried out during the Mediterranean summer drought. There was no rain in the 32 days prior to the experiments.

2.3. Statistical analysis

Prior to statistical comparisons, data normality was tested using the Shapiro–Wilk test. Data normality was considered at a $p < 0.05$. Among all the variables, only bulk density (BD) followed the Gaussian distribution. Soil moisture (SM) followed normality after a logarithmic transformation. The other variables (vegetation cover, soil organic matter, runoff coefficient, sediment concentration, total runoff, sediment yield and soil erosion) in the study did not follow normality, even after square-root and Box–Cox transformation. Thus, a one-way ANOVA was used to identify significant differences among plots in BD and SM (using logarithm transformed data). If significant differences were found the Tukey HSD post-hoc test was applied. The non-parametric Kruskal–Wallis ANOVA test (KW) was used to identify differences among plots for variables that did not follow normality after transformations. If significant differences were found, non-parametric multiple comparisons were applied to identify differences within management practices. In all cases, significant differences were considered at $p < 0.05$. A Principal Component Analysis (PCA) was carried out (using the square root transformed data, since the data distributions were closest to normality), based on the correlation matrix, in order to identify correlations among the variables. Statistical analyses were carried out using Statistica 10.0 for windows.

3. Results

3.1. Vegetative cover and soil properties

Significant differences in vegetative cover were identified between the different plots ($KW = 43.31$, $p < 0.001$). Vegetative cover was significantly higher in covered plots (54.4%) than in the tilled (0.90%) and herbicide treated plots (2.3%) (Table 1). The covered plots showed vegetation cover that ranged from 15 to 97% as some areas were bare. The herbicide and tillage plots showed almost completely bare soils, as the maximum vegetation cover recorded was 6 and 4% respectively (Table 1).

Significant differences among treatments were also identified in soil moisture ($F = 4.41$, $p < 0.05$). Soil moisture was significantly higher in the covered plots (4.44%) than in the tillage (3.47%) and herbicide plots (3.50%) (Table 1). In the 0–1 cm depth layer, soil moisture was very low (<7% in all plots) and homogenous for all management strategies. The herbicide plots ranged between 2.26 and 5.15%, the tillage plots between 2.45 and 5.86% and the covered plots between 1.69 and 6.25% (Table 1).

Soil organic matter showed significant differences between plots ($KW = 27.49$, $p < 0.001$). On average, the SOM content was significantly higher in the covered (1.75%) plots than in the tilled (1.06%) and herbicide treated plots (1.04%) (Table 1). The variability in measurements was very similar between the herbicide treated plots and the tillage plots (std of 0.12 and 0.19). However, the highest variability was identified in the covered plots (std = 0.59).

Significant differences were observed in soil BD between plots ($F = 61.40$, $p < 0.001$). It was the highest in herbicide treated plots (1.45 g cm^{-3}) and the lowest in the covered plots (1.10 g cm^{-3}) (Table 1). Soil BD values ranged from 1.23 to 1.65 g cm^{-3} in the herbicide treated plots, from 1.19 to 1.38 g cm^{-3} in the tillage plots, and from 0.98 to 1.35 g cm^{-3} in the covered plots.

When the soil characteristics are compared with the vegetation cover in the plots (Fig. 2), it is clear that the different treatments form groups when plotted. In the vegetated plots the BD becomes lower when the vegetation cover is higher (Fig. 2A). In the herbicide and tilled plots there is no or very little vegetation, but in the tilled plots the BD is lower than in the herbicide plots (Fig. 2A). Similar relations can be observed when the SOM content is compared to the vegetation cover (Fig. 2B), although here the difference between tilled and herbicide treated plots in not clear. When the relation between BD and OM is plotted (Fig. 2C) we can observe three groups: the covered plots with low

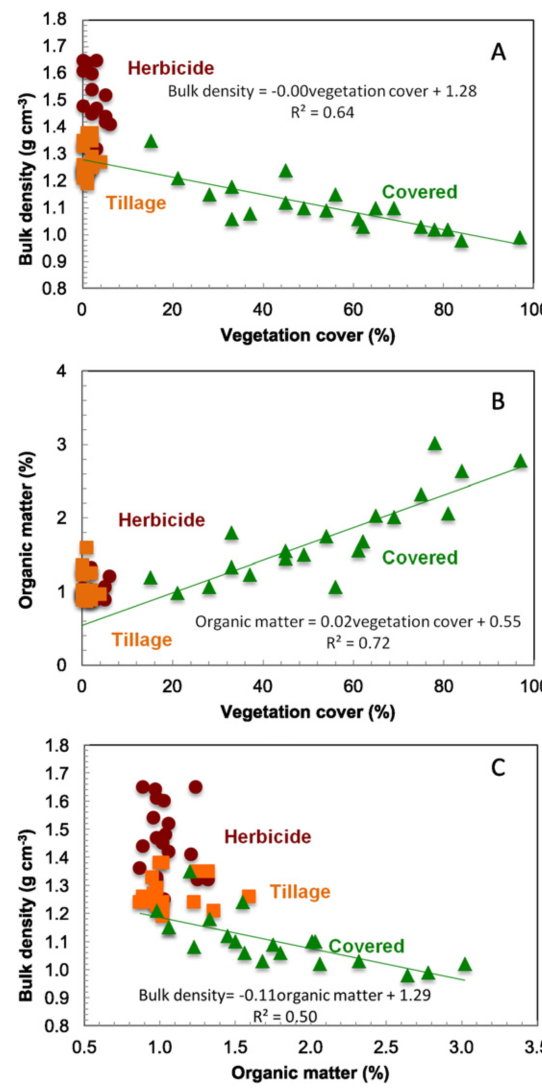

Fig. 2. Relationship between vegetative cover and soil bulk density (A) and organic matter (B) and Bulk density and organic matter (C) in apricot orchards at the Vall d'Albaida research site, Eastern Spain.

Table 2
Runoff coefficient (%), Sediment concentration ($g\ l^{-1}$) and Total runoff (l) for the 60 plots researched at the three experimental site on Herbicide (n = 20), Tillage (n = 20), and Covered plots (n = 20) in the Vall d'Albaida research sites on apricot production. Different letters represent significant differences at a $p < 0.05$.

Plots	Runoff coefficient (%)			Sediment concentration ($g\ l^{-1}$)			Total runoff (l)		
n = 60	Herbicide	Tillage	Covered	Herbicide	Tillage	Covered	Herbicide	Tillage	Covered
1	49.52	5.32	2.32	5.32	18.54	1.20	6.81	0.73	0.32
2	45.25	6.30	5.32	5.32	16.32	2.01	6.22	0.87	0.73
3	23.32	4.58	1.02	4.25	14.25	0.98	3.21	0.63	0.14
4	45.60	5.69	1.36	5.36	13.36	1.35	6.27	0.78	0.19
5	48.25	7.58	2.32	3.65	14.25	1.26	6.63	1.04	0.32
6	46.50	10.20	2.98	2.15	13.25	1.32	6.39	1.40	0.41
7	48.20	10.36	4.35	5.32	16.32	3.00	6.63	1.42	0.60
8	47.50	9.36	6.32	4.25	16.32	2.50	6.53	1.29	0.87
9	56.32	8.54	1.25	3.25	16.32	1.30	7.74	1.17	0.17
10	45.14	7.36	2.32	5.36	10.25	1.65	6.21	1.01	0.32
11	26.98	9.54	4.25	4.25	14.25	2.54	3.71	1.31	0.58
12	45.32	8.65	0.36	9.32	19.32	1.36	6.23	1.19	0.05
13	23.25	4.58	1.58	5.98	12.25	1.24	3.20	0.63	0.22
14	47.25	2.36	3.65	3.26	12.36	2.01	6.50	0.32	0.50
15	48.32	3.65	0.25	4.25	14.25	0.81	6.64	0.50	0.03
16	26.32	4.58	0.35	6.32	10.32	0.98	3.62	0.63	0.05
17	26.98	2.36	0.68	2.15	16.25	1.30	3.71	0.32	0.09
18	42.50	9.85	4.25	1.32	9.35	1.34	5.84	1.35	0.58
19	33.33	10.25	1.98	4.25	9.89	0.89	4.58	1.41	0.27
20	32.69	14.25	3.45	5.65	5.65	1.25	4.49	1.96	0.47
Average	40.43a	7.27b	2.52c	4.55b	13.65a	1.51c	5.56a	1.00b	0.35c
Max	56.32	14.25	6.32	9.32	19.32	3.00	7.74	1.96	0.87
Min	23.25	2.36	0.25	1.32	5.65	0.81	3.20	0.32	0.03
Std	10.29	3.13	1.75	1.76	3.37	0.59	1.41	0.43	0.24

BD and high OM; the herbicide plots with high BD and low OM; and the tilled plots with low BD and low OM.

3.2. Soil losses and runoff

Table 2 shows the average runoff coefficient (%), sediment concentration ($g\ l^{-1}$) and total runoff (l) for each type of plot. Significant differences were observed in runoff coefficient between each of the plots (KW = 48.72, $p < 0.001$). On average, the runoff coefficient was significantly higher on the herbicide treated plots (40.43%) than for the tillage plots (7.27%) and the covered plots (2.52%). The values ranged from 23.25 to 56.32% in the herbicide plots, from 2.36 to 14.25% in the tillage plots and from 0.25 to 6.32% in the covered plots.

The sediment concentration showed different behaviour. Significant differences were identified in sediment concentration among all the studied management strategies (KW = 50.10, $p < 0.001$). It was the highest in the tillage plots (13.65 $g\ l^{-1}$), followed by the herbicide plots (4.55 $g\ l^{-1}$), and was the lowest in the covered plots (1.51 $g\ l^{-1}$). The values ranged from 1.32 $g\ l^{-1}$ to 9.32 $g\ l^{-1}$ in the herbicide treated plots, from 5.65 $g\ l^{-1}$ to 19.32 $g\ l^{-1}$ in the tillage plots and from 0.81 $g\ l^{-1}$ to 3.00 $g\ l^{-1}$ in the covered plots. The variability in the

Table 3
Sediment yield (g), Soil erosion ($g\ ha^{-1}\ h^{-1}$), and Soil erosion ($Mg\ ha^{-1}\ h^{-1}$) for the 60 plots researched at the three experimental sites on Herbicide (n = 20), Tillage (n = 20), and Covered (n = 20) plots in the Vall d'Albaida research site on apricot production. Different letters represent significant differences at a $p < 0.05$.

Plots	Sediment yield (g)			Soil erosion ($g\ m^{-2}\ h^{-1}$)			Soil erosion ($Mg\ ha^{-1}\ h^{-1}$)		
n = 60	Herbicide	Tillage	Covered	Herbicide	Tillage	Covered	Herbicide	Tillage	Covered
1	8.99	8.96	0.40	35.95	35.84	1.58	0.36	0.36	0.02
2	26.44	10.71	1.47	105.77	42.83	5.88	1.06	0.43	0.06
3	11.70	8.97	0.11	46.81	35.90	0.45	0.47	0.36	0.00
4	13.48	12.77	0.47	53.92	51.07	1.87	0.54	0.51	0.02
5	35.29	17.01	0.41	141.18	68.04	1.66	1.41	0.68	0.02
6	13.75	14.38	0.68	54.99	57.50	2.70	0.55	0.58	0.03
7	8.75	19.03	0.81	34.99	76.13	3.23	0.35	0.76	0.03
8	27.76	18.34	1.09	111.03	73.36	4.38	1.11	0.73	0.04
9	25.17	15.56	0.23	100.67	62.24	0.91	1.01	0.62	0.01
10	33.02	16.52	0.96	132.08	66.06	3.83	1.32	0.66	0.04
11	19.74	18.69	1.48	78.94	74.77	5.94	0.79	0.75	0.06
12	26.48	22.98	0.07	105.94	91.91	0.27	1.06	0.92	0.00
13	17.14	11.68	0.26	68.54	46.70	1.04	0.69	0.47	0.01
14	21.18	5.30	1.01	84.72	21.18	4.04	0.85	0.21	0.04
15	28.24	7.15	0.03	112.95	28.61	0.13	1.13	0.29	0.00
16	22.87	6.50	0.05	91.49	26.00	0.19	0.91	0.26	0.00
17	19.88	5.27	0.12	79.54	21.09	0.49	0.80	0.21	0.00
18	24.84	12.66	0.78	99.34	50.65	3.13	0.99	0.51	0.03
19	42.71	13.94	0.24	170.85	55.75	0.97	1.71	0.56	0.01
20	25.40	11.07	0.59	101.58	44.28	2.37	1.02	0.44	0.02
Average	22.64a	12.87b	0.56c	90.56a	51.50b	2.25c	0.91a	0.51b	0.02c
Max	42.71	22.98	1.48	170.85	91.91	5.94	1.71	0.92	0.06
Min	8.75	5.27	0.03	34.99	21.09	0.13	0.35	0.21	0.00
Std	8.85	4.99	0.46	35.38	19.96	1.83	0.35	0.20	0.02

measurements was the highest in the tillage plots and lowest in the covered plots (Table 2).

The average total runoff was significantly different among plots (KW = 48.72, $p < 0.001$). The highest runoff was identified in the herbicide treated plots (5.56 l) and the lowest in the covered plots (0.35 l) with intermediate values in the tillage plots (1.00 l). Total runoff values ranged from 3.20 to 7.74 l in the herbicide treated plots, 0.32 to 1.96 l in the tillage plots, and 0.03 to 0.87 in the covered plots. The variability in the measurements was the highest in the herbicide treated plots, the lowest in the covered plots, and intermediate in the tillage plots (Table 2).

Significant differences were observed in sediment yield between plots (KW = 45.14, $p < 0.001$). On average, sediment yield was significantly higher in herbicide treated plots (22.64 g) than tillage (12.87 g) and covered plots (0.56 g). Covered plots sediment yield was also significantly lower than in the tillage plots. Sediment yield values ranged from 8.75 to 42.71 g in herbicide treated plots, from 5.27 to 22.98 g in tillage plots, and 0.03 to 1.48 g in covered plots. The sample variability was the highest in herbicide treated plots and lowest in covered plots (Table 3).

Soil erosion as calculated in g m^{-2} h^{-1} and Mg ha^{-1} h^{-1} (Table 3) were significantly different between plots (KW = 45.14, $p < 0.001$, g m^{-2} h^{-1}). In both unit measurements, the highest values were identified in the herbicide treated plots (90.56 g m^{-2} h^{-1} and 0.91 Mg ha^{-1} h^{-1}) and the lowest in the covered plots (2.25 g m^{-2} h^{-1} and 0.02 Mg ha^{-1} h^{-1}), with tillage plots having intermediate values (51.50 g m^{-2} h^{-1} and 0.51 Mg ha^{-1} h^{-1}). The values ranged from 34.99 to 170.85 g m^{-2} h^{-1} and 0.35 to 1.71 Mg ha^{-1} h^{-1} in the herbicide treated plots, from 21.09 to 91.91 g m^{-2} h^{-1} and 0.21 to 0.92 Mg ha^{-1} in the tillage plots and from 0.13 to 5.94 g m^{-2} h^{-1} and from 0.00 to 0.06 Mg ha^{-1} h^{-1} in the covered plots. The variability in the measurements was the highest in the herbicide treated plots and the lowest in the covered plots (Table 3).

When the data was combined (Fig. 3) we observed that in the vegetated plots the runoff was very low regardless of the vegetation cover and the OM (Fig. 3A and B). In the tilled plots the runoff was also low, however there was more scatter. Because there was no vegetative cover, there was also no relation between the two parameters (Fig. 3A); however OM causes some scatter in the data (Fig. 3B). In the herbicide plots the runoff seemed to be scattered regardless of the OM and vegetation cover (Fig. 3A and B). In Fig. 3C where the runoff coefficient was plotted against the sediment concentration three groups can be clearly identified; the covered plots had low sediment concentration and a low runoff coefficient; the tilled plot showed low runoff coefficients but high sediment concentrations; and the herbicide treated plots showed a low sediment concentration but very high runoff coefficient.

3.3. Multivariate analysis

The first two factors explained a total of 81.85% of the total variance. The multivariate analysis identified 3 main groups, the first composed of vegetation cover, soil moisture and SOM, the second of bulk density, total runoff, runoff coefficient, sediment yield and soil erosion, and the third of sediment concentration (Fig. 4). These results show that the variables in the first group were negatively correlated with the variables in group 2. The variable in group 3 (sediment content) also had a negative correlation with the variables of group 1 and had a low positive correlation with the variables of group 2. Fig. 5 shows that the variables studied strongly depended on the type of management. The soil properties and runoff are more similar in the herbicide treated and tilled plots than in the covered areas.

