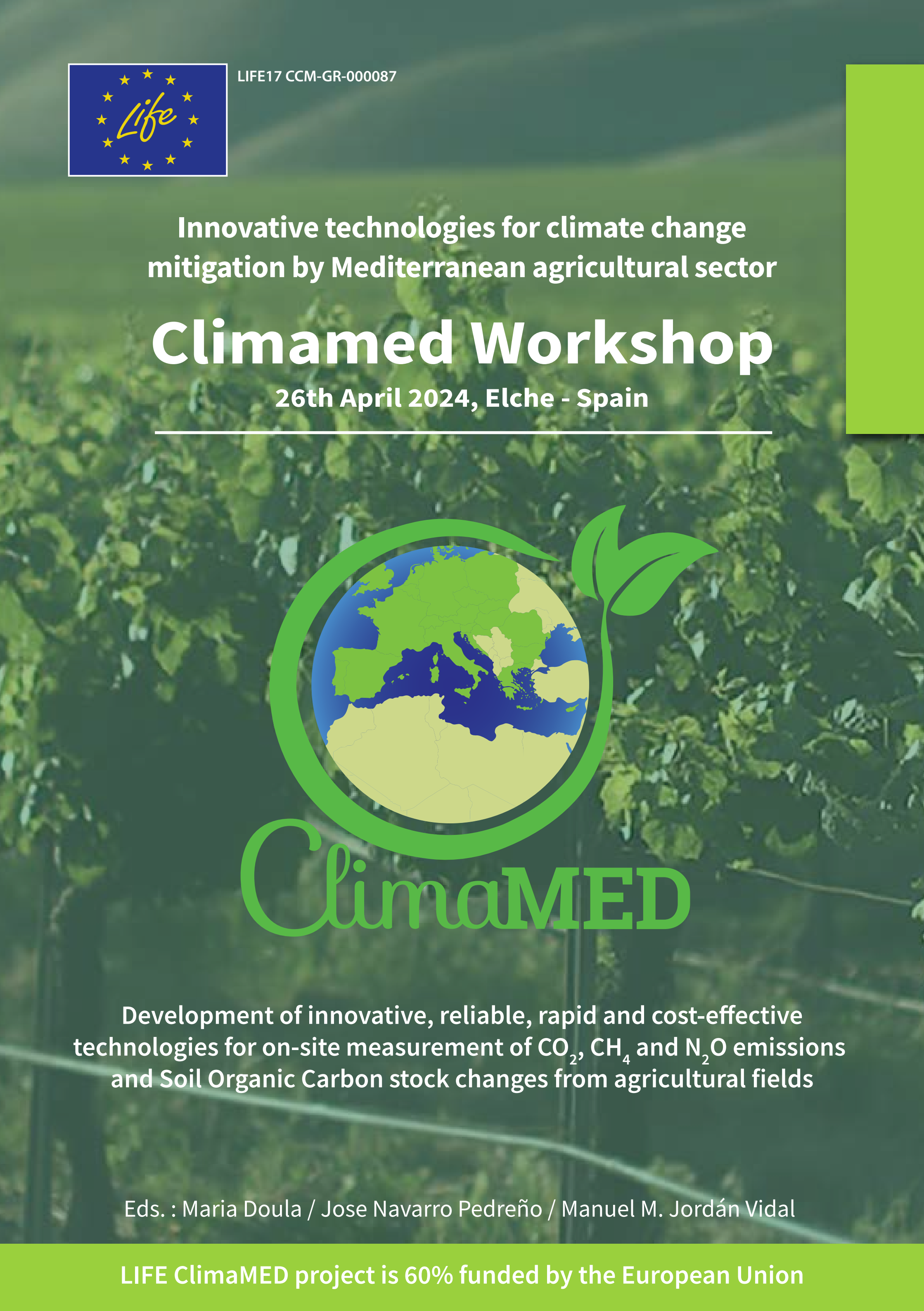

LIFE17 CCM-GR-000087

Innovative technologies for climate change mitigation by Mediterranean agricultural sector

Climamed Workshop

26th April 2024, Elche - Spain

Development of innovative, reliable, rapid and cost-effective technologies for on-site measurement of CO_2, CH_4 and N_2O emissions and Soil Organic Carbon stock changes from agricultural fields

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INDEX

Soil organic carbon and GHGs in farming systems

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ABSTRACT

Climate change is impacting on the primary sector, but specially in farming systems. The production of food is necessary to maintain the population and to achieve the Sustainable Development Goals (SDGs) proposed by United Nations. At the same time, we have to reduce the carbon footprint from our activities. It is crucial the role associated to the mitigation of climate change storing soil organic carbon. To achieve these objectives, SDGs and climate change mitigation, it is necessary to modify agricultural practices so that greenhouse gases (GHGs) emission will be reduced. In order to demonstrate the effectiveness of the changes done by farmers, it is necessary to have a reliable measurement system. This is the fundamental objective of the LIFE ClimaMed project, to demonstrate it based on the use of LIDAR systems and remote monitoring in real time. Moreover, this project tries to help in the recognition of farmers that are using good practices by using a demonstrable system.

Keywords: carbon sequestration, good agricultural practices, Lidar, soil organic matter, sustainability.

INTRODUCTION

The growing world population is expected to increase to 9.8 billion by 2050 (Population Reference Bureau, 2020), and occupation of land with superior agricultural potential for the expansion of cities will intensify pressure on the agricultural capacity to meet resulting agri-food demand (Aksoy et al., 2017). These two situations seem to be contradictory. At the same time, both lead to scenarios where greater greenhouse gas emissions will occur while the possibilities of reducing atmospheric carbon are reduced as agricultural areas disappear.