The total sediment generated averaged 22.64 g per plot in the herbicide treatment, while the tillage treatment was 12.87 g and the covered plots 0.56 g. The plots under herbicide treatment ranged from 8.75 to 42.71 g, tillage from 5.27 to 22.98 g, and covered from 0.03 to

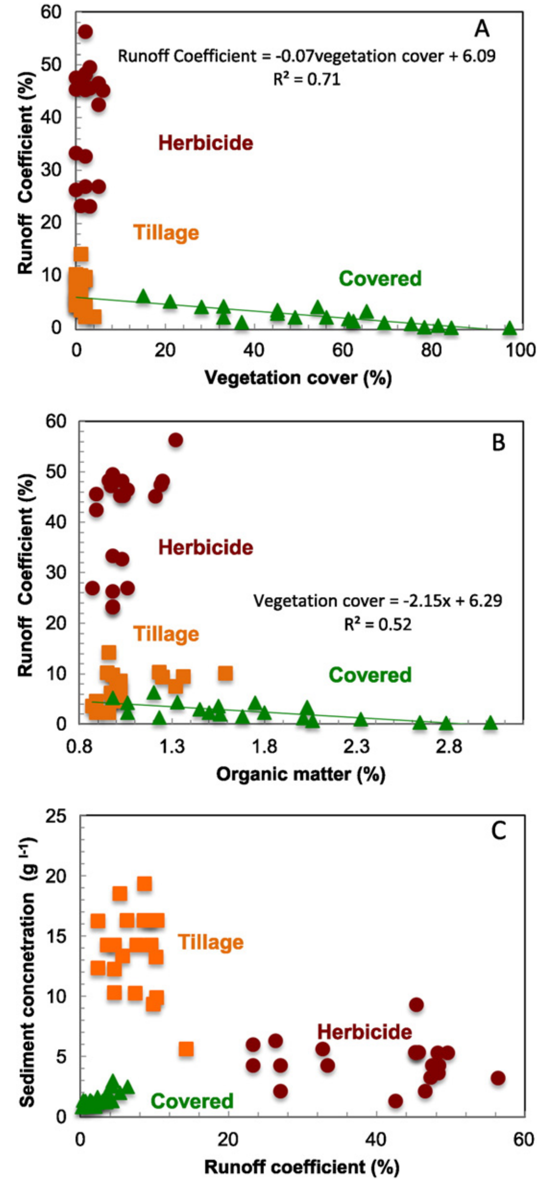

Fig. 3. Relationship between the organic matter (A) and vegetation cover (B) with the runoff coefficient, and the runoff coefficient with the sediment concentration (C).

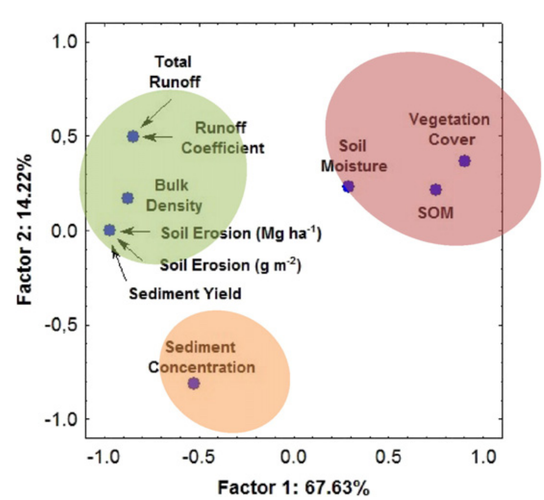

Fig. 4. Relation between factor 1 and factor 2 variables. Different colours show the groups identified.

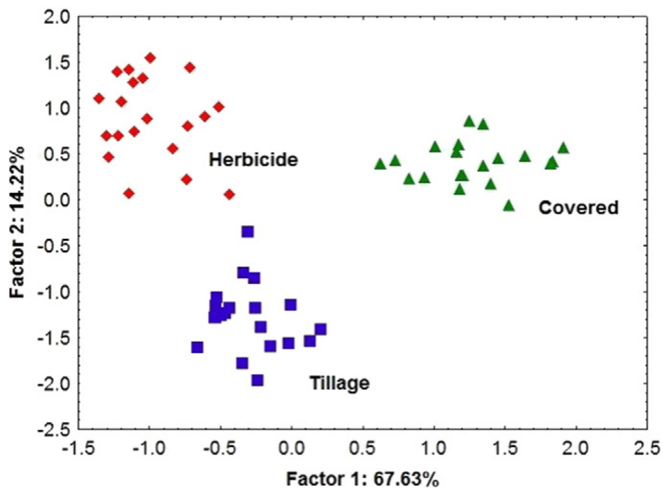

Fig. 5. Relationships between factor 1 and factor 2 cases. Different colours show the groups identified.

1.48 g. Soil erosion showed a similar pattern: covered plots lost 2.25 g m^{-2} h^{-1}/0.02 Mg ha^{-1} h^{-1}, meanwhile the tillage plots lost 51.50 g m^{-2} h^{-1}/0.51 Mg ha^{-1} h^{-1} and the herbicide plots 90.56 g m^{-2} h^{-1}/0.91 Mg ha^{-1} h^{-1}.

4. Discussion

Rainfed agriculture in the Mediterranean belt produces fruits for international markets in orchards that often have extensive areas of bare soils due to intense tillage or the massive use of herbicides. Soil and water conservation strategies are rarely applied. Sustainable land management strategies are very infrequent and there is a need to research which management strategies are sustainable. Soil erosion is one of the consequences of the bare soils, and soil erosion contributes to soil degradation, but also results in damages due to floods and the sedimentation of lakes, reservoirs and rivers, and the loss of soil fertility and farmers' income (de Graaff et al., 2010; Adimassu et al., 2012; Yuan et al., 2015). This study demonstrates that the use of herbicides (leading to bare soils the whole year round) and the conventional tillage system applied in Spain on rainfed orchards (three to four tillage events yearly) results in negligible vegetative cover, high soil bulk density, and extremely high runoff sediment concentrations that result in high erosion rates. The measurements carried out here simulated high magnitude low frequency rainfall events and showed that apricot orchards can lose as much as 0.5 Mg ha^{-1} of soil in one hour, when measured at the plot scale, which make these land management practices unsustainable. Tillage has been seen as a major cause of soil erosion since agriculture was developed (Brevik and Hartemink, 2010), both in terms of water erosion (Novara et al., 2011; Casalí et al., 2015) as well as wind erosion (Gao et al., 2015). Tillage is also seen as a key factor for agricultural production (Singh et al., 2014) as it modifies soil properties such as organic carbon (Hassan et al., 2014; Parras-Alcántara and Lozano-García, 2014;), the habitat for biota (Balota et al., 2014; Costantini et al., 2015) and chemical properties (Laudicina et al., 2015; Zornoza et al., 2015). Tillage is usually seen as the primary cause of soil erosion in rainfed agriculture (Lieskovský and Kenderessy, 2014), and the cause of the acceleration of sediment fluxes on all the continents (Dupin et al., 2009; Van Oost et al., 2009; Zhang et al., 2009).

In the Vall d'Albaida research area tillage caused high erosion rates. Over the last two decades tillage management for weed control has been replaced by herbicides at many orchards. Although herbicides were recommended to be used only during the spring, many farmers use high doses of herbicides throughout the growing season to avoid any weeds and keep the orchards "clean". This is likely culturally inherited, as under tillage the soil is bare the whole year round and farmers now use herbicides with this same goal. This is why the soil surfaces in the orchards managed with herbicides are almost bare and soil erosion rates are twice as high as the rates measured in the tilled orchards, as herbicides also contribute to compaction of the surface layer of the soil due to wheel traffic during application (Bayhan et al., 2002). The misuse and abuse of herbicides has been observed in other orchards, such as olive (Gómez et al., 2004; Gómez et al., 2009) and citrus (Cerdà et al., 2009a, 2009b). In a study by Francia Martínez et al. (2006) in an olive orchard, soil loss at the hillslope scale (24 m long plots) under natural condition rainfall was studied for sites under tillage, herbicides and a combination with vegetation and herbicides. This experiment showed the same trend in sustainability as found in the current study. Also a study under natural rainfall in a vineyard showed no-tilled herbicide treated hillslopes experienced more soil loss than a tilled hillslope (Raclot et al., 2009). These results are contrary to the findings of pioneering researchers who found that a sustainable use of herbicides reduced soil losses and runoff in comparison to tillage (Locke and Bryson, 1997; Shipitalo and Edwards, 1998; Sanchez et al., 2002). This study was done on a plot scale, which is representative for the interrill erosion and sheet erosion component of the sediment yield of a total field, hillslope or even catchment. This information cannot be unscaled by simply multiplying the numbers found; however, it gives good insights and quantifies changes in water and sediment dynamics at the small scale due to differences in soil properties resulting from the management treatments studied. The insights generated for the plot scale show the differences in soil properties that develop due to the management strategies employed. The impact of the soil and surface properties that influence the processes of infiltration and soil detachment can be best studied in detail at the plot scale as no other factors can disturb the measurements.

Fig. 2 shows the importance of vegetative cover in the recovery of organic matter in the soils. Herbicides and tillage do not allow vegetation to grow which causes an extremely low organic matter content of approximately 1%. However, when vegetative growth was re-established for a period of 20 years the organic matter in the top soil (0–1 cm of depth) increased significantly (1.75%). The correlation between vegetative cover (in the covered plots) and soil organic matter shown in Fig. 2a demonstrates their positive relationship. This increase in organic matter results in a decrease in bulk density, which is due to the fact that organic matter has a low particle density as well as the effect of roots, insects and burrowing animals drawn by the vegetative food source creating macropores and aggregate formation. More vegetation means more organic matter and more organic matter results in a lower bulk density (Fig. 2c) (Brevik and Fenton, 2012; Srinivasarao et al., 2014; Parras-Alcántara et al., 2015).

When looking at the whole hillslope other processes such as rill and gully erosion (Poesen et al., 2003) and the impact of roads and man-made structures (Parsons et al., 2006) enter the picture. These features can increase total erosion and facilitate sediment transport downstream; however, large volumes of water and sediment can also be retained in (temporal) storage sites along the hillslope (Baartman et al., 2013). The connectivity issue is of great importance to understand the impact of the land management on the detachment of soil particles that is studied here, but also the transport and sedimentation. There is a need to understand how the land management affect the connectivity of water, sediments, nutrients and seeds along the fields, trams of slopes, slopes, watershed and basin (Marchamalo et al., 2015; Parsons et al., 2015).

This research demonstrates that tillage results in non-sustainable management in Mediterranean orchards from the point of view of soil and water conservation. However, the misuse of herbicides produces even higher soil erosion rates, and the sustainability is not improved. The erosion rates in this study was twice as high in the plots treated with herbicides than in the tilled plots (Fig. 3). Moreover, runoff was 5.6 times higher in the herbicide treated than in the tilled orchards. The use of vegetative cover and chipped pruning residuals was the best management practice studied to reduce soil losses and runoff. The experiments carried out in the Vall d'Albaida traditional apricot production region demonstrated that soil losses from the covered soils (0.02 Mg ha^{-1} h^{-1}) were lower than the herbicide plots (0.9 Mg ha^{-1} h^{-1}) and tillage plots (0.5 Mg ha^{-1} h^{-1}). This has been recently found in other experiments in the same region with the use of straw mulch as a cover (Cerdà et al., 2015; Prosdocimi et al., 2016).

The literature shows that vegetation can control soil erosion (Beadle, 1948; Ola et al., 2015), in other regions and on forest and agriculture soils (Borrelli et al., 2015; Nanko et al., 2015; Ochoa-Cueva et al., 2015). The reason for the decrease in soil erosion rates as a consequence of vegetation recovery is because the vegetation reduces or avoids the rainfall erosivity (Cerdà, 1998; Keesstra, 2007; Ni et al., 2015; Taguas et al., 2015), improves soil properties and reduces runoff and soil losses. Keesstra et al. (2009) found that vegetation recovery reduced sediment losses in Slovenia. Similar findings were reported by Palacio et al. (2014) at pachy-pedon scales in Patagonia. Land use and land cover changes are the reason for the changes this study found in runoff and soil erosion, as Gessesse et al. (2014) found in Ethiopia and Cao et al. (2015) found in China as a consequence of the conservation programmes of their governments. Cerdà (2000) reported similar findings when measuring aggregate stability in Bolivia under different land uses and management. Over long time scales vegetative cover not only shields the soil surface from the force of rain, it improves the quality of soil and thus reduces soil erosion as infiltration increases and surface runoff is reduced (Brevik, 2009).

At the research sites in Vall d'Albaida, tillage was the only management strategy used by farmers until the 1990's when the use of herbicides was introduced and runoff and soil losses increased. The influence of the demand for organic products and the change in management adopted by some pioneering farmers led to vegetative cover between the trees in some orchards and to chipping after pruning and spreading the chips on the soil's surface, rather than burning them. This allowed the soils to recover, increasing soil organic matter and reducing soil bulk density. The vegetative cover is not only reducing soil erosion due to the direct effects of the cover, it is also a long-term soil changes. Vegetation and the associated ecosystem including biota create a higher soil quality with more macro-pores, better soil structure and higher soil fertility (Reicosky and Forcella, 1998). The effectiveness of the vegetative cover management was confirmed with the PCA. The variables of group 1 (vegetative cover, soil moisture and SOM) showed high values in covered plots, while the variables of group 2 (bulk density, total runoff, runoff coefficient, sediment yield and soil erosion) and 3 (sediment concentration) were low. In the other management types, the values of group 1 were low and from groups 2 and 3 were high. Overall, group 1 showed high values in covered management, group 2 in herbicide treatments, and group 3 in tillage plots. The PCA identified that the variables studied were importantly different according to the type of management. From a soil erosion and water conservation perspective, the management types studied can be classified as covered > tillage > herbicide.

In addition, the changes in soil erosional and hydrological response introduced by the soil cover from vegetative growth and the use of mulch (litter) plus the chipped pruning residuals, which is a regular practice in farms with covered fields, is clearly shown by the results of this study: a reduction in surface runoff and sediment concentration. Fig. 3a and 3b show the relationships between soil organic matter and vegetation cover and soil runoff coefficient, showing that as soil organic matter or vegetative cover increase, the runoff coefficient decreases.

Fig. 3c shows that there is a clear correlation between land management and the erosional and hydrological response of soils under rainfed apricot production. There are three clear responses to the rainfall: the vegetation covered soils had low runoff and sediment concentration and as a consequence low erosion rates. The soils under tillage had high sediment concentrations due to the high erodibility of tilled soils, but had lower runoff rates in comparison to the herbicide treatment. Finally, the soils with herbicide treatment showed very high runoff discharges due to their high bulk density (crusting) and the low organic matter content, but the runoff sediment concentration was not as high as under tillage. However, the total soil loss from the plots treated with herbicides was the highest of all studied management strategies due to the very high runoff discharge.

5. Conclusions

The soil and water losses in rainfed apricot orchards in Eastern Spain are not sustainable when traditionally tilled. The use of herbicides aggravates the situation, increasing the erosion rates to as much as two times the rates in traditionally tilled plots in one hour of intense rain. However, in orchards where the soil is covered with vegetation and chipped pruning residuals there is an increase in vegetative cover and soil quality. There, erosion rates are reduced by as much as an order of magnitude. Those findings show that from a soil erosion and water conservation perspective, the management types studied here can be classified as covered > tillage > herbicide. Following the practice of keeping the soil covered with vegetation would contribute to better land use management in apricot orchards in the Eastern Iberian Peninsula, and this is a general rule for the Mediterranean Type Ecosystems such as we found in the literature.

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COMMUNITY-BASED REHABILITATION OF MOUNTAIN TERRACES IN CYPRUS

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ABSTRACT

Participatory methods and community-based approaches have an important role to play in combating land degradation. This paper follows a well-defined participatory framework to identify key stakeholders and to select Sustainable Land Management approaches for reducing soil erosion and land degradation in the Troodos Mountains of Cyprus. Among the options suggested and evaluated by stakeholders, terrace rehabilitation had the best overall performance, followed by crop diversification and afforestation. Stakeholders agreed that the rehabilitation of dry-stone terraces was the preferred option, as it is a practice with high environmental benefits and fits well in the local socio-cultural context, despite the higher cost compared to other options. In the first year of implementing the approach, three mountain communities co-organised hands-on terrace maintenance events, engaging more than 160 people in rehabilitation activities. The community-based approach has sparked the interest of people within and beyond the research site, and another series of events is scheduled for the coming season. This outcome indicates that social innovations can benefit from the integration of local and scientific knowledge, while participatory process can enhance the self-confidence and organisational structures of local communities. Sustaining and enhancing the impact of the approach in the long-run require developing local terrace maintenance institutions, actively engaging the youth in terrace management and improving the profitability of mountain farming through the differentiation of local products. Copyright © 2016 John Wiley & Sons, Ltd.

KEY WORDS: participatory action research; Mediterranean mountains; dry-stone terraces; sustainable land management; soil erosion

INTRODUCTION

The construction of dry-stone walls is a millennium-long process of establishing complex systems to manage slope dynamics (Tarolli *et al*., 2014; Agnoletti *et al*., 2015). Considering the relative scarcity of suitable land for farming in mountain regions, dry-stone terraces provide an intensive cultivation form which requires little mechanical aid but high input in terms of labour (Rolé, 2007). The obvious purpose of agricultural terraces is food production, although their relevance to modern concerns relates these man-made structures to sustainable land management (SLM), water retention and control of soil erosion in sloping hillsides (Li *et al*., 2014), as well as being a biodiversity habitat (Agnoletti *et al*., 2015). Because of their important multifunctional uses and their long existence over many human generations, terraced landscapes are a well-regarded form of *landesque* capital (Widgren, 2007) and are considered imperative cultural landscapes (Torquati *et al*., 2015).

The importance of agricultural terrace systems has been widely recognised in recent years, which has led to the proliferation of protective actions at the European level. For instance, to increase the competitiveness and to sustain the ecological functions of landscape features such as dry-stone terraces, the European Commission (2009, 2013) provides subsidy support to farmers for their conservation, restoration and maintenance. Conserving and maintaining terrace also contribute to the achievement of sustainability goals such as food and water security, land management, climate change and biodiversity conservation (Brevik *et al*., 2015; Keesstra *et al*., 2016). Furthermore, the agronomic, historic and biocultural value and diversity provided by traditional landscapes have been also recognised by UNESCO's (2014) Florence Declaration.

Despite their importance in terms of ecological provision and cultural heritage, and the financial support for their preservation, mountain terrace landscapes in the Mediterranean region are gradually abandoned as a result of socio-economic changes and radical Common Agricultural Policy reforms (Koulouri & Giourga, 2007). The economic significance of Mediterranean mountain farming has been drastically diminished over time mainly because of high production costs, low response to market demands and limited development opportunities. Consequently, mountains have become marginal territories with few inhabitants because of population migration to urban centres (Lasanta *et al*., 2001). Abandonment of terraced agricultural systems introduces geomorphic processes such as soil erosion and slope failures (Camera *et al*., 2014) and represents considerable sediment sources in semi-arid environments, as reported by Lesschen *et al*. (2008) in Spain and Djuma *et al*. (2016) in Cyprus. Soil erosion is one of the major threats to soils in the Mediterranean EU Member States (Panagos *et al*., 2015). In mountain

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regions, soil erosion infers drastic reduction in soil productivity and exposure of bedrock, which could eventually result in desertification (Vieira *et al*., 2015; Xie *et al*., 2015). In addition to land degradation, terrace abandonment implies detachment of the young generation from traditional agronomic practices and loss of indigenous knowledge (Tarolli *et al*., 2014).

Terrace abandonment in southern Europe and the associated erosion risks have been increasingly reported in the literature (Arnáez *et al*., 2015). According to the review study of García-Ruiz and Lana-Renault (2011), narrow bench terraces that were impossible to work with machinery have been gradually abandoned since the 1950s. These authors indicate that the evolution of land following abandonment depends on the time of abandonment, the climatic conditions, the field characteristics and the management regime, and highlight the need of targeted policies capable to remediate the consequences of soil degradation. Tarolli *et al*. (2014) also provide a review of the critical issues associated with land abandonment and explore the potentials of structural (e.g. identification of failure mechanisms and maintenance of collapsed walls) and non-structural measures (e.g. awareness campaigns, international initiatives and training of young people to maintain terraced landscapes) for the management of such environments.

There is a growing recognition that participatory methods and community-based approaches have an important role to play in combating land degradation, as technocratic and top-down approaches have often led to implementation failures or low acceptance by land users (Ludwig, 2001). Given the complexity, diversity and dynamics entailed in soil degradation issues, the need to engage multiple stakeholder groups, and especially local stakeholders and land users, is nowadays widely accepted as the way forward. According to Berkes (2004: 628), "*to ground conservation effort*, *we need a more nuanced understanding of the nature of people*, *communities*, *institutions*, *and their interrelations at various levels*". Schneider *et al*. (2009) note that the quest for sustainable soil protection should be conceived as a process of knowledge creation and co-production between farmers, experts and scientists.

In essence, a key objective of participatory research processes is to foster knowledge exchange and mutual learning among different stakeholders (Vila Subirós *et al*., 2015; Pereira *et al*., 2016), which can potentially lead to the development of innovative, sustainable and broadly accepted solutions (Schwilch *et al*., 2009; Giger *et al*., 2015). Knowledge of different stakeholder groups is often highly disconnected. Thus, achieving an effective interdisciplinary research foundation requires understanding of the main issues in the area of interest and identifying relevant stakeholders from the early stages of the process (Reed *et al*., 2009). This highlights the usefulness of developing multi-stakeholder platforms, which can function as decision-making bodies and enable an empowered and active engagement of interdependent stakeholders in the search for solution-oriented SLM options to a common problem (Faysse, 2006). There is also a need to shift from conceptual frameworks to dynamic knowledge–action interfaces, to implement SLM practices that benefit local societies and to provide feedback to policy makers (Wolfgramm *et al*., 2015). Interestingly, participatory methodologies and community-based approaches have been formulated and mainly applied in the context of developing countries (Yuliani *et al*., 2015; Beyene, 2015; Blaikie, 2006), and as such there is much less documentation in the European context.

The aim of the presented action research is to identify and test a SLM option for reducing soil erosion and land degradation in terraced mountain environments. A community-based approach has been developed with three communities in the Troodos Mountains of Cyprus. The paper describes the interdisciplinary process and the lessons learned from the integration of local and scientific knowledge to combat land degradation, and discusses the implications and outlook of the approach.

MATERIAL AND METHODS

Research site

The Troodos Ophiolite Complex on the island of Cyprus covers an area of 2332 km^2 (i.e. 40% of the area under the effective control of the Republic of Cyprus) with 31% mean slope gradient; it consists of 140 communities with a population of around 50,000 inhabitants. Abandonment of agriculture, practiced on terraces, is pervasive; 20% of the agricultural land of the communities above 600 m has been abandoned in the past two decades (Agriculture Census, www.mof.gov.cy/cystat). The research site in this paper refers to the area comprised by the communities of Polystypos, Alona and Platanistasa, located along the northern slopes of the Troodos Mountains (Figure 1). These communities are representative of the agricultural practices and land use trends in the region.

Agriculture is practiced on dry-stone terraces with narrow (1–3 m) to medium-base (3–6 m) bench, constructed by cutting and filling in slopes with gradient between 20 and 40%. The main crop grown on terraces is wine grapes, followed by almond and deciduous fruit trees. The population of the three communities has decreased by 73% over the past 30 years; from 1,142 inhabitants in 1982 to 312 in 2011 (Population Census, www.mof.gov.cy/cystat). The depopulation of mountain communities along with high farming costs constitutes the main constraining factors for soil conservation. Consequently, many mountain terraces have been abandoned and dry-stone walls remain unmaintained, sometimes causing a domino effect of collapsing terraces (Figure 2). In some locations, nature is taking over and the degradation of dry-stone walls and soil erosion is more gradual than on the poorly vegetated terraces. In addition, the semi-arid climate and the high summer temperatures imply high fire risks and increase the susceptibility of the area to further land degradation and potential desertification.

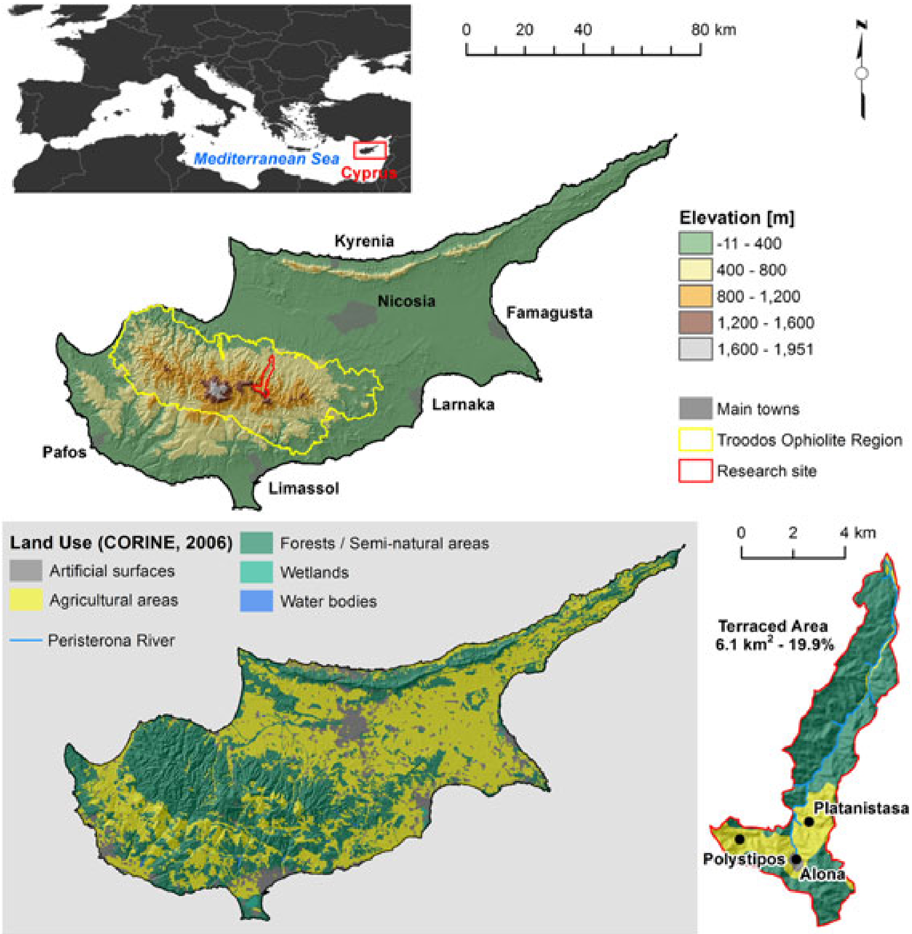

Figure 1. Location, topography and land use of the research site.

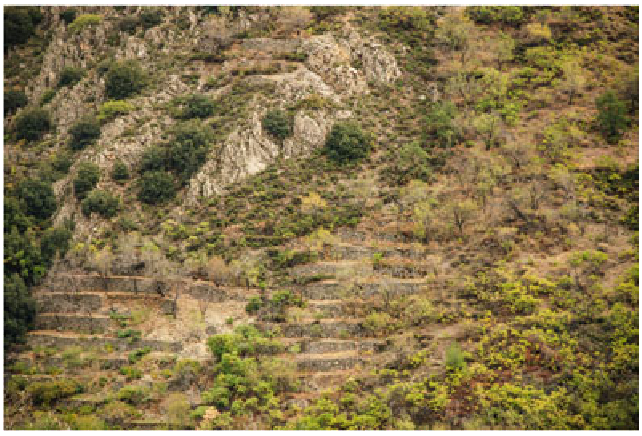

Figure 2. Unmaintained and collapsing dry-stone terraces in Polystipos community.

Participatory Process

The participatory process followed consists of four main steps (Schwilch *et al*., 2009, 2012): (i) establishment of a stakeholder platform; (ii) identification of SLM options to combat land degradation and soil erosion in the research site; (iii) assessment of SLM options using the World Overview of Conservation Approaches and Technologies (WOCAT) questionnaires (www.wocat.net); and (iv) selection of a SLM option for implementation using a Multi Objective Decision Support System.

Stakeholder Platform

The stakeholder platform is the principal component of the participatory process and consists of two components: a network of stakeholders and the tools utilised to interact, communicate and promote the co-production of knowledge with stakeholders (e.g. formal and informal meetings, stakeholder workshops, field visits, focus group discussions, dissemination material etc.).

Stakeholder identification was based on a structured snowball sampling method (Reed, 2008), using a two-part questionnaire: (i) the first part focused on stakeholder characterisation (e.g. by activity, sector, role and interest) and on collecting information on the administrative structures and the nature of soil degradation in the area; (ii) the second part prompted the identification of existing forums for stakeholder communication and collaboration (such that the subsequent participatory steps are planned to complement rather than distract existing processes), while responders were asked to identify stakeholders that they considered important for the process. Two categories of stakeholders constitute the network:

- Core stakeholders are those whose actions and decisions have a direct influence on land management, they are affected by land degradation and soil erosion in the area, and have a strong interest in preventing and mitigating these threats. Stakeholders in this category will be more actively involved in the participatory learning activities, and they are sub-divided into local and external stakeholders:

  Local stakeholders are those who live in the area, they know the rural landscape characteristics and have site-specific knowledge and land management experience (e.g. land users/owners, community leaders).
  External stakeholders are those who have interest and work within the specific rural environment, they have different levels of professional experience on soil-related issues, and are able to suggest and evaluate alternative SLM practices (e.g. researchers, public and civil society officers working on relevant issues).

- Secondary stakeholders are those selectively engaged in the participatory process, for example through expert interviews, or by receiving information on the activities within the study area (e.g. policy makers, the media and the general public).

Participatory Identification of SLM Options

Stakeholder workshops are the cornerstone of the followed participatory approach and bring together actors with different experiences and perspectives, thus offering an interactive basis for combined thinking towards a shared vision (Schwilch *et al*., 2009). The aim of the first workshop was the participatory identification of existing and potential prevention, remediation and restoration options to address soil erosion by water in the study area. To create an appreciative working atmosphere and enable mutual trust and open-minded attitudes, the workshop was organised in a mountain community within the study area in November 2014. The workshop was structured to follow a logical and consecutive sequence of interactive exercises, directly related to the local context, and was facilitated by two moderators who guided the process. The major steps are shown in Table I.

Assessment of SLM options identified

The WOCAT inventory questionnaires (www.wocat.net) were used as a documentation and appraisal tool for the assessment of the SLM options identified by stakeholders. The WOCAT framework focuses on evaluating both the conservation technologies and their implementation approaches, which are jointly referred to as SLM practices (Liniger & Schwilch, 2002). The technology questionnaire focuses on agronomic, vegetative, structural and management conservation measures, or a combination of these, and addresses the specifications, the natural and human environment where it is implemented, and the impact of each technology (i.e. advantages and disadvantages, economic impacts, acceptance and adoption). The approach questionnaire addresses how the implementation of a SLM practice is achieved and by whom, by documenting the objective, the operation and participation, the inputs and means (e.g. material, financial, etc.), the necessary know-how (e.g. technical, scientific, etc.) and the levels of intervention (i.e. from individual farm applications to the context of national or international initiatives). Each identified SLM option was evaluated in consultation with experts from the established stakeholder network. Four focus group meetings were organised with expert stakeholders willing to share their knowledge regarding the aspects of each technology; additional information was also collected from the WOCAT database and the literature. Similarly, the potential implementation approaches were explored in focused group meetings with local community leaders, a representative of farmers' unions and an expat association (i.e. families that have moved to the urban areas but still own properties in the research site).

Selection of SLM option for implementation

A second stakeholder workshop was organised in July 2015. The aim was for stakeholders to jointly select a SLM option for implementation, monitoring and evaluation at the research site; the major workshop steps are shown in Table I. Having reached a consensus among participants regarding the objective of the SLM options identified and assessed earlier by stakeholders (i.e. to reduce soil erosion and land degradation in mountain communities), the selection was based on a comparative process of ranking evaluation criteria and scoring of options against those criteria. Evaluation criteria representing the three sustainability dimensions (i.e. seven economic, seven environmental and six socio-cultural criteria) were pre-selected by the interdisciplinary team of seven researchers from the full list of 70 criteria in the WOCAT technology questionnaire, considering the land degradation issues in the area and the SLM options at stake. The stakeholders first voted on the 20 criteria to rank them in order of importance. The top 12 criteria (4 per category) were selected for the scoring of SLM options (see Appendix S1).