Climate change is impacting in our life. Even more in our farming systems. Agricultural production is by far the biggest source of anthropogenic non-CO_2 greenhouse gasses (GHG), contributing to around 54% of all non-CO_2 GHGs emissions worldwide (U.S. Environmental Protection Agency, 2012). But, agriculture can at the same time be a fundamental part in reducing the serious effects derived from rapid climate change.

As much as we know, different types of land use, particularly in agriculture and forestry, result in increased or decreased carbon emissions into the atmosphere, accounting for nearly one-quarter of greenhouse gas emissions (Veni et al., 2020). Thus, the possibilities to mitigate and adapt to changes also involve improving the management of farming systems.

The European Union (EU) has implemented various directives, actions and plans to regulate and make food production more efficient, environmentally friendly and safer (European Comission, 2020) and most of them consider the soil, the farming systems, as a key element.

As a major carbon sink, soils play an important role in combating rising atmospheric greenhouse gases (GHG) concentrations (Navarro-Pedreño et al., 2021). This is why their use is at the heart of many sustainable development issues and objectives (Abera et al., 2021), like those proposed by United Nations for 2030 called Sustainable Development Goals (SDG).

The role of farming systems in the reduction, mitigation and adaptation to climate change should be measured and important decisions should be taken to facilitate the application of good agricultural practices. Not all these practices are related to soil management because other actions can be improved to reduce GHG emissions, but soils play a crucial role.

The reduction potential in the agricultural sector is less precisely defined than in other sectors due to the largely diffuse nature of emissions, the complexity of the underlying biophysical and behavioral processes, and the vast diversity of production systems (Benslama et al., 2024a). Under this scenery, we need methodologies and technical devices that can give good results to ensure the effectiveness of agricultural practices in reducing GHG emissions.

AGRICULTURAL PRACTICES

Although crop yield has increased worldwide from 1,100,750 tons per hectare in 2019 to 1,114,524 tons per hectare in 2021 (FAOSTAT, 2021, 2023), it is estimated that by 2050, crop yields will decrease by 6 to 13 % (Brunelle et al., 2015). One of the main issues is the reduction of soil quality by many processes like salinization, pollution or soil sealing, that affected the yield. On the other hand, the increment of food production sometimes leads to overproduction with serious environmental consequences, including deforestation, soil degradation, and greenhouse gas emissions from food waste (Economou et al., 2024).

Many soil improvements and farming management practices have been discussed and have the potential to enhance SOC stocks (Benslama et al., 2024b). The good agricultural practices to reduce the emission and impact of GHG can vary, depending on the place and environmental conditions, but they include reusing and recycling farming wastes and leaving fields fallow. The reuse of wastes can boost local economies and reduce environmental damage. Since these wastes are unavoidable, farms would benefit economically and environmentally. Additionally, animal digestion produces biomass, biofuel, and manure-based organic fertilizer while reducing greenhouse gases and improves soil fertility (Rodríguez-Espinosa et al., 2023). There are also situations where farmer’s efforts to mitigate climate change are paid. Such is the case of, a Boston-based company called Indigo paid $26,232 in late 2021 and an even larger chunk late last year. That’s how much an emerging market values the hundreds of tons of carbon that, in theory at least, yanked out of the atmosphere with his cover crops or left in the soil by not tilling (Popkin, 2023).

In this sense, the results from projects that are checking the effects of several agricultural practices and those measuring the GHG emissions from them, gave tips that can be applied to improve food production and to know how to reach the balance between food production to sustain people and keep the environment in healthy conditions, these include mitigation of climate change.

MEASURING CARBON FOOTPRINT

As we preciously commented, it is important to compensate farmers that reduce their carbon footprint. However, it is crucial to fairly assess and contrast the costs of the several available levers for purposes of policymaking (Pellerin et al., 2013). Sustainability should consider environment, but society and economy. Solutions should be applied to reduce negative effects but considering those that are realistic and can be applied taking into account farmers' costs to produce food. Compensation measures through tax reductions and other measures could help achieve positive changes in farming systems.

Measure of the carbon footprint with lidar devices, like those presented in this project called LIFE ClimaMED, could help administration to find how to compensate and facilitate the application of fair and adequate measures.

Many works done under the LIFE or H2020 Europeans Research Programs, as well as other many research programs in many countries, have favored finding solutions following the minimization of the GHG emissions and reducing our carbon footprint. Some of those results and projects are included in this short publication from the workshop held in Elche (Spain) called “Soil organic carbon and GHGs in farming systems”.

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Climate change and agriculture - Is it time for decisive decisions?

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ABSTRACT

The Mediterranean region holds only 3% of global water resources but hosts over 50% of the world's water poor populations, around 180 million people, while its population is predicted to reach 572 million in 2030. It is expected that after 2030, available water supplies will fall below demand. With 40% of its 450 million inhabitants living in coastal areas, the Mediterranean basin is one of the most vulnerable areas on the planet in terms of climate change impacts. Agriculture, particularly the cultivation of olives, grapevines, cereals, fruits and vegetables, plays also an important role in the economy of countries around the Mediterranean. Since the impacts of climate change are expected to be particularly severe in the Mediterranean countries and their socioeconomic network, which is mainly built on agriculture (and tourism), it becomes increasingly imperative to make correct and timely decisions for adapting agricultural practices to ensure the survival and resilience of this crucial sector in synergy with other productive sectors of the area, in the face of environmental challenges.

Keywords: Agriculture, climate change, soil, soil mapping, biodiversity, Mediterranean.