The scoring was undertaken in three rotating groups, one for each sustainability dimension. Scoring values ranged from 1 (very bad) to 5 (very good). Following the first scoring round, one expert from each group remained to enlighten the next group, while the rest of the group moved on to the next dimension. The groups could adjust the initial scores by no more than 1 score point. Scores were subsequently normalised using a linear function ($v = 0.25v_0 - 0.25$, where v is the normalised score and v_0 is the original score).

The normalised scores were weighted, based on the importance order of the criteria. Instead of allocating weights arbitrarily, the range of all possible combinations of weighted scores was computed as follows (Yakowitz & Weltz, 1998):

Table I. Sequence of first and second workshop exercises

	Exercise	Objective	Method
First workshop	Influence and motivation of stakeholders in the area	Establish a pleasant working atmosphere, give participants the opportunity to present themselves and get an overview of stakeholder influence and motivation regarding sustainable land management in the area	Picture gallery and stakeholder matrix (influence and motivation)
	Land degradation and conservation in the area	Identify (i) soil erosion threats at the site; (ii) current and potential prevention, mitigation and restoration options for soil conservation	Group walk, on-site observations and discussions, followed by group work (discussion and documentation), plenary session (presentation and discussion)
	Assessment of identified land management options for soil conservation	Assess and prioritise applied and potential options	Group discussion and prioritisation through individual voting
Second workshop	Clarifying the objective	Clarify and establish consensus on the objective of SLM options	Plenary presentation and discussion
	Overview of SLM options	Update all participants on the SLM technologies and approaches under evaluation	Plenary presentation of technologies (by respective experts) and approaches (by moderator)
	Ranking of evaluation criteria	Understand the use of criteria and assign hierarchy	Plenary discussion and individual voting
	Scoring of options	Score SLM options against criteria	Rotating group work
	Data analysis and interpretation	Visualise, discuss and interpret results	Multi Objective Decision Support System and plenary discussion
	Negotiation and decision-making	Reach agreement and commitment of stakeholders on how the selected option should be applied	Plenary discussion

$$S_{kj} = \frac{1}{k}\sum_{i=1}^{i=k} v_{ij}$$
$$MaxS_j = \max(s_{kj}) \quad (1)$$
$$MinS_j = \min(s_{kj})$$

where$_{ij}$ is the normalised score of option j for criterion i, s_{kj} are weighted scores for option j, k is an index for the weighted scores ($k = 1, n$), n is the number of criteria, $MaxS_j$ is the best possible score and $MinS_j$ is the worst possible score for option j. The above equations automatically ensure that the scores are weighted by the importance order of the criteria ($W_1 \geq W_2 \ldots \geq W_n$) and that the sum of the weights is equal to one $\left(\sum_{i=1}^{n} W_i = 1\right)$. Data analysis was implemented in an Excel workbook. A range of weighted scores was computed for all criteria together and for each sustainability dimension separately.

A moderator guided the participants through the consecutive steps, and assisted the exchange of ideas towards selecting a promising option that best meets the specific conditions of the local human and natural environment. The results were displayed in plenary for evaluation, and to assist the negotiations among participants towards the final decision (Schwilch *et al*., 2012).

RESULTS AND DISCUSSION

Identification of stakeholders and SLM options

The stakeholder identification process was undertaken with regular site visits and interaction with local and external actors, and proved to be very important and useful. The snowball sample started with 9 institutions and 23 stakeholders identified by the research team, while stakeholders identified 6 more institutions and 52 additional stakeholders (Figure 3). Information on the role and influence of different stakeholders on land management and abandonment was collected through conversations rather than following a typical interview format. Knowing who the stakeholders are ensures the engagement of the 'right' actors at different stages of the transdisciplinary research process (Lang *et al*., 2012). As pointed out by Cuppen (2012), the engagement of non-experts, and especially marginalised local actors, in a way that allows real effect in the process, enables a wider range of opinions to be contested and discussed. Furthermore, researchers were positioned as stakeholders in the process rather than as outsiders or more powerful actors. As Bracken *et al*. (2015) note, this does not only facilitate better communication and effective knowledge exchange, but also empowers stakeholders to perceive the process more positively when feeling that their views and opinions are equally weighted to those of scientific experts.

Twenty-four representatives of the wider stakeholder environment from the established network were invited to attend the workshop; 12 local (i.e. land users and community leaders) and 12 external (including officers of public institutions, scientists and NGO representatives). The step-by-step procedure of the first workshop improved everyone's understanding of the causes and effects of land degradation at the research site. Although most stakeholders – and especially the local actors – did not initially perceive

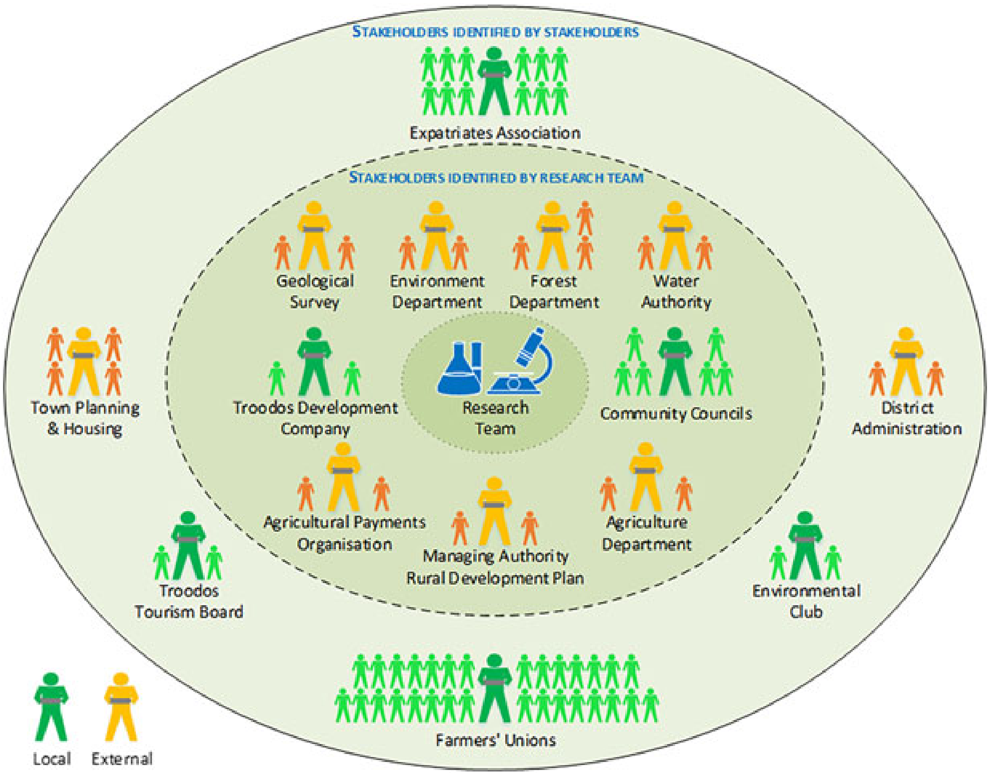

Figure 3. Local and external institutions and stakeholders identified by structured snowball sampling.

soil erosion as an imminent threat, progressively the discussion revealed drivers and problems associated to land management and soil erosion in mountain communities. This was partly because of the background information provided to stakeholders and the awareness raised during the workshop regarding the biophysical aspects of soil functions and soil threats. The on-site observations helped to visualise the land degradation issues in the area, with local stakeholders sharing their knowledge and experiences. The main issues identified were the following:

- Unmaintained terraces and gradual collapse of dry stone walls as a result of rural depopulation, land abandonment and soil erosion. The stability of terraces is determined by the building technique, the location, the slope and the crops grown. Terrace abandonment is associated with the socio-economic changes in the area and the profitability of farming in mountain environments.
- Dieback of fruit and nut trees and susceptibility to fires because of land abandonment, and higher temperatures and lower precipitation amounts over time.
- Soil erosion in and resulting from the rural unpaved road network, driven by intense precipitation events.
- Root rot associated with poor drainage and waterlogging as a result of substandard dry-stone terrace building techniques.

The interest of stakeholders was also reflected during the group discussions and diagramming of existing and potential solutions. The integrated knowledge of local and external actors resulted in a total of 15 solutions, ranging from "soft" (e.g. awareness-raising) to more "technically advanced" solutions (e.g. road maintenance). The options were discussed in a plenary session and were prioritised through voting, to enhance their suitability, appreciation and ownership. The four options selected for further assessment and appraisal are shown in Table II.

It is often the case that during participatory processes, hidden aspects and stakeholder interests that are not obvious at first glance are discovered (Reed *et al*., 2009). Soil erosion in and from the unpaved road network – an issue not previously raised – was highlighted by local land users during and after the observation walk. Furthermore, the interest of most local stakeholders was dominated by socio-economic aspects such as insufficient subsidy schemes. In general, although the workshop structure and content were well appreciated by participants, some local actors had more conservative and pessimistic views than the external stakeholders (including the research team) on the effectiveness of voluntary initiatives in maintaining dry-stone terraces. These findings were taken into account during the next step of the process.

SLM assessment and selection

The WOCAT inventory questionnaires were used as a starting point to evaluate each SLM option, in consultation with local and external experts. While relative knowledge abundance was found regarding the technologies, the proposed approaches were associated with more site specific issues and were – to a certain extent – focused on improving

Table II. Potential SLM solutions identified by stakeholders

Technology	Approach
Hydrologically sound, unpaved mountain roads	Multi-stakeholder cooperation for construction and maintenance of hydrologically sound, unpaved roads in mountainous areas
Agricultural terraces with dry-stone walls	Community-based maintenance and rehabilitation of agricultural terraces in mountain environments
Crop diversification	Diversification to low input and high value crops (e.g. herbs) on mountain terraces
Afforestation of abandoned and degraded terraces	Improvement of extension services for the establishment and maintenance of natural vegetation (e.g. forests) on abandoned and degraded mountain terraces

organisational structures, especially at the local level. In addition, three out of four options involved interventions on privately owned terraces, meaning that the owners had to be identified and then convinced to cooperate in implementing them. To overcome this issue, as well as the scepticism raised by some workshop participants, the potential ways in which the proposed approaches could be implemented were further explored in the mentioned focus meetings with community leaders and a representative of farmers' unions and an expat association. Considering the willingness of the local focus group to cooperate, the spontaneous response of the research team to overcome these issues was to test the implementation of community-based maintenance of degraded dry-stone terraces on selected fields. Therefore, local and scientific stakeholders agreed to co-organise a public terrace maintenance event prior to the second workshop; the approach is described in the next section.

The second workshop was attended by 16 local and 15 external stakeholders. The features of each technology were presented by local and external experts, while the respective approaches were outlined by the moderator. The added value of this procedure was the direct response and clarification of questions raised by participants. The rotating group-scoring of options against ranked criteria was perceived positively by participants. Figure 4 shows the final normalised criteria scores per SLM option, after the three group-scoring rounds. Terrace rehabilitation had the highest scores for all criteria compared to the other three options, except for the "low cost" criterion. The performance of SLM option per category was evaluated using Equation 1 and is shown in Figure 5. These results were presented to stakeholders and facilitated the negotiations regarding the trade-offs of each option in relation to the three sustainability dimensions. Terrace rehabilitation had the best mean overall performance score (0.78), followed by crop diversification (0.77) and afforestation (0.72). Stakeholders agreed that the rehabilitation of dry-stone terraces was the preferred option. They noted that it is a well-established practice that fits within the local socio-cultural contexts and has high environmental benefits, despite the higher cost compared to other practices. The comprehensive WOCAT questionnaires were then completed for the selected option (codes T_CYP004en and A_CYP001en in the www.wocat.net database).

From selection to implementation

Between the first and the second stakeholder workshops, the research team envisioned a small scale demonstration event to test the potential implementation of community-based terrace maintenance activities. The community leaders agreed on the organisation of a pilot event in Platanistasa. Following the success of the first event, the other two community leaders expressed their interest in organising similar events in their respective communities. The hosting community gave each event its own character. In Platanistasa, the community selected a degraded terrace on the main road to the communities to ensure visibility. The community arranged sun-protection tents and requested police presence to ensure road safety; a bag of Cypriot village flour was given at the end to each participant, as a symbol of gratitude for their attendance. At the second event, in Alona, a presentation on the technical and cultural aspects of dry-stone wall construction was given in the community hall, prior to the hands-on maintenance. The terrace selected for reconstruction was inside the village and many people stopped by to watch and chat. In Polystipos, the leading local expert, notwithstanding his advanced age, managed to instruct everyone in the art of dry-stone wall construction and a beautiful terrace was built along the road. In all events, easily accessible sites were identified by community leaders and terrace experts and the site-selection was finalised in cooperation with the research team, after the approval of land owners was obtained. Locally sourced stones were provided by the communities. All events were advertised with flyers and posters in central locations within the communities, in social media, and through personal communication. In total, 164 people attended the three events; 51% have their residence beyond the three communities while 26% of the participants were female.

Key actors for the implementation of the approach were identified from the network of stakeholders; these are community leaders, terrace experts, local institutions (i.e. expat associations and farmers' unions) and extension services. The main target groups in terms of engagement and motivation in the learning-by-doing activities are land users and land owners, mountain community inhabitants and other interested stakeholders (Figure 6). During the practical (i.e. hands-on) public events, local dry-stone experts had the leading role as they explained the best practices in terms of maintenance techniques, and guided the event's

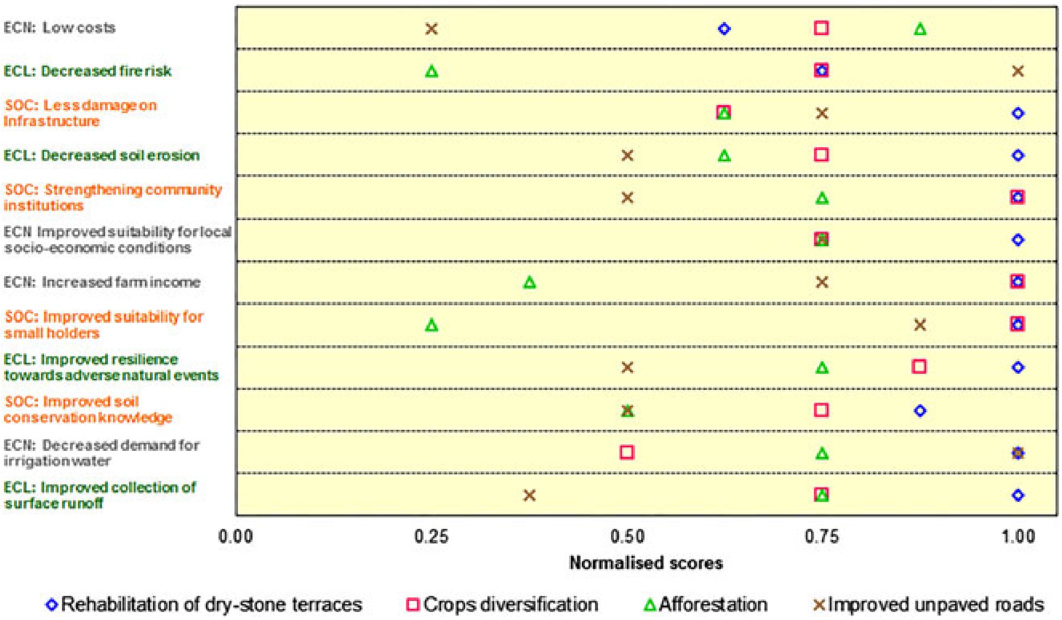

Figure 4. Overview of normalised scores per SLM option and ranked criteria in order of importance, as per the stakeholder votes (ECN: Low cost had received the most votes); the acronyms ECN, ECL and SOC indicate the economic, ecological and socio-cultural criteria categories, respectively.

attendees in collectively restoring collapsed or poorly maintained terraces (Figure 7). It is worth noting that all stakeholders were engaged in the implementation of the approach on a voluntary basis. Furthermore, the events provided the opportunity for awareness-raising of a wide audience on the environmental and cultural importance of dry-stone terraces.

Implications, constraints and outlook

The community-based approach has been initiated in an effort to reduce soil erosion and to maintain the production capacity of soils in the terraces of the Troodos Mountains. Moreover, the approach aims to strengthen science–society cooperation in solving land degradation issues, by building the capacity of local communities in terms of planning, organisation and implementation of participatory soil-conservation activities. By its nature, the construction and maintenance of dry-stone terraces is a laborious practice that relies on indigenous knowledge. Thus, the approach is also aiming at maintaining this traditional know-how through community engagement and joint-learning activities between land users, terrace experts and interested stakeholders.

Research based on interdisciplinary methods and participatory principles can potentially empower marginalised communities, once external actors have a better understanding of the complex, dynamic and multi-scale nature of socio-

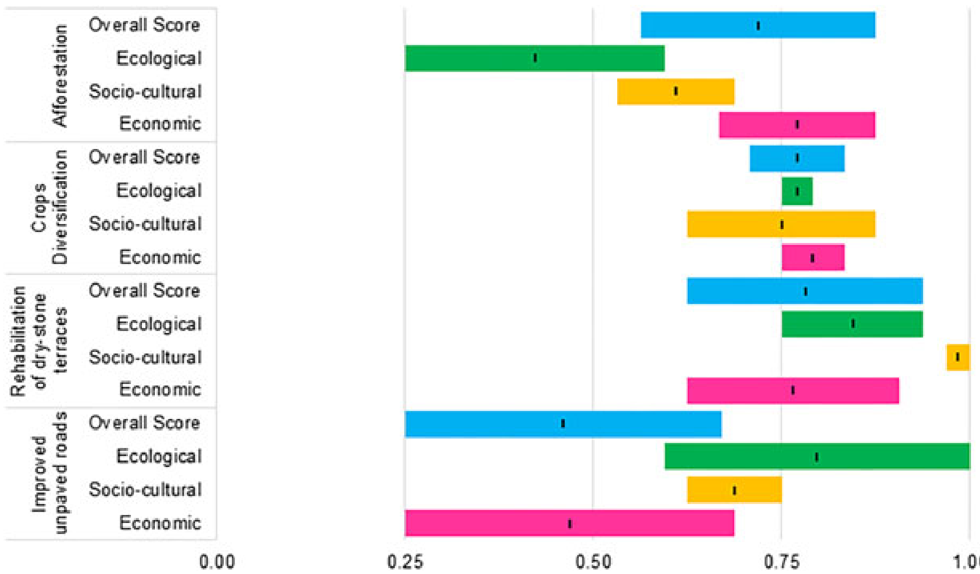

Figure 5. Range of scores per SLM option and sustainability dimension; the bar's position indicates its performance relative to other options.

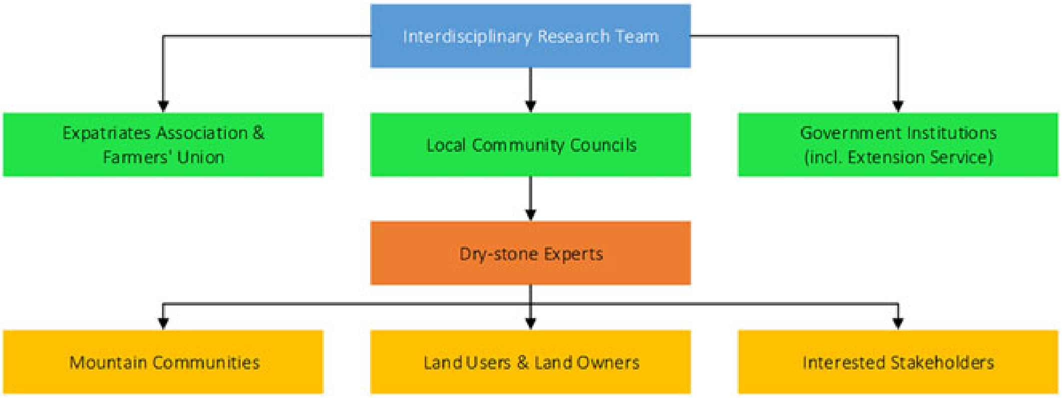

Figure 6. Organogram of the approach.

Figure 7. Experts guiding volunteers during public terrace maintenance events.

ecological systems (Berkes, 2004). Frequent interaction with key local stakeholders created conditions of mutual trust, which led to the co-development and implementation of the terrace rehabilitation approach. Yuliani *et al*. (2015) note that the use of indigenous knowledge as the basis for community empowerment is critical for successfully implementing community-based approaches. Kieninger *et al*. (2013) found that the main motivations of volunteers participating in maintaining rice terraces in Japan are the spiritual value and beauty of cultural landscapes. Furthermore, community-based approaches can be strengthened when activities focus on building social capital, improve the socio-economic well-being of local people and promote local leadership, creativity and resilience, instead of relying on monetary incentives (Pretty & Smith, 2004). The experience from implementing the community-based approach in Cyprus concurs with these findings, as the process helped build the self-confidence of sceptical local actors. In addition, some volunteers were keen to learn about indigenous agronomic practices while others joined the events to reconnect with their roots.

The restoration of degraded terraced landscapes requires continuous attention and combined efforts of multiple stakeholders (including city dwellers), as this task cannot be solely assumed by a small group of dry-stone experts. The constraints and potential responses for implementing the approach are summarised in Table III. As an initial step, the community-based rehabilitation approach has sparked the interest and has been appreciated by local and external actors. To this end, the communities have agreed to co-organise another series of events this year and engage more people. Furthermore, five mountain communities in Cyprus beyond the research site have expressed their interest in adopting the approach and organise similar events. In the short-run the positive spirit can be maintained by organising such cooperative activities. However, these efforts alone would be insufficient to restore and maintain the terraced landscape and the challenge remains in enhancing the positive SLM impact in the long-run. It is also important to assess the impact of such initiatives by integrating quantitative and qualitative approaches.

Beyene (2015) notes that externally introduced community-based rehabilitation initiatives may fail when land users put emphasis only on short-term economic gains. On the contrary, collective actions, awareness of impacts and designing of institutions, contribute to effective SLM adoption and can potentially generate income streams in the long-run. In other words, the success of the rehabilitation efforts depends on the long-term provision of environmental and socio-economic benefits for the mountain communities. Torquati *et al*. (2015) found that the financial success or failure of investments in restoring traditional terraced vineyards in Italy is not only determined by the socio-economic context but by the ability of land users to differentiate their products. Terrace maintenance can benefit by combining the peculiar landscape characteristics with agro-tourism, cultural or leisure activities, and by improving post-harvest processing and marketing of agricultural products. Tarolli *et al*. (2014) also stressed the importance of involving active people and the younger generation in terraced land management. It is also critical that information and knowledge of best practices, arising from the implementation of community-based processes, reach policy-makers and enhance their understanding towards designing more effective rural development policies.

Table III. Constraints and responses for implementing the community-based terrace maintenance approach

Category	Constraint	Response
Technical	Loss of indigenous knowledge	The terrace events are led by dry-stone experts to practically demonstrate and pass the technical know-how to the next generation. Efforts were made to engage terrace experts from different communities
Workload	Terrace maintenance is a laborious activity	The community-based approach aims to engage and build the capacity of a large group of people in terrace maintenance
Social-cultural	Land abandonment, rural depopulation and lack of motivation	Organise and advertise terrace maintenance events frequently to stimulate the interest; invite and engage local communities and land owners (including expats) to participate. The terrace events also turned into social happenings, with various people joining just to watch and chat.
Legal	Terraced land is privately owned, thus implementation of community-based maintenance requires the approval of land owners	Community leaders request the approval of land owners
Institutional	No formal terrace maintenance institutions	Maintain cooperation and organise events on annual basis in the short-run and gradually institutionalise the process to sustain the positive impact on land management in the long run.
Financial	High terrace maintenance cost	Engage, motivate and train volunteers through hands-on terrace maintenance events

CONCLUSION

This paper presented the participatory framework followed to select SLM approaches to control soil erosion in the Troodos Mountains of Cyprus. Key local and external stakeholders were identified and invited to participate in interactive workshops. The rehabilitation of abandoned and collapsing dry-stone terraces was considered by stakeholders as the preferred practice, having high environmental benefits and good suitability for the local socio-cultural context, and despite being a more expensive solution compared to other options. Three mountain communities implemented the selected option by co-organising communal rehabilitation events, where dry-stone experts guided volunteers in restoring collapsed terrace walls. To increase the impact of this approach, visible and easily accessible sites were selected. In the first year of implementation, a total of 164 people attended the events. To maintain the positive momentum, stakeholders suggested another series of events, which has been scheduled for the coming season. In the long-run, the sustainability of this initiative can be achieved by institutionalising the approach, by actively engaging young people in terrace land management, and through co-operation with agro-tourism businesses. Furthermore, community activities for improving the profitability of local farming, such as through the differentiation of local products and a value chain approach, should be explored. Finally, measuring and showing stakeholders differences in sediment loss from degraded and maintained terraces can provide further motivation for rehabilitation.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's web site.

Appendix S1: Criteria selected for assessing the Sustainable Land Management (SLM) options

Table S1: Criteria pre-selected by experts and voted by stakeholders in the second workshop

A Future for Mountain Terraces: Experiences from Mediterranean Wineries

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A Future for Mountain Terraces: Experiences from Mediterranean Wineries

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Agriculture in mountain areas is typically practiced on terraces. This form of farming is facing significant challenges across the globe related to high production costs, land abandonment, and rural depopulation. The aim of this study was to explore the viability and prospects of mountain farming using the wineries in the terraced mountains of Cyprus as a case study. A semistructured questionnaire was developed, and 11 family wineries were selected and surveyed. The study found that mountain winery owners envision a future where abandoned mountain plots are productively utilized. The survey showed that mountain wineries are financially viable agribusinesses and share a common desire for sustaining and enhancing the quality of the wine produced to support their long-term success. The revitalization of mountain farming can potentially lead to the development of other rural enterprises and create employment opportunities to sustain young families in the mountains. Investments in drystone terraces were found to be costly, especially for wineries that were located at higher elevations (€ 150/m or US$ 171.30/m) compared to those on gentler slopes and lower elevations (€ 20/m or US$ 22.84/m). Nevertheless, the majority of winery owners recognized the provision of ecosystem services by drystone terraces, such as the reduction of soil erosion and the formation of a unique mountain terroir that enables the production of niche wines. Although the survey found that subsidies for terrace construction and maintenance are a small part of the revenue for these wineries, policy measures can become more targeted, effective, and equitable by considering the actual costs of terracing, as determined by site-specific characteristics such as elevation, slope, and geology.

Keywords: *mountain agriculture; grape; wine; cultural landscape; rural development.*

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Introduction

Agriculture in mountain areas across the globe is typically practiced by family farmers (Wymann von Dach et al 2013). Although there are many diverse features of mountain farming, owing to the different elevations, climate regimes, and landscape features, mountain agricultural systems share many common characteristics. For instance, mountain farms utilize marginal lands that would otherwise remain uncultivated, and they are often overlooked in national accounting systems due to their relatively smaller contribution in terms of product quantity (Tarolli et al 2019). Mountain farmers are often motivated by social and cultural factors. Although these incentives do not generate income directly, they contribute to the maintenance of mountain landscapes, which provide indispensable ecosystem services, sustain the natural production base, and support development beyond rural mountain areas (Bernues et al 2014; Schirpke et al 2016; Cicinelli et al 2021). Mountain farmers are also custodians of place identity, cultural values, and indigenous knowledge, which is exemplified by the terraced landscapes found in all major mountain regions of the world.

The main purpose of terraces has been the cultivation of land in high and steep areas, with farmers devoting substantial amounts of hard work to transpose mountain slopes into cultivable land suitable for production. The terraced fields control soil erosion through soil and water retention and provide microclimatic adjustments that create suitable conditions for farming (Maetens et al 2012). For centuries, agricultural terraced areas worldwide have been growing. The most common type is bench terraces, which are often supported by drystone walls and are now characterized as land with "high nature value" (Bignal and McCracken 2000; Keenleyside et al 2014). Terraces are part of traditional cultural landscapes; that is, they have distinct structures and elements of high significance for sustainable land management practices, as well as for natural (eg biodiversity), cultural, and aesthetic values (Antrop 1997; Harrop 2007).

In Europe, and more evidently in the Mediterranean region, the cultivation of important permanent crops such as vines was a powerful push toward terracing (Bonardi 2019). Despite the important role that terraces have played in sustaining mountain families, this trend began to change in the mid-20th century (MacDonald et al 2000). The greater socioeconomic opportunities in urban centers compared to those in the mountain farmlands induced younger generations to migrate, and consequently many terraced areas were gradually abandoned. The development trends that followed contributed to the loss of cultural values, in addition to the loss of valuable farmland that had been shaped for centuries in European and Mediterranean mountain areas (MacDonald et al 2000).

Numerous studies have been devoted to documenting the adverse effects of terrace abandonment in countries such as Spain (Arnaez et al 2011; Rodrigo-Comino et al 2019), France (Van Eetvelde and Antrop 2004), Italy (Tarolli et al 2014), Greece (Koulouri and Giourga 2007; Tzanopoulos et al 2011), Cyprus (Camera et al 2018; Djuma et al 2020), and Malta (Cyffka and Bock 2008), and also in central Europe (Lieskovský et al 2015). The majority of these studies reported the collapse of drystone terraces and increasing risk of soil erosion, which progressively leads to land degradation and desertification. However, several studies have also noted the reduced soil erodibility of abandoned terraced slopes following their colonization by natural vegetation (eg Djuma et al 2017). Apart from the changes in the socioeconomic status of mountain communities, the high labor effort and the cost of the maintenance and cultivation of terraces are often cited as the main reasons for their abandonment (Zoumides et al 2017). According to Louwagie et al (2009), research on the economics of terraces is limited to a few studies that have been conducted in Europe (eg case studies in Italian terraced vineyards and olive groves by Torquati et al 2015, 2019). Louwagie et al (2009) also pointed out that terraces are located in geomorphologically heterogeneous areas, and additional factors should be taken into account when assessing their economic viability, such as the ecosystem benefits and the perception of farmers.

Following the recognition of the cultural and environmental consequences of abandonment, the past 2 decades have seen a renewed interest in the protection and rehabilitation of agricultural mountain terraces (Tarolli 2018). In terms of rural policy, this recognition is evident in, for instance, the European Union regulation for common organization and support programs for the wine market of 2008 (European Commission Regulation No. 555/2008 [European Commission 2008]), as well as in the more recent establishment of ecological focus areas within the Common Agricultural Policy (CAP) and the Farm to Fork Strategy (European Commission 2020), where drystone terraces are considered to be landscape features that safeguard and improve biodiversity. While terracing is one of the more effective techniques for reducing soil loss and conserving water (Maetens et al 2012), there are no relevant findings on the long-term environmental effectiveness of greening measures, such as terraces, ditches, and ponds (Alliance Environnement 2017). Investigations into the unique characteristics, potential successes, and future prospects of mountain terraces and family agribusinesses are also lacking from the literature.

The aim of this study was to explore the viability, strategies, and visions of mountain wineries in terraced environments. The wine sector is multifaceted; on the one hand, terraced vineyards form a distinct landscape category within the wider framework of agricultural terraces (Bonardi 2019), and, on the other hand, wine is an agricultural product associated with its place of origin, and its production is responsive to market changes toward quality (Torquati et al 2015). The study followed a bottom-up approach, with the analysis being based on surveys of winery operators in mountain communities of Cyprus. The specific objectives of the study were (1) to identify the structural characteristics of mountain vineyards, (2) to document the motivations and costs associated with the establishment and maintenance of drystone terraces, (3) to analyze the economic performance of mountain wineries, and (4) to investigate the winery operators' parameters of success and perspectives for the future of mountain agriculture.