INTRODUCTION

The IPCC (2019) has repeatedly highlighted Mediterranean region as particularly vulnerable. At global level, Mediterranean and Northeastern Europe regions are defined as the most prominent climate response hot spots (i.e. areas most responsive to climate change), followed by high latitude northern hemisphere regions and Central America (EEA, 2018). As regards Greenhouse Gas (GHG) emission, the good news is that the Mediterranean region emits low levels of GHGs, as compared to other areas in the world, i.e., 2019 data revealed that the CO2 emitted by the Mediterranean countries was up to 6.7% of the world's emissions, equivalent to more than 2 billion tons of CO2. An issue of concern, however, is that, although low compared to other areas of the world, this CO2 amount has increased by a factor of 4 in the last 50 years, with an increase in the contribution from countries from the southern region of the Mediterranean from 9% to 30%. Meanwhile, the contribution from all EU Mediterranean countries has decreased over the same period from 88% to 54% (EEA, 2015).

As regards Mediterranean agriculture, the potential impacts of climate change on the sector will be tremendous. Future scenarios and projections point to intensification of agriculture in northern and western Europe and extensification and abandonment in the Mediterranean region, which result in economic and social unsustainability in the region (Holman et al., 2017).

The Mediterranean basin is inherently susceptible to various hazards, including earthquakes, volcanic eruptions, floods, fires, and droughts. These challenges, coupled with climatic and environmental factors, create a multifaceted and complex scenario that is addressed by diverse policies and approaches. Given that a significant portion of the Mediterranean population relies on agriculture, it's evident that impending changes will pose considerable social, environmental, and economic challenges if proactive management plans are not promptly implemented.

To address challenges related to agriculture, comprehensive assessments of available resources, with a particular emphasis on soils and biodiversity should be always conducted. Methodical characterization and mapping of these resources in conjunction with climate data are imperative for informed decision-making. Embracing a holistic approach that encompasses soil health, biodiversity protection and climate resilience emerges as vital for fostering long-term sustainability in agriculture.

FARMERS FACING DECISION CHALLENGES

Farmers today find themselves in dire circumstances, experiencing low yields and diminished incomes, a situation that continues to stabilize gradually. Previously, approximately 0,20-0,25 ha were sufficient to support a family of four in Greece, but today, around 0,60 ha are needed. Apart from adverse climatic conditions, adversely affecting crop cultivation, rising costs of fertilizers, pesticides, and fuel further worsen the economic situation of farmers, threatening their prosperity.

The most significant challenges in agricultural production in the EU are currently observed in the Mediterranean basin, which is gradually losing its ability to produce sufficient varieties to secure food production in quantities and for prices that can support and guarantee farmers' income. According to climate models, the Mediterranean region should prepare to lose crops, i.e., it is characteristic that countries north of the Mediterranean are already preparing to adopt traditional Mediterranean crops, such as vineyards.

Mediterranean agricultural systems, due to the region's geomorphological characteristics (uneven terrain, steep slopes, water scarcity, land vulnerable to erosion and floodings, e.g., coastal systems), as well as the peculiar climatic conditions (intense and short-duration rainfall, high temperatures), are particularly vulnerable. Moreover, the intensity of agriculture and mainly its unsustainable practices have caused the collapse of the balance of agricultural ecosystems in many areas, making them even more vulnerable to climate crises.

Given these circumstances, farmers are paying increasingly more money to ensure desired productivity levels, often with uncertain or even adverse results. The position of producers is truly difficult today, as, in addition to the very serious issues they face, without knowing the outcome of their actions on an annual basis, they are called upon to implement a series of environmental measures as indicated by European Climate policy, the Green Deal, legislation on nitrate pollution, water protection, biodiversity protection and enhancement, resulting in confusion or even misunderstanding of basic concepts, such as biodiversity, which they are called upon to protect. Nevertheless, many producers have succeeded in this and enter the markets with environmentally friendly products, primarily with regard to biodiversity, targeting a specific consumer base, which desires and can pay for such products. Yet, in this case as well, the benefit arises from the "myth" accompanying the product (i.e. environmentally friendly) and its quality, and not its quantity, which, due to reduced interventions at the level of practices, as well as climatic conditions, remains small or gradually decreases.

The impasse is real; however, in many cases, finding a way out is postponed for the next or subsequent years, hoping that the situations will change in favor of production, and farmers will be able to compensate for the loss of production and income.

It is a fact, however, that even if some are willingly blind or await positive change, the productivity of Mediterranean soils has declined. The reasons are known: adverse climatic conditions, degraded and poor soils with depleted productivity due to intensive and non-sustainable practices, and declined or gradually declined biodiversity.

These undoubtedly place farmers in a decision-making position. It is not solely the climate crisis that places them in this transitional state, but a combination of events and outcomes of practices applied to date, which, combined with adverse climatic conditions, have worsened the situation they now have to face. Therefore, it is evident that past mistakes, i.e., the non-holistic approach to agricultural ecosystems, must be avoided, and the focus must be on seeking adaptation measures not solely for climate change. Also crucial is the timing of the decisions to be made, as time has different significance for annual crops than for perennials.

In any case, decision-making is the first step towards an adaptation path, as it indicates an understanding of the impasse.

A crucial question that must first be answered is whether to maintain the same cultivation for the coming years. This question, which the majority of farmers, especially those cultivating trees, struggle to answer, either because they are traditionally and emotionally committed to their cultivation or because of fear of the unknown and uncertainty of a new cultivation, with all that it entails (e.g., new and mostly unknown behaviors of the new cultivation, existence of markets and creation of a new product distribution network, yields, requirements, etc.). It is truly unreasonable to expect Andalusia to consider stopping olive cultivation when 60% of its area is covered by olive groves. However, it is logical to expect some skepticism about the sustainability of olive cultivation in the minds of olive growers, given the yields of recent years, culminating in the production of 2023 and the skyrocketing price of olive oil.