Methodology

Study area

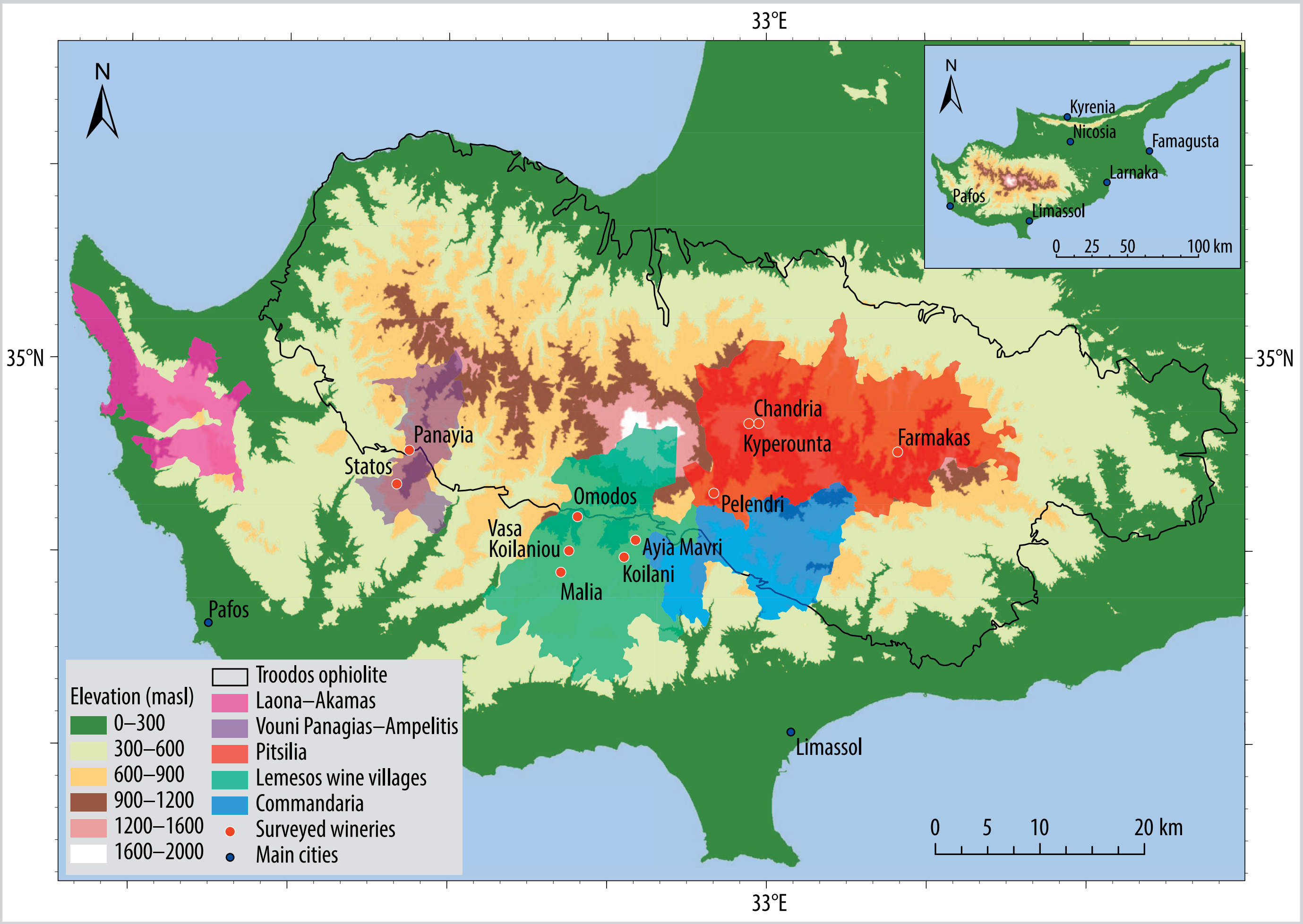
The island of Cyprus is located in the eastern Mediterranean. The Troodos Mountains that dominate the center of the island comprise an ophiolite complex, which is surrounded by sedimentary cover. The Troodos Ophiolite Complex, with its highest peak at 1952 masl, has a mean slope gradient of 31% and covers 40% (Zoumides et al 2017) of the island's area (Figure 1). Average annual rainfall ranges between 500 mm in the foothills to 1100 mm near the peak at 1950 masl (Camera et al 2014).

The study focused on vineyards in the Troodos Mountains, which are typically found on drystone terraces (Figure 2). At higher elevations with steep slopes (eg 20–40% gradient), terraces are constructed by cutting and filling, and terrace benches tend to be narrow (1–3 m) to moderately wide (3–6 m) (Zoumides et al 2017). At lower elevations, terraces can be wider, for example, with more than 20 m bench width. The share of the terraced land and the importance of grapes increase progressively with elevation. Based on data from the Cyprus Agricultural Payments Organisation, in 2016, grapes accounted for more than 40% of the total crop land utilization in communities at elevations above 600 m (Figure 3). Abandonment of agricultural terraces is pervasive across the mountain region; over the past 2 decades, 20% of agricultural land in communities above 600 m has been abandoned (Cystat 2014).

Despite these decreasing trends, grapes remain an important mountain crop. More recently, grape growers and winemakers have shifted the production from quantity to quality, following the wider market direction for better quality wine products. Significant efforts were also placed on improving indigenous grape cultivars such as *Mavro*, an ancient red variety that is well adapted to mountain slopes, and *Xynisteri*, a white variety. By 2009, these 2 varieties covered 66% of the wine grape cultivated area and constituted 53% of the wine production (Cystat 2011).

Regarding quality parameters, the national legal framework is aligned with European Union (EU) regulations. For instance, among other provisions, EU Regulation No. 1308/2013 stipulates suitable grape varieties, wine-growing methods, and yield limits per hectare, as well as ensuring that grape production and wine making are carried out in a specific region. Based on the EU (eg EC regulation No. 607/2009 [European Commission 2009]) and the equivalent national regulations (ie Administrative Act 48/2016), wines produced in Cyprus are currently classified and labeled in the following categories: wine, local wine, and wine of protected designation of origin. The latter is the most

FIGURE 1 Wine regions with protected designation of origin and surveyed mountain wineries.



prestigious category and specifies the wine-producing regions of Cyprus (Table 1; Figure 1). Today, according to the official registry of the Cyprus Department of Agriculture, there are 115 local enterprises that are licensed to commerce or produce wine products. The list includes 4 big companies, which, apart from utilizing grapes from various farmers, have also developed their own vineyards. Fifty of the listed enterprises are small, regional wineries, while the remaining 61 enterprises focus on trading wine products.

Survey design, sample selection, and analysis

A semistructured questionnaire was developed to collect primary information and insights regarding the wineries' structure, strategies, and farming practices on terraces and conducted through face-to-face interviews with winery owners. The questionnaire consisted of 9 sections, with ranking, scoring, and open questions. The questionnaire covered 4 main topics: (1) winery characteristics and farming practices, including year of establishment, managed area (owned or rented), employment, and grape varieties grown, (2) drystone terrace construction and maintenance costs, (3) production output, including the cost, revenues, and factors determining the success of wineries, and (4) concerns, visions, and prospects of mountain wineries.

The selection of the wineries for the survey followed these criteria and steps:

- Family-based: The starting point of the sample selection was the list of the 50 regional and predominantly family-based wineries reported in the official registry. Some wineries are owned by the 4 big companies but operate as an estate (or family-based) winery (eg the winery located in Malia community).
- Elevation: The focus of the study was on mountain terraced vineyards, so the elevation threshold was set to wineries located at 600 masl and above, in line with the protected designation of origin regulation (Regulatory Administrative Act 48/2016). This resulted in a subset of 32 mountain wineries located in 4 of the 5 wine regions. The Commandaria region was not included because it did not have wineries above 600 m.
- Regional coverage and active market presence: Based on expert knowledge, 14 wineries were selected, representing at least 28% of the mountain wineries in each region.

The questionnaire (see Appendix S1, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00031.1.S1) was first sent to the selected wineries via email, followed by phone communications to confirm their interest and arrange the face-to-face interviews. At this stage, the only eligible winery in the Laona–Akamas region noted that its vineyards are on a plateau and not on terraces, so it was excluded from the sample. In addition, one of the selected

FIGURE 2 Vine terraces in Troodos Mountains. Red boxes on Google Earth images (right) show the photographed terraces (left) in (A) Pelendri, (B) Kyperounta, and (C) Panayia mountain vineyards. (Photos by Christos Zoumides)

wineries indicated that it did not own any vineyards, and all the wine was produced using grapes from different farmers, while another winery refused to participate. Thus, the final sample consisted of 11 wineries, still maintaining a minimum of 28% of the wineries in the 3 main wine regions. These winery operators were interviewed in the summer of 2017. A follow-up survey was conducted in 2020 to verify and gather further data on the economics of the wineries.

The information collected from the interviews was coded and categorized in tabular format. In line with the objectives of the study, the analysis followed a descriptive and interpretive approach (Elliott and Timulak 2005). The responses to the scoring and ranking questions from all wineries were averaged, and the mean values were used for interpretation. To assess the profitability of mountain wineries, we computed the standard gross margin, in both absolute (€) and per hectare (€/ha) terms, which is the difference between the revenues of each winery and variable production cost (including terrace maintenance), based on the definition outlined by the European Commission Decision (EEC) No. 377/1985. Information on the geology at the wineries' locations was obtained from the geological map of Cyprus (Geological Survey Department of Cyprus 2019).

Results and discussion

Winery characteristics and farming practices

The surveyed Cypriot mountain wineries are structurally different from each other, and, although they share common

FIGURE 3 Area cultivated with grapes by elevation, and share compared to all other crops in 2016, based on data obtained from the Cyprus Agricultural Payments Organisation.

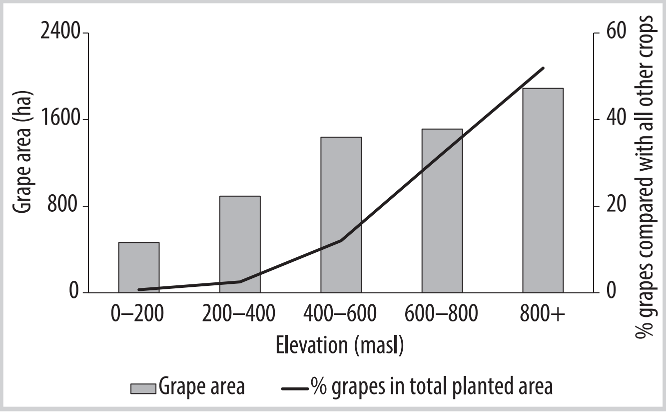


TABLE 1 Wine regions with protected designation of origin status in Cyprus.

Characteristic	Wine-producing region of Cyprus				
	Laona–Akamas	Vouni Panagias–Ampelitis	Pitsilia	Lemesos wine villages (Krasochoria)	Commandaria
Location	Northwestern part of Cyprus	Southwestern slopes of Troodos Mountains	Eastern slopes of Troodos Mountains	Southern slopes of Troodos Mountains	Southern slopes of Troodos Mountains
Elevation range (masl)	400–600	600–1145	800–1400	500–1100	500–900
Dominant geological formation	Calcareous	Diabase	Gabbro and diabase	Calcareous	Ophiolite formations/ calcareous
No. of communities	6	4	32	22	14
Grape area[a)] (ha)	650	600	1282	1653	538
Grape production[a)] (tons)	2602	2249	4848	6891	2141

[a)] Grape area and production refer to the period of 2016–2018 (average values), based on Department of Agriculture data.

entrepreneurial goals, as is later discussed, each case is unique. An overview of the winery characteristics is presented in Table 2, which lists the surveyed wineries by elevation. The highest surveyed winery was located at 1216 masl, and the lowest surveyed winery was located at 674 masl. An interesting characteristic that indicates the diversity of wine-growing regions and conditions in Cyprus is the geological formations where mountain vineyards are located. The higher vineyards are generally on steeper slopes, and the predominant geology consists of gabbro, followed by the less permeable rocks of the diabase formation, both of which are part of the Troodos Ophiolite Complex (Constantinou and Panayides 2013). At lower elevations and slope gradients, vineyards are found on autochthonous sedimentary rocks and the calcareous Pachna Formation and Lefkara Formation. Geology and various other territory values and physical environmental factors, such as landscape characteristics, soil, and climate, are ingredients of the terroir concept, which determines to a large extent the style and quality of wines produced (van Leeuwen 2010).

With the exception of the winery located in Malia, all other mountain wineries are newly established enterprises that started operating in the last 3 decades (Table 2). This characteristic is indicative of the peculiarities of mountain rural development and the commercialization of wine production in Cyprus; while the island has a long wine production history, small, family-based wineries are a recent development. Seven out of 11 winery owners are above the age of 50, but they have identified a successor within the family. As family-based enterprises, the investment of the sampled wineries is driven by, inter alia, the creation of prospects and financially sustainable rural businesses that can be inherited by their children, some of which are already working in the family business following their studies in agronomy or enology.

Another important structural characteristic is the area managed by the mountain wineries, that is, the combined owned and rented area. The area ranged from 3 to 48.5 ha and averaged 18.5 ha. Also, 8 out of the 11 wineries were planning to expand the vineyard area under their management in the next decade, aiming to become more self-sufficient in wine grape production and to have better control of the growing conditions (Table 2). Comparatively, the average vineyard area per holding in the European Union in 2015 was 1.3 ha (Eurostat 2017); France had by far the highest average area per holdings with 10.5 ha, while Romania, Malta, Croatia, Cyprus, and Greece ranked among the countries with lowest vineyard areas per holding, with 0.5 ha or less. This finding indicates that the operation of wineries entails the consolidation of farm holdings and the expansion of managed vineyards; even the smallest mountain winery in this study's sample was managing 4 times more land than the average vineyard holding in Cyprus and almost twice the European average.

In terms of employment, the average number of full-time personnel (including grape and wine production) at mountain wineries in Cyprus was 11.5 people, ranging from 6 to 24 full-time employees; these numbers included family members. Also, the wineries employed on a part-time basis 10.3 people for 75 days, on average, per year. Part-time employment is primarily associated with grape harvesting, which takes place between June and November.

Regarding vineyard management, the average plant density was found to be 3700 plants/ha, ranging from 2500 up to 5000 plants/ha. The winery owners explained that spacing depends on grape variety. Also, traditionally, vineyards tend to be more spaced at lower elevation, while the more densely planted vineyards are found at higher elevations. This is also related to the higher rainfall and the limited cultivable land on the steeper mountain slopes at higher elevations. In terms of irrigation, 4 wineries relied exclusively on rain for grape production, while in the remaining 7 wineries, the share of irrigated land ranged from 4 to 100%. These numbers refer to the vineyard areas that are equipped with irrigation systems and do not mean that wineries are fully irrigating these areas. The winery owners explained that they provide irrigation on a supplementary basis during critical crop growth periods. For instance, the winery owner in Koilani mentioned that he applies controlled irrigation volumes to ensure yields of good-quality grapes for wine making. In their in-depth review of the international literature on climate change

TABLE 2 Characteristics of surveyed mountain wineries. (Table extended on next page.)

Characteristic	Winery				
	Chandria	Kyperounta	Farmakas	Pelendri	Statos–Agios Photios
Elevation (masl)	1216	1123	959	902	831
Slope (%)	39	30	43	33	25
Geological formation	Gabbro	Gabbro	Diabase	Gabbro	Calcareous
Wine region	Pitsilia	Pitsilia	Pitsilia	Pitsilia	VPA
Age classes of owner	30–39	40–49	>65	60–65	60–65
Establishment year	2013	1998	2015	1988	2007
Agricultural education	Yes	Yes	Yes	No	No
Full-time employees	8	24	6	13	10
Part-time employees (no. days/y)	4 (90)	2 (60)	3 (120)	20 (25)	14 (90)
Owned land (ha)	7	11	3.5	5	6.1
Rented land (ha)	8	5	19	3	13
Irrigated land (%)	55	53	4	100	0
Average plant density (vines/ha)	5000	3850	4500	4000	2500
Local/ international grape varieties	4/6	1/3	2/0	5/7	4/2
Change in vineyard area in the past decade (ha)	2.2	10	22.5	9	3.5
Expansion plans in the next 10 years (ha)	1	23	20	15	10

Note: VPA, Vouni Panagias–Ampelitis.

effects and adaptation strategies in the wine sector, Sacchelli et al (2016) reported that irrigation is an emerging topic of significance in recent studies on climate vulnerability.

The grape varieties that are grown on the mountain terraces of the wineries is another interesting characteristic (see Table S1, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00031.1.S1). The first impression from this matrix is the wide range and mixture of local and international varieties. Banilas et al (2009) noted that the genetic diversity of the indigenous Cypriot germplasm requires further attention to be conserved and productively exploited. In essence, each winery seeks to produce niche wines that will be distinct, recognizable, and competitive in the market. The choice of the varieties grown depends on the strategy, the philosophy, and the range of wines that each winery wants to produce. For instance, the wineries located in Panayia and Farmakas were only producing wines from local varieties, as they considered them to be better suited and more resilient to the semiarid conditions of Cyprus. Other wineries, such as those located in Chandria, Pelendri, and Koilani, had a balanced mixture of local and international varieties, while the winery in Ayia Mavri, which specializes in dessert wines, was the only surveyed winery that grew the local Muscat variety. Another factor that affects the variety choice is enological developments and trends. Eight of the winery owners mentioned that, apart from the well-developed local varieties of *Xynisteri*, *Maratheftiko*, and *Mavro*, all other local varieties have, until recently, not been explored in terms of their potential to produce good-quality wine. Gradually, however, more and more wineries are investing and experimenting with local varieties such as *Yiannoudi*, which was cultivated by 5 out of the 11 surveyed wineries.