Such a difficult decision, namely the change of cultivation type, cannot be made and implemented impulsively or superficially, without being based on evidence, without developing a detailed timeline and financial plan, and finally without ensuring the product's distribution in the market.

The choice to maintain cultivation, obviously aware of the unfavorable conditions and yields, should be supported by adaptation measures to the greatest extent possible to the new conditions and by measures to increase the resilience and flexibility of the rural environment to climate change. And of course, there is no one-size-fits-all solution, as each system may require different treatment and yield different results, depending on the region, the type of cultivation, and the particular socio-economic conditions of the area.

Soil and biodiversity stand as two crucial parameters within agricultural landscapes, demanding the producer's focused attention. However, collective action, such as collaboration through cooperatives or producer groups, holds promise for enhanced outcomes. Through collective efforts, costs and resources can be shared, and benefits accrue collectively. Safeguarding and enhancing both these natural resources contribute significantly to ecosystem stability and resilience. While water's critical importance is undeniable, it's essential to recognize that soil and biodiversity have not historically received the same level of attention and protection from growers, particularly when compared to water resources. Fortunately, there's gradual improvement concerning soil management, but the same cannot be said for biodiversity conservation efforts.

Within a holistic approach of a decision-making framework, it is necessary to characterize and record the available resources and their quality. Especially for soils and biodiversity, resources that farmers directly manage (in contrast to water, for which management decisions are made by the competent management authorities), systematic characterization, mapping, and evaluation are required before making any decision. Incorporating periodic quality control and assessment stages into management plans is equally indispensable. These steps pave the way for nature-based approaches, fostering resilience and adaptability within agricultural systems. Thus, the foundational principles of (1) resource mapping and characterization, (2) evidence-based decision-making, and (3) identification of nature-based solutions, should be highlighted as the cornerstone of sustainable thinking and acting.

SOIL MAPPING

The first necessary step is the development of the soil and cultivation map of the area of interest, which will provide significant information about the physical and cultivation properties of the soils, respectively, and will serve as the starting point for management plans, whether they involve maintaining or changing cultivation.

As an example of soil map, Fig. 1 presents the respective map for Aegina Island in Greece, developed in the framework of LIFE project Agrostrat (2017). After methodological soil sampling and soil/and characterization the soil map units were characterized in terms of specific physical properties, which are expressed by a symbol, included in each map unit.

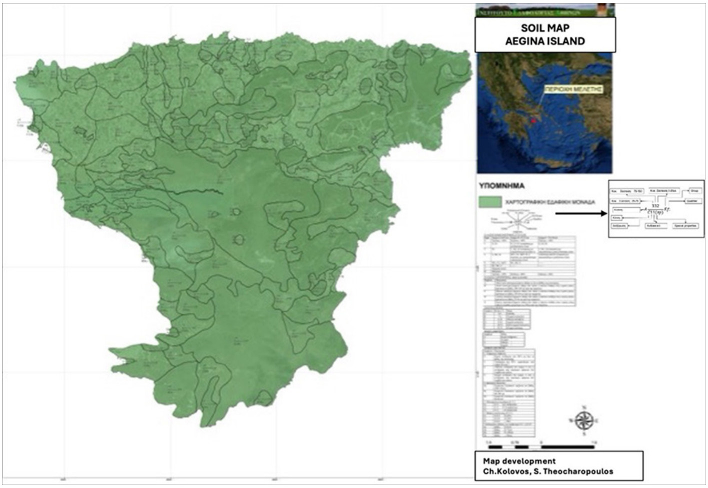

Figure 1. Soil map of Aegina Island in Greece (LIFE Agrostrat, 2017).

The symbol characterizing the map units, includes the properties as seen in Fig. 2 (Yassoglou, et al., 1982).

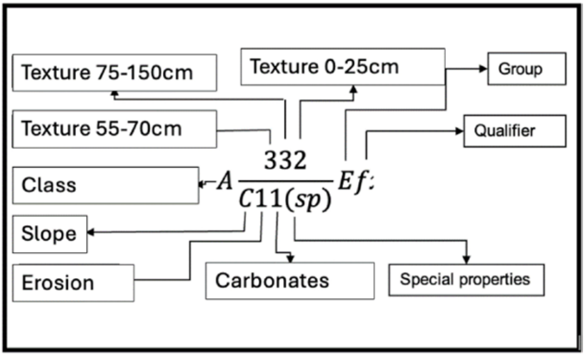

Figure 2. The cartographic symbol and the properties included.

Thematic soil maps (e.g., organic matter, macro- and micronutrients, pollutants), if developed, can provide additional significant information (Fig.3). From these maps, in combination with the requirements of various cultivated species (soil, water and climate), derivative cultivation suitability maps can be produced, which are particularly important tools in decision-making for maintaining existing cultivation or establishing new ones (Fig.4).

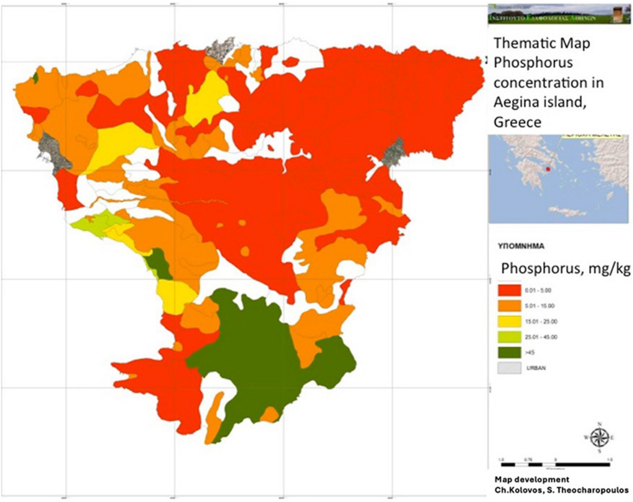

Figure 3. Soil phosphorus-Thematic map of Aegina island (LIFE Agrostrat, 2017).

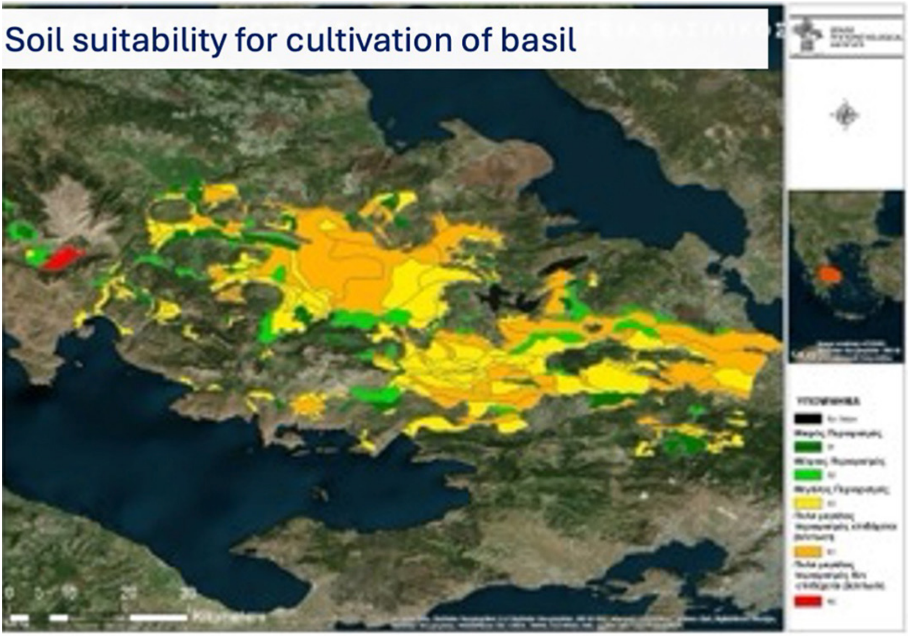

Figure 4. Soil suitability for basil cultivation (unpublished data).

Furthermore, the combination of the above cultivation suitability maps can be combined with predictive climate maps to produce cultivation suitability maps for the coming years, allowing adaptation strategy development. It should be noted that the question of "maintenance or change of cultivation type" is addressed today, in most cases, considering only the climatic factor, i.e., predictive models and the climatic requirements of plants. Soil is not taken into account as a parameter, and this is one of the "mistakes of the past" mentioned above.

The management of soils is as effective and sustainable as the level of detail provided by these maps. For example, based on the soil map and the thematic maps mentioned above and the introduction of additional data (legislative restrictions, crops nutritional requirements), maps of suitability for the dispersion-reuse of organic waste from agricultural production or animal husbandry can be created, and the appropriate dispersal dose can be calculated based on soil properties, legislation, and the nutrient needs of plants (Fig. 5).

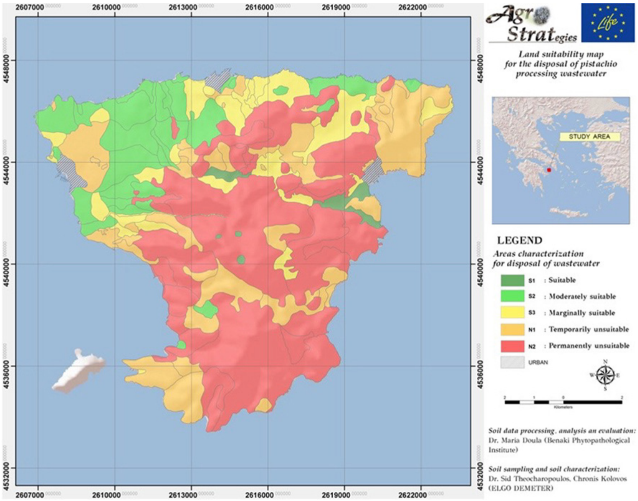

Figure 5. Soil suitability of dispersion of wastewater generated by pistachios processing-Thematic map of Aegina island (LIFE Agrostrat, 2017).

BIODIVERSITY MAPPING

In the realm of agricultural land management, understanding and preserving biodiversity is a critical component of sustainable practices. Just as soil mapping provides valuable insights into soil health and properties, mapping and characterizing biodiversity offer essential guidance for decision-making processes. This involves a systematic approach that begins with a thorough assessment of the agricultural landscape, considering factors such as historical land use, soil types, topography, and surrounding environment (Volpato et al., 2024).

Data collection plays a pivotal role in biodiversity mapping, encompassing various indicators such as plant species diversity, wildlife presence, insect populations, and microbial communities. Field surveys, remote sensing techniques, and existing biodiversity databases contribute to this comprehensive data gathering process.

The integration of Geographic Information Systems (GIS) and remote sensing technologies facilitates the mapping of biodiversity indicators across the agricultural land. Species distribution maps, habitat suitability models, and biodiversity hotspots maps emerge as valuable tools in this endeavor (Vihervaara et al., 2019).