Terrace construction and maintenance—motivations and costs

The characteristics of the terraced fields and the costs of terrace construction and maintenance at the surveyed wineries are summarized in Table 3. Five out of 11 wineries had all their vineyards (100%) on well-maintained drystone terraces, while at the remaining 6 wineries, the share of well-maintained terraced fields ranged from 5% in Farmakas to 70% in Malia. The small share of terrace maintenance in Farmakas is attributed to the recent establishment of the winery. Although vineyards are on old terraces, few were in a well-maintained state; the owner mentioned that maintaining the collapsed drystone walls is a laborious and costly activity. In other cases, such as the winery in Koilani, the owner mentioned that he prefers fields that are relatively flat or with gentle slopes for his vineyards, and he uses terraces only when it is necessary. Also, 70% of the vineyards in the Malia winery were on terraces, but instead of drystone walls, they were vegetated to ensure stability. Vegetation cover to reinforce terrace stability requires careful selection of drought-tolerant plants (Novara et al 2011; Lieskovský and Kenderessy 2014; Rodrigo-Comino et al 2019). Vegetating the terrace façade is, however, not common in the mountain vineyards in Cyprus.

Regarding terrace dimensions, there was a wide range of terrace sizes. Terrace height ranged from 1.0 m to 3.5 m, while for the width, the range was even larger, from narrow

TABLE 2 Extended. (First part of Table 2 on previous page.)

Characteristic	Winery					
	Ayia Mavri	Koilani	Omodos	Panayia	Vasa Koilaniou	Malia
Elevation (masl)	820	820	817	814	805	674
Slope (%)	28	28	26	41	25	23
Geological formation	Calcareous	Calcareous	Calcareous	Diabase	Calcareous	Calcareous
Wine region	Krasochoria	Krasochoria	Krasochoria	VPA	Krasochoria	Krasochoria
Age classes of owner	>65	40–49	50–59	60–65	40–49	50–59
Establishment year	1986	1998	2010	1987	1993	1927
Agricultural education	No	Yes	No	Yes	No	Yes
Full-time employees	13	10	6	6	13	22
Part-time employees (no. days/y)	10 (60)	2 (60)	6 (30)	25 (180)	7 (30)	20 (75)
Owned land (ha)	3	15.4	12	10.5	7.5	0
Rented land (ha)	0	6	15	5	0	48.5
Irrigated land (%)	0	44	0	0	70	100
Average plant density (vines/ha)	3750	3500	2500	4000	4500	2700
Local/ international grape varieties	4/3	4/6	6/4	7/0	1/5	3/4
Change in vineyard area in the past decade (ha)	1	6	27	30	1	0
Expansion plans in the next 10 years (ha)	0	15	0	20	1	0

2 m terrace benches at Pelendri to 80 m wide at Vasa Koilaniou. The dimensions of terraces (including their average length, measured as running meter of walls per hectare) are additional characteristics that indicate the diversity and complexity of mountain terraced systems. Although the principles of terrace construction were similar across the surveyed vineyards, their dimensions were shaped by site-specific geomorphological characteristics. This complexity was noted by the respondents to the questionnaire. In other words, there was no homogeneity between mountain terraced fields, even between those of the same winery, which made it challenging for respondents to provide this information. Thus, the terrace dimensions should be treated as rough estimations for each case.

The average total establishment cost, including both the labor and the material costs, was found to be € 75/m (US$ 85.65/m) of drystone wall. This average excludes the winery at Malia, where the cost refers to the planting of the terrace façade for stability. Similar to the terrace dimensions, the establishment cost is also subject to site-specific characteristics, and it varied widely between the surveyed wineries, from € 20/m (US$ 22.84/m) at Ayia Mavri to € 180/m (US$ 205.56/m) at Vasa Koilaniou. The establishment cost was generally higher for vineyards that were located on steeper slopes, where the predominant rocks consist of gabbro, than for those on calcareous geological formations. Besides the steeper slopes, the hardness of gabbro and diabase rocks requires more effort and time for wall construction, which explains the higher cost. The case of the winery located at Vasa Koilaniou is an exception to this rule; although the vineyards are on calcareous formations, it had the highest terrace establishment cost within the sample. As explained by the winery owner, this was due to the lack of good raw materials for wall construction, so a large share of the total establishment cost came from to purchasing stone. Regarding the maintenance of drystone terrace walls, the average annual cost was € 3058/ha (US$ 3492.24/ha), based on the responses of 5 out of the 11 surveyed wineries (Table 3).

Currently, there are 2 subsidy measures that are related to terrace construction and maintenance. The first is an agro-environmental measure under Cyprus' Rural Development Program 2014–2020 that subsidizes the maintenance of existing terraces (MANRE 2019). In particular, the measure refers to the maintenance of traditional terrace walls that have collapsed (eg due to high rainfall and surface runoff), and the subsidy rate for vineyards is € 100/ha (US$ 114.20/ha). Mountain farmers were allowed to apply for the maintenance of collapsed terraces support measure once a year within the 2014–2020 period. Considering the responses of the winery owners, this subsidy scheme covered a very small fraction of the annual average maintenance cost. The second subsidy scheme fell within the National Support Programme for the Wine Sector 2014–2018, which was implemented in line with EU Regulation No. 1308/2013. This scheme subsidized both the construction of new and the maintenance of existing drystone walls at a much higher rate than the Rural Development Program, € 30/m^2 of terrace wall (US$ 34.26/m^2). The average length of terrace walls across the 11 surveyed wineries was ~1500 m/ha (Table 3), which implies a subsidy of € 45,000/ha (US$ 51,390/ha), on average.

TABLE 3 Terrace characteristics, construction, and maintenance cost.

Characteristic	Winery										
	Chandria	Kyperounta	Farmakas	Pelendri	Statos–Agios Photios	Ayia Mavri	Koilani	Omodos	Panayia	Vasa Koilaniou	Malia
Terraced vineyards with maintained drystone walls (%)	100	100	5	100	60	50	15	20	100	100	70[a]
Terrace height (m)	1.5	1.2–1.5	1.5	1.2–3.5	2.5	2–2.5	1	2	2–5	1–1.5	2–2.5
Terrace width (m)	6	2.5	8	2–5	15	10	10	8	3–20	4–80	15–50
Average length of terraces (running m/ha)	200–1500	4000	200	5000	450	300	300	2000	500–1000	200	1750
Terrace establishment labor cost (€/m)[b]	60	25	–	75	35		15	30	25		2
Terrace establishment material (eg stones) cost (€/m)	40	45	–	75	15		10	20	8		3
Total terrace establishment cost (€/m)	100	70	–	150	50	20	25	50	33	180	5
Annual terrace maintenance cost (€/ha)	5000	1000	–	3750	–	3600	3000	–	–	2000	–

[a] The terraces of the winery located in Malia are not supported by drystone walls but are vegetated to enhance stability; the costs refer to planting when the terraces are established.
[b] Conversion rate at time of study: € 1 = US$ 1.142.

There are, however, specific requirements; for example, the height of new drystone walls should be between 0.8 to 1.2 m. In our survey, we found that some of the existing traditional terraces were higher than these requirements (Table 3). Also, the maximum area per applicant was limited to 1 ha, while vineyard terraces that had already been subsidized through the Rural Development Program were excluded to avoid double funding. This subsidy scheme was certainly more attractive for the wineries because it covered a larger share of the terrace establishment cost, ranging between 20% for vineyards located at higher elevations up to full cost recovery for those at lower elevations. At the same time, this finding indicates that further research is required to establish more equitable and targeted policy measures.

To obtain further insights into the establishment and maintenance costs of mountain terraced vineyards, the Chandria and Pelendri wineries were asked to provide additional techno-economic details (Table 4). The vineyards of both wineries are located at higher elevations and on gabbro formations, thus representing the more costly terrace investments in Cyprus. The total terrace establishment cost, including the plantation cost, was € 313,400/ha (US$ 357,903/ha) in Chandria and € 832,500/ha (US$ 950,715/ha) in Pelendri. The highest share of the cost was attributed to the labor cost for wall construction and the cost of the stones (which also included their transport to the terrace sites). Torquati et al (2015) found that the cost of establishing terraced vineyards in Costa Viola (Reggio Calabria), Giano dell'Umbria (Perugia), and Lamole (Firenze) in Italy was € 78,168/ha, € 98,166/ha, and € 134,458/ha, respectively, based on 2012 values. When comparing these findings with the current study, it seems that establishing terraced vineyards in high mountainous regions in Cyprus can be up to 8 times more costly than in the reported Italian regions. Regarding vineyard management and terrace maintenance, the total annual cost was € 12,050/ha (US$ 13,761/ha) in Chandria and € 10,450/ha (US$ 11,934/ha) in Pelendri.

The average scores of a list of predefined reasons for investing in terrace construction and maintenance are presented in Figure 4. The reduction of soil erosion was by far the most important reason, according to winery owners. Their experience is backed up by the monitoring study of Camera et al (2018), who quantified the effectiveness of drystone terraces on mountain vineyards in Cyprus using sediment traps and laser scans and found an annual soil erosion rate between 2.4 to 3.2 mg/ha. They also reported that soil loss increases by a factor of 3.8 in degraded walls compared to well-maintained ones. Giannakis and Bruggeman (2018) estimated that for each 1 ton/ha increase in the annual soil erosion rate, the likelihood that European regions would attain high agricultural labor productivity decreased by 28%. The reduction of soil erosion is an important ecosystem service provided by terraces (Schwilch et al 2018), which is well appreciated by the mountain wineries. The provision of soil ecosystem services, including erosion control, water retention, and the enriched soil biota due to low-input farming methods, is also one of the main

TABLE 4 Detailed cost of establishing and maintaining mountain terraced vineyards.

Establishment and activity costs[a)]	Winery	
	Chandria	Pelendri
Establishment cost—labor (€/ha)		
Land levelling, ploughing/harrowing, destoning	20,000	20,000
Terrace wall construction	150,000	375,000
Irrigation system installation	1000	6000
Planting	4000	3500
Staking/wiring	2500	5000
Total	**177,500**	**409,500**
Establishment cost—material (€/ha)		
Stones	100,000	375,000
Machinery (tractor)	2500	–
Irrigation (pipes, drippers)	3000	30,000
Planting equipment	1000	500
Vine plants	15,000	4000
Wire	7200	3500
Staking poles	7200	10,000
Total	**135,900**	**423,000**
Vineyard maintenance cost—labor (€/ha/y)		
Terrace wall maintenance	5000	2000
Ploughing/harrowing	700	1000
Fertilization	600	350
Plant protection and weed control	100	1000
Irrigation	250	100
Pruning	1250	2000
Toping/thinning	1500	150
Harvesting	1000	2000
Total	**10,400**	**8600**
Vineyard maintenance cost—material cost (€/ha/y)		
Stones	–	–
Machinery (tractor)	100	300
Fertilization	50	150
Plant protection and weed control	50	1000
Irrigation	1000	400
Pruning	450	–
Total	**1650**	**1850**

[a)] Conversion rate at time of study: € 1 = US$ 1.142.

reasons why terraces are included in the greening CAP measures (Alliance Environnement 2017). Other important reasons for maintaining mountain terraces mentioned by the surveyed wineries were to facilitate agricultural works on mountain hill slopes and to improve land cover, while subsidies and enhanced sociocultural opportunities (eg landscape aesthetics and agritourism) received the fourth average scores (Figure 4).

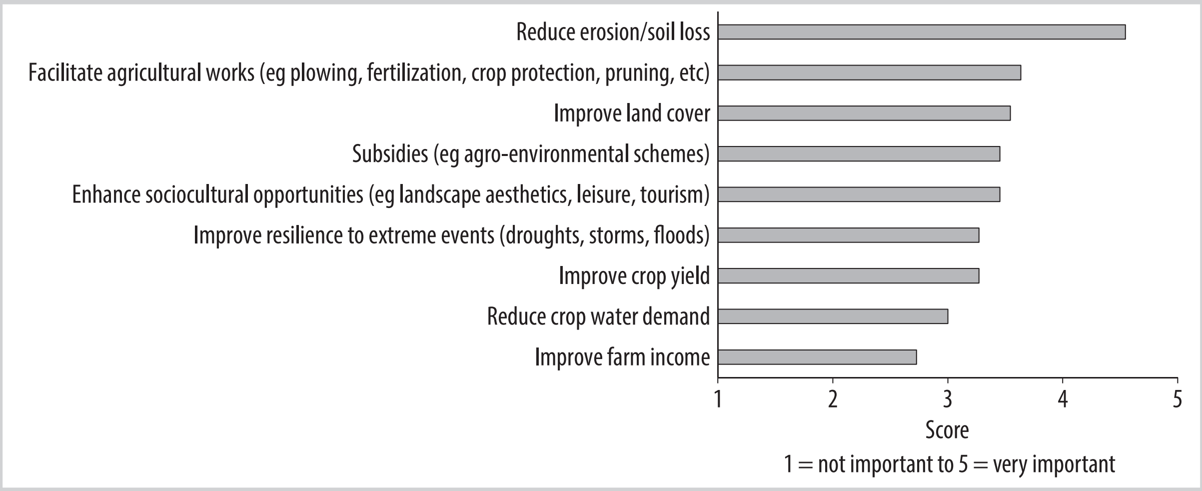
The winery owners were also asked to rank potential solutions that could be applied to revitalize mountain terrace farming (Figure 5). The 2 options that had the same average rank and were at the top of the ranking were "legal framework that supports the renting or selling of unused land" and "more or different agricultural subsidies." Apart from the socioeconomic issues associated with land abandonment in Cyprus, additional shortcomings include the small size and fragmentation of agricultural plots, the lack of road access, and issues relating to ownership rights. Demetriou et al (2012) suggested that land consolidation and reallocation using an integrated planning and decision support system could help to overcome these issues. The concept of "land banks" is a potential solution that has been discussed and applied in some European countries to overcome the risk of farmland abandonment (Terres et al 2015), such as in Italy (Strambi 2015) and Spain (Corbelle-Rico et al 2012). Another option that ranked relatively high among the respondents was "financial incentives for improved agritourism facilities." In fact, some of the wineries, such as the one located in Panayia, were planning to invest in agritourism facilities in the near future. The reconstruction of traditional landscapes can enrich terraced agriculture by stimulating the development of recreational tourism (and thus an additional income source for the mountain population) while helping to protect the environment (Torquati et al 2015).

Production output and financial viability

The grape and wine production output, the cost, and the gross returns per bottle of the surveyed mountain wineries are listed in Table 5. The yield from the vineyards managed by the wineries (ie grapes produced in owned and rented land) enables comparison between the sampled case studies. Based on the managed vineyard areas and production output, the computed average yield across the 11 wineries was 4.4 ton/ha, which is above the 3.1 ton/ha average that is reported in national agricultural statistics for wine-growing areas in the period 2009–2017 (Cystat 2017). However, there was large yield variation between the surveyed wineries. One reason could be the varieties grown and the different vineyard management practices applied at each winery vineyard. Also, the low yield of some winery vineyards, as explained by the respondents, was due to the young age of the vines, and the yield was expected to increase in the coming years.

The wine production, measured in bottles produced per year, is indicative of the size and production capacity of each winery. Two mountain wineries (located in Kyperounta and Panayia) were producing a relatively high amount of wine, around 300,000 bottles/year or more. Another interesting finding is the share of own-produced grapes used in wine making. The wineries located in Chandria, Farmakas, Malia, and Vasa Koilaniou relied almost exclusively on their own grapes, while only 6% of the wine produced in Kyperounta was obtained from the winery's vineyards. In most cases,

FIGURE 4 Reasons for constructing or maintaining drystone terraces; average score is based on the responses of 11 winery owners.



wineries purchased grapes from other farmers based on contract agreements. These agreements not only define the quantities and the price but also the quality of grapes. To ensure that the quality of the purchased grapes is adequate for wine production, the agronomists working for the wineries often provide vineyard management advice to the farmers with whom they collaborate. This strategy reduces the grape production cost for the wineries, but it also benefits other mountain grape producers, as the sale of the produced grapes is ensured. In addition, the wineries are among the few rural business in the mountain areas, and so their existence benefits and sustains the mountain agriculture of nearby communities.