Crucially, biodiversity mapping intersects with soil mapping efforts to unveil the intricate relationship between soil characteristics and biodiversity patterns. Overlaying biodiversity maps with soil maps illuminates areas of high biodiversity associated with specific soil types or conditions (Duivenvoorden and Lips, 1995).

Quantitative analysis further enriches the understanding of biodiversity metrics, employing statistical techniques such as species accumulation curves, diversity indices, and spatial autocorrelation analysis.

The culmination of these efforts results in the derivation of decision support maps, which serve as practical guides for land management strategies. These maps highlight areas of significant biodiversity value, pinpoint conservation priorities, and inform agricultural practices aimed at both productivity and biodiversity conservation. As an example, Fig. 6 presents mapping of biodiversity quality developed by Volpato et al., (2024), concerning an area of 750 km^2 in Burren, Ireland. Through a mixed methodological framework, they assessed and mapped biodiversity in the Burren agricultural landscape using habitat quality as a proxy. This methodology involved the use of data collected in the field using Rapid Assessment Cards and data obtained from an expert knowledge-based model.

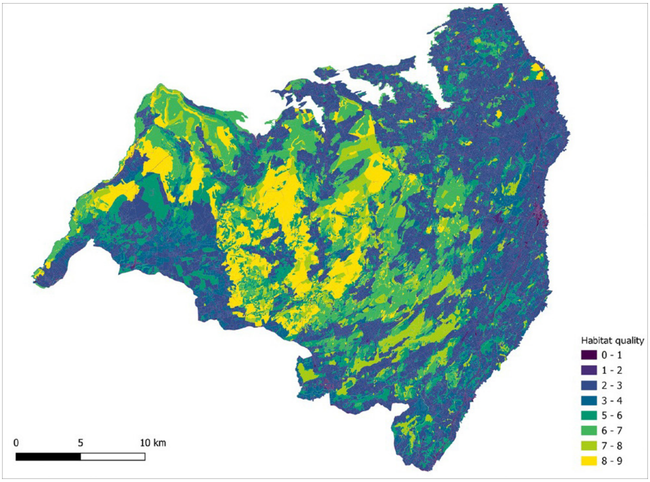

Figure 6. Habitat quality map of the Burren (Ireland) agricultural landscape (Volpato, et al., 2024).

An example of including soil properties in the evaluation methodology of biodiversity is presented in Fig. 7, derived from the work of Velázquez and Bocco (2001). The researchers studied an area of 600 km^2 in Sierra Chichinautzin, a Quaternary volcanic unit in central Mexico. Apart from biodiversity indicators, five soil and landscape variables were considered at each sampling unit, i.e. soil moisture, soil depth, elevation, slope steepness and slope length. Terrain units and vegetation clusters were used to typify and delineate land units.

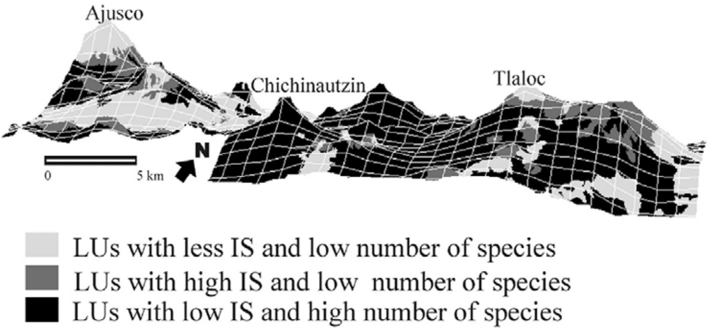

Figure 7. Biodiversity mapping-Distribution of key species in contrast with species assemblages (LU: Landscape units; IS: indicator species).

Continual monitoring and adaptive management practices ensure that biodiversity conservation remains a dynamic and integral aspect of agricultural land management. Through this holistic approach, agricultural practitioners can navigate the complexities of biodiversity preservation while advancing sustainable agricultural production.

CONCLUSIONS

The pressing challenge of climate change compels us to reevaluate agricultural decision-making processes with a sense of urgency. As we stand at the crossroads of tradition and innovation, the need for decisive action becomes increasingly apparent. Farmers are confronted with the daunting task of balancing historical/traditional practices with the imperative to adapt to changing environmental conditions.

Sustainability emerges as a linchpin in this paradigm, urging farmers to proactively embrace practices that mitigate climate risks while ensuring long-term productivity. This entails not only the adoption of resilient crop varieties and conservation measures but also a fundamental shift towards regenerative agricultural practices that restore ecosystem health and enhance resilience.

Furthermore, the comprehensive assessment of available resources, including soils, water, and biodiversity, lays the groundwork for informed decision-making. By harnessing the power of data-driven insights and embracing technological innovations, farmers can optimize resource utilization and mitigate the adverse effects of climate variability. The time for decision-making is now, and the stakes have never been higher.

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Crop diversification and sustainable soil management can enhance soil carbon sequestration in agroecosystems

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ABSTRACT

The combination of soil management strategies such as crop diversification, reduced tillage or organic amendments can improve not only soil health and carbon sequestration but the sustainability of agroecosystems. This can contribute to improved ecosystem services related to supporting and regulating as biodiversity, nutrient cycling, water infiltration and retention, and carbon storage, among others, with influence on crop production. The main goal of this study was to assess the effect of crop diversification under conservation management practices (reduced tillage, green manure or reduced fertilizer application) in woody (almond) and vegetable (melon) crops on soil carbon sequestration and storage, soil structure, and its relationship with crop yield. Almond was diversified with alley crops of thyme and caper, while melon was diversified intercropping cowpea. After three crop cycles, crop diversification associated to conservation management led to an improvement of the soil structure in all crops studied, measured as soil aggregate stability and bulk density. In addition, crop diversification also increased soil moisture and carbon content. Hence, crop diversification combined with conservation practices resulted in the best alternative for improving soil health and carbon sequestration and storage in almond and melon crops.

Keywords: almond, melon, intercropping, alley cropping, reduced tillage.

INTRODUCTION

Agricultural intensification as a result of increased demand for food linked to the growing world population has been accompanied by a decline in the soil health (Sünnemann et al., 2021). This is because the growth in agricultural systems to satisfy the demands of more number of people leads to higher pressures on natural resources as land, water and energy (OECD/FAO, 2018). In Spain, Mediterranean agriculture is generally intensive, with high variety in terms of crop types and high specialisation. This kind of agriculture negatively influences soil health, mainly due to soil organic matter losses, decreased biodiversity and soil pollution. Specific conditions such as the low water availability, high mineralization rates or the difficulty of land recovery after degradation make this area sensitive to perturbations as those associated with the climate change. In addition, the excessive use of fertilizers and pesticides in this typology of agriculture increases the risk of nutrients that are leached into the groundwater, contributing to water pollution (Eurostat, 2015). Almond (*Prunus dulcis*) cultivation is among the most important nuts for commercial production. However, its distribution is limited to dry areas with high temperatures such as the Mediterranean basin (Rabadán et al., 2017). Regarding horticultural crops, Spain represents approximately 22% of the total European production, with an average production of 15 million tons, mainly due to outdoor horticultural production (MAGRAMA, 2023).

As a result of an intensive agriculture, several conservation and agricultural practices should be developed, with the aim to enhance soil health and carbon sequestration to tackle climate change, but keeping high crop production to maintain international competitiveness and ensure food security. Conservation practices include no-tillage, crop diversification, mulching, or incorporation of crop residues (Lal, 2004).

These conservation practices are linked to several advantages such as the reduction of greenhouse gas emissions, mainly due to the reduction of labours, energy and the use of mineral nitrogen fertilizers (Alam et al., 2019). In this context, the establishment of crop diversification can optimize crop production and increase soil health and carbon sequestration and storage through improvement of the soil physical structure, enhancement of nutrient availability and increase in soil microorganisms function and diversity (Bardgett & van der Putten, 2014; Maron et al., 2011). This is because crop diversification can increase soil C and N contents, soil aggregates stability, water retention and infiltration (Congreves et al., 2015), reduce soil erosion (Feng et al., 2020), and increase microbial diversity and activity (Congreves et al., 2015).

The provision of ecosystem services by agricultural ecosystems also depends on the management practices developed by the farmer and the pedoclimatic characteristics of the region (Chabert & Sarthou, 2020). With this regard, Palomo-Campesino et al. (2022) concluded that the application of more agroecological practices compared to the conventional farming increased the potential for the supply of provisioning and regulating ecosystem services such as carbon storage, erosion control, pollination, pest control, and food diversity.

In line with the expected benefits linked to the crop diversification concerning soil health and carbon sequestration and storage, and associated improved crop productivity, we studied and compared different soil physicochemical properties and crop yield in two different woody and horticultural crops (almond and melon).

Our objective was to assess if crop diversification and conservation management practices such as reduced tillage, green manure or reduced fertilizer application, can improve soil health, carbon sequestration and storage and crop productivity. We hypothesized that crop diversification and conservation management may promote the improvement of soil health and carbon sequestration while the use of external inputs is reduced, associated with increases in overall production by introduction of new commodities with high facilitation processes growing together in the field.

MATERIALS AND METHODS

This study has been developed in two different farms dedicated to almond, and melon production, with the following diversification strategies and management practices:

Case study 1 (CS1) (Figure 1): rainfed organic almond orchard (*Prunus dulcis* (Miller) D. A. Webb) with an extension of 2.63 ha, with 540 trees planted in 1950, cultivated on terraces with a 7 m x 7 m spacing. This farm is located in the Region of Murcia, SE Spain (37^{0} 57′ 31′′ N, 0^{0} 56′ 17′′ W), The climate is semiarid Mediterranean with a mean annual precipitation and air temperature of 231 mm and 17.5 ^{o}C, respectively. The mean potential evapotranspiration reaches 1300 mm yr^{-1}. The soil, developed on marl, is classified as Calcaric Eutric Regosols (IUSS, 2014) and have a silt-loam texture. Two different treatments were established as randomised block design with three replicates. Plots of 210 m^{2} were established, with the long side of each one following the direction of the maximum slope, including rows of 5 trees. The average plot slope was 8 %. Treatments were: i) almond monocrop with tillage in all plot surface (chisel ploughing 2 times yr^{-1} at 20 cm depth) and ii) almond plantation with reduced tillage (rototiller (Lander 180, Spain) 2 times yr^{-1} at 20 cm only 1.5 m around each tree trunk), with no till in the rest of the alley, and diversified with the aromatic species *Thymus hyemalis* Lange (thyme) as alley cropping, at a spacing of 0.5 m (between rows) × 1 m (between individuals within the same row). Thyme was selected as alley cropping because this is native of the area, spontaneously growing in the surroundings, and have commercial interest by sale of herbs/essential oil. In addition, thyme was also selected because it can successively resprout after harvest and can produce high quantity of essential oil. Although the orchard was kept at rainfed conditions, thyme cultivation was irrigated in four occasions to ensure proper establishment, adding 12 L of water per plant, on 05/11/2018 (planting day), 15/01/2019, 04/03/2019 and 02/07/2019. No pesticides were applied during the experiment duration, and weeds were controlled by tillage in the monocrop. No control of weeds was performed in the no-till area. Almond diversified with thyme was colonized mainly by *Artemisia herba-alba Asso*, *Piptatherum miliaceum* (L.) *Coss, Dittrichia viscosa* (L.) *Greuter, Phagnalon saxatile* (L.) Cass. *Sonchus tenerrimus* L. and *Diplotaxis erucoides* DC, although no negative effect on alley crops growth was observed. Plots were only fertilized each September by adding the dry outer green shell cover of the almond rind after harvest in all plots regardless the treatment, at a rate of 290 kg ha^{-1} and 205 kg ha^{-1} in 2019 and 2020, respectively (differences due to differences in almond production). This experimental design is described in detail in Almagro et al. (2023); Sánchez-Navarro et al. (2022).