Regarding the trading of wine produced, most wineries had sales agreements with local stores, while small quantities were sold to winery visitors. Exceptions to this rule were the wineries located in Omodos and Ayia Mavri, where 80% and 50% of the wine was sold to visitors, respectively. Another interesting example is the trading collaboration of Pelendri, Koilani, and Vasa Koilaniou wineries. These wineries established a distribution company that exclusively trades their wines. Kyperounta winery, on the other hand, has its own distribution company. It is noteworthy that although 9 out of 11 wineries also export their wines, the exported production averaged just 5% per winery. The average gross profit margin of all surveyed wineries was € 226,595 (US$ 258,771), which implies a general efficiency in the production process. Although there was a wide range of costs and revenues for each winery, this metric is informative when comparing across the different wine regions and at the field (per hectare) level. The gross profit margins in Pitsilia, Vouni Panagias–Ampelitis, and Krasochoria regions were € 24,406/ha (US$ 27,872/ha), € 13,396/ha (US$ 15,298/ha), and € 8,368/ha (US$ 9556/ha), respectively. This is an interesting finding, since the wineries located at higher elevations (Pitsilia region) had bigger production costs (including terrace construction and maintenance), but at the same time, they were able to market their products more efficiently, in general. Thus, although the production conditions are more difficult and costs are bigger at higher elevations, investment in productive agriculture can be an efficient and financially viable business.

Parameters of success, concerns, and future visions

When asked if they considered their business to be successful, all surveyed wineries responded positively. This success can be partly explained by the decisions made by winery owners. As shown in Figure 6, these decisions are

FIGURE 5 Solutions to revitalize rural mountain communities and terrace farming; ranking is based on the responses of 11 winery owners.

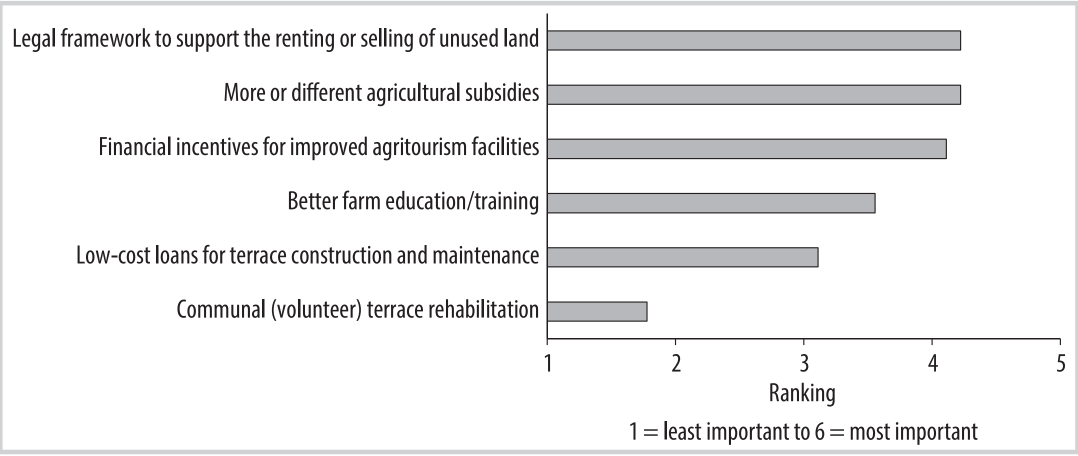


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FIGURE 6 Support in vineyard management decisions; average score is based on the responses of 11 winery owners.

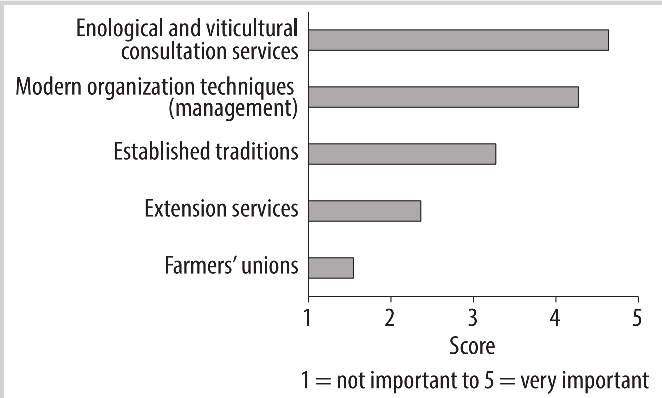
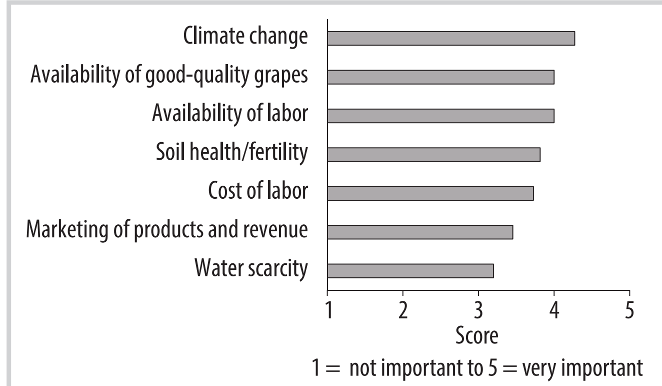


FIGURE 7 Major concerns; average score is based on the responses of 11 winery owners.



taken in consultation with enologists and viticulture professionals. In addition, the modern management option was highly scored. The use of information and communications technologies plays a key role in what Milone and Ventura (2019) called "new generation farmers." With an open question, the respondents were also asked to define the factors determining the success of mountain wineries (Table 6). The quality of grapes and wines produced was mentioned by 9 out of 11 wineries, while the mountain terroir, marketing, and sales/profit were mentioned by 7 wineries.

Terroir has been defined as "a unique and delimited geographic area for which there is a collective knowledge of the interaction between the physical and biological environment and applied vinicultural practices. The interaction provides unique characteristics and creates a recognition for goods originating from that area" (van Leeuwen 2010: 274). As terroir is typically associated with distinctiveness, the marketing value of products with a defined terroir tends to be higher (Cross et al 2011). In France and Italy, the concept of terroir is the basis for certification and geographical indication, protection of origin, and labeling (Lamine et al 2019). In Spain, there is no terroir characterization; however, as González and Dans (2018) noted, the emergence of the *terroirist* social movement created rural networks of small-scale farmers that aim to produce quality wines with added value. Similar to Spain, there are no defined terroir regions in Cyprus yet; however, the respondents considered that the mountain growing conditions are unique and therefore add to the value and success of their wines.

The most important concern identified by mountain wineries, as shown in Figure 7, is climate change. Interestingly, the respondents did not relate this issue to water scarcity, since the Troodos aquifer system is not as depleted as the coastal aquifers of Cyprus (Zoumides et al 2013, 2014). Mozell and Thach (2014) explored the consequences of climate change on the global wine industry and noted that premium wine grape production that occurs in very narrow climate ranges can be severely affected by changes in temperature. According to winery owners, the microclimate determines to a great extent the character of the wines produced at each site. Nicholas et al (2011) studied the effects of climate variability on the phenolic composition of pinot noir grapes cultivated in California's North Coast. Their findings indicate that the tremendous variability observed within vineyards implies that further research and monitoring are needed to understand the influence of climate and temperature on inter alia canopy, and plant and soil water status, and therefore the effects on grape and wine quality characteristics. Other important issues of concern that were revealed by the responses are the availability of good-quality grapes and the scarcity of labor. Both issues are associated with the depopulation of rural communities and the gradual abandonment of mountain agriculture.

Despite these concerns, the majority of the surveyed wineries were optimistic about the future of their business and mountain agriculture in general. The establishment of local wineries is the main driver that sustains mountain farming in the area, and it creates prospects for other associated industries (eg agritourism) to be developed in the near future. As noted by Farmaki (2012), much of the promotion surrounding agritourism in Cyprus revolves around the activities that can be performed in the Troodos Mountains, ranging from nature-based activities to visiting wineries. Efforts to enhance agritourism began in the mid-1990s with the aim of diversifying the mass "sun and sea" tourism model (Farmaki 2016). These efforts continue to this day and include, for instance, financial incentives to renovate and convert traditional houses into guesthouses. The number of licensed holiday accommodations in the Troodos region increased from 49 in 2006 to 256 in 2017 (CDMC 2019). As indicated by 8 out of 11 respondents, the creation of family wineries implies that more people have become aware of local wines, while the competition between the wineries is a motivation to further improve the quality of the wines they produce. The surveyed wineries shared a number of common visions for the future, which can be summarized as follows:

- Ensure the sustainability of their business and leave something for their children and the future generations, for example, continue a tradition, create points of reference and excellence regarding mountain farming;
- Improve the quality of wine produced, especially from local varieties, so that it is competitive locally and internationally;
- Increase production from current vineyards by utilizing abandoned land;
- Revitalize the mountain communities and provide employment opportunities, so families can return and

TABLE 5 Annual wine production output, costs, revenues, and trading channels. (Table extended on next page.)

Inputs and outputs[a)]	Winery				
	Chandria	Kyperounta	Farmakas	Pelendri	Statos–Agios Photios
Grape production from own vineyards (tons)	60	25	22	30	25
Grapes purchased from other farmers (tons)	–	375	–	200	260
Portion of own grapes used in wine production (%)	100	6	100	13	9
Yield in vineyards managed by wineries (tons/ha)[a)]	4.0	1.6	1.0	3.8	1.3
Wine production (750 mL bottles)	40,000	375,000	20,000	200,000	290,000
Total variable cost of grape production: labor, mechanical, fertilizers, etc (€)	30,000	163,000	66,000	270,000	31,350
Total variable cost of wine production: labor, operation, winemaking, etc (€)	133,000	278,000	45,000	500,000	608,000
Total revenue from wine sales (€)	150,000	1,400,000	90,000	1,000,000	680,000
Other revenue, eg catering, tasting, etc (€)	5000	10,000	110,000	25,000	–
Subsidies (€)	7500	10,000	1500	4000	5000
Value of wine stock (€)	30,000	600,000	35,000	500,000	1,795,650
Gross profit margin (€)[b)]	–500	979,000	90,500	259,000	45,650
Gross profit margin per hectare (€/ha)[b)]	–33	61,188	4095	32,375	2341
Trading channels					
Direct sales at the winery (%)	20	1	20	10	5
Sales agreements with local stores (%)	72	–	80	–	80
Exports (%)	8	5	–	8	15
Private distribution network (%)	–	94	–	82	–

[a)] Conversion rate at time of study: € 1 = US$ 1.142.
[b)] Own elaboration based on the responses of winery owners (see Table 2 for vineyard area).

raise their children in an environment outside the cities and have a good standard of living.

The survey was conducted in 2 phases: The main data were gathered in 2017, and the validation of data with clarification questions on the economics of wineries was conducted in early 2020. As such, the impacts of the coronavirus disease 2019 (COVID-19) pandemic are not reflected in the responses. It is, however, evident that the wine market at European and international levels has been affected, both in the lockdown phase, and in the new normal reality post-2020. Indicatively, the Comité Européen des Entreprises Vins (CEEV 2020) reported a decrease of global wine trade of 17% (equivalent to € 1.8 billion) in the period March–June 2020, compared to 2019. At EU level, winery turnover decreased by 35% in the first semester of 2020; the impact of the pandemic is more evident in microcompanies. In Cyprus, wine production, consumption, and exports were, respectively, 9, 48, and 30% lower in 2019–2020 compared to 2017–2018, based on data provided by the Department of Agriculture. The high reduction in consumption is linked to the restricted social events (eg weddings, graduation ceremonies, etc), where wine is typically consumed, during the COVID-19 pandemic. The sustainability of the wine sector will depend on its capacity to recovery in the next 2–3 years and to adapt to the new realities. For instance, in the first phase of the crisis, wine e-commerce at the global level increased by 180% (CEEV 2020). Although this reflects only 1% of wineries' turnover, it could potentially grow steadily, considering the new post-COVID-19 realities. At the EU level, an efficient support package for the quick recovery of the on-trade channel has been discussed, while, in Cyprus, a support package to enhance the competitiveness and export capacities of wineries was put forward in April 2021. It remains to be seen how fruitful these policies are and whether mountain wineries can remain successful in the near future, following the COVID-19 shock.

Conclusion

Terraces are a landscape characteristic of mountain regions around the globe. In the Mediterranean basin, these farming systems are associated with the cultivation of grapes. While studies on terrace abandonment are pervasive, there are very few studies that analyze viable mountain production systems. To contribute to the recent and growing interest in the renaissance of agricultural mountain terraces, this study aimed to shed light on the often-overlooked socioeconomic drivers, prospects, and

TABLE 5 Extended. (First part of Table 5 on previous page.)

Inputs and outputs[a)]	Winery					
	Ayia Mavri	Koilani	Omodos	Panayia	Vasa Koilaniou	Malia
Grape production from own vineyards (tons)	18	290	30	95	50	160
Grapes purchased from other farmers (tons)	40	200	80	150	2	–
Portion of own grapes used in wine production (%)	31	59	27	39	96	100
Yield in vineyards managed by wineries (tons/ha)[a)]	6.0	13.7	1.1	6.1	6.7	3.3
Wine production (750 mL bottles)	40,000	220,000	80,000	192,000	40,000	50,000
Total variable cost of grape production: labor, mechanical, fertilizers, etc (€)	29,100	55,000	42,000	42,000	47,000	53,924
Total variable cost of wine production: labor, operation, winemaking, etc (€)	90,000	470,000	150,000	350,000	140,000	192,184
Total revenue from wine sales (€)	150,000	1,000,000	370,000	750,000	170,000	250,377
Other revenue, eg catering, tasting, etc (€)	–	10,000	–	5000	17,500	–
Subsidies (€)	1300	5000	8000	16,000	3500	23,429
Value of wine stock (€)	150,000	500,000	225,000	160,000	200,000	141,165
Gross profit margin (€)[b)]	32,200	490,000	186,000	379,000	4000	27,698
Gross profit margin per hectare (€/ha)[b)]	10,733	23,113	6889	24,452	533	571
Trading channels						
Direct sales at the winery (%)	50	10	80	20	3	–
Sales agreements with local stores (%)	45	–	20	77	–	98
Exports (%)	5	1	–	3	1	2
Private distribution network (%)	–	89	–	–	96	–

TABLE 6 Factors determining the success of mountain wineries.

Winery	Success factor					
	Quality of grapes and wine	Mountain terroir	Niche products	Marketing	Sales/profit	Confidence in mountain agriculture potential
Chandria	✓	✓	✓	✓		✓
Kyperounta		✓		✓	✓	
Farmakas	✓	✓				✓
Pelendri	✓	✓	✓	✓		✓
Statos–Agios Photios	✓	✓	✓	✓	✓	✓
Ayia Mavri	✓		✓		✓	
Koilani	✓	✓	✓	✓	✓	
Omodos	✓				✓	
Panayia	✓	✓	✓		✓	✓
Vasa Koilaniou	✓			✓		✓
Malia				✓	✓	
Total no. of wineries	**9**	**7**	**6**	**7**	**7**	**6**

visions of farmers, using the mountain family wineries of Cyprus as a case study. The bottom-up approach and the outcomes of the study provide insights and a broader view that can be of relevance to other terraced farming areas, given that the challenges and opportunities are often common in such environments. For instance, although investments in drystone terraces were found to be costly, the wineries cherish their role as sustainable and viable mountain agribusiness and recognize that beyond the historical heritage, landscape aesthetics, and cultural values, terraces provide important ecosystem services, such as the prevention of environmental risks, the control of soil erosion, and the creation of a unique mountain terroir. Furthermore, the semistructured survey revealed that farmers are concerned and well aware of global challenges, such as climate change. At the same time, the shared vision for a future where abandoned mountain terraces can be productively utilized is indicative of the prospects for job creation, while the spin-off effects and synergies with complementary industries can be leveraged to effectively sustain mountain livelihoods. These attributes are particularly important for creating well-informed and innovative regional and rural development policies at European, national, and territorial levels. The development prospects of mountain farmers need to be supported and enhanced, while the site-specific challenges that they face need to be better understood and taken into account during this process to move toward a new, sustainable, effective, and equitable policy paradigm. The survey developed and applied in this study (see Appendix S1, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00031.1.S1) is a useful tool for initiating a dialogue with farmers. Similar studies are encouraged, so as to create a global collection of mountain agriculture success stories.

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Supplemental material

APPENDIX S1 Questionnaire.
TABLE S1 Grape varieties.

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