Figure 1. Almond monocrop (left) and almond diversified with thyme (right) from CS1.

Case study 2 (CS2) (Figure 2): Tomás Ferro Experimental Farm of the Universidad Politécnica de Cartagena, SE Spain (37^0 41` N; $0^0$ 57` E). The climate is semiarid Mediterranean with a total annual precipitation of 275 mm and a mean annual temperature of 18 °C. The annual potential evapotranspiration surpasses 900 mm. The soil is classified as Haplic Calcisol (loamic, hypercalcic) (IUSS, 2014), and have a clay loam texture. Treatments were: (i) melon monocrop (*Cucumis melo* L.) with intensive tillage and elimination of crop residues, and (ii) mixed intercropping system (alternation within the same row of melon and cowpea (*Vigna unguiculata* (L.) Walp) plants), with reduced tillage and addition of crop residues. This crop is grown on summer growing season, each lasting from May to August. Tillage was performed at the beginning of each crop cycle. For the monocrops, we used chisel plow as a traditional practice in the region, which involved plowing the soil to a depth of 30-40 cm. Afterwards, beds were shaped into elevated ridges by double mold-board, and only the tops of the ridges were cultivated. In the mixed intercropped system, we employed reduced tillage, which involved shallower chisel plowing at a depth of 15-20 cm, followed by double mold-board to make the ridges. The main difference in tillage treatments between the monocrop and mixed intercropped system was the depth of tillage, with the aim of reducing soil disturbance in the mixed intercropped system. In the melon monocrop, the crop was mowed after harvest and crop residues used for livestoock feed, as traditionally performed in the area. In the mixed intercropped system, one month after harvest, to ensure that all plants from both crops were totally dry, the crop residues were incorporated into the soil up to 15 cm with a chisel plower as a strategy to increase soil organic matter. After this, soil was let aside until next season (from September to April), with implementation of no treatment. In both systems, compost (derived from sheep manures) was added annually at the beginning of each cycle (April), as a traditional practice in the region, with a dose of 14,000 kg ha^{-1}. Melon monocrop received the equivalent of 3000 kg ha^{-1} of organic fertilizer NORGAN (plan-based fertilizer with 45% humic and fulvic acids, 3.2% N, 7% K_2O, Fyneco SL, Spain), mixed intercropping system received 30% less fertilizer quantity than the melon monocrop to verify a saving in the use of fertilizers as a result of the development of the legume. This reduction rate in fertilizer application was based on the N contribution of legumes cultivation in soil. No herbicides were added, and the weed control was done by hand-hoeing. All crops were drip irrigated and grown under organic management. The irrigation was scheduled according to climatic conditions, crop coeficient and evapotranspiration rate. The average irrigation amount was 3016 m^3 ha^{-1} per crop cycle for all treatments. Thus, with the same quantity of water used to produce melon under monocropping, we performed two associated crops in the mixed intercropping system. We followed a completely randomised experimental design. Treatments were randomly setup in plots of 120 m^2 (12 m x 10 m) established in triplicate. Melon seedlings were planted in a density of 0.4 plants m^{-2}, with a spacing of 200 cm between rows and 120 cm between plants in both plots (monocrop and intercropped plot). Cowpea seeds in the mixed intercropping system were sown in all melon rows between two melon plants, with a spacing of 200 cm between rows and 120 cm between plants, in a density of 0.4 plants m^{-2}. Then, density of melon was the same in the different treatments. Crop cycles lasted from May to August. Harvest of these two species is manual in commercial farms, and there was no need for special machinery. This experimental design is described in detailed in Marcos-Pérez et al. (2023).

Figure 3. Melon monocrop (left) and melon-cowpea mixed intercropping (right) from CS2.

Two soil samplings were carried out at 0 – 10 cm and 10-30 cm soil depth: at the beginning of the trial and after 3 crop cycles. Three composite samples (derived from 5 samples) were randomly taken in each plot. In CS1, soil samples were collected in the alleys between the tree rows, 2 m from the tree trunks. In CS2, soil samples were collected between two plants in the crop line. Soil was analysed for different soil chemical and physical properties using standardised methods (Alvaro-Fuentes et al. 2019).

In CS1, almond crop yield was calculated by weighing all the almonds harvested directly from the trees in each plot. In CS2, melon crop yield was determined by weighing all the fruits per plot when they were ripe and ready for consumption. With regard to cowpea yield, all the pods in each plot were harvested when the seeds were dried at the end of the crop cycle.

RESULTS

Average almond crop yields in CS1 ranged from 49.5 to 187.2 kg ha^{-1}. The crop management practice did not significantly affect the main crop yields when pooled across years.

Total organic carbon (TOC) content ranged from 3.2 to 4.7 g kg^{-1} depending on the crop management practice and soil depth and it increased with time only in the topsoil of the almond inter-cropped with winter thyme. Particulate organic carbon (POC) content significantly increased with time in the subsoil of both crop diversification systems (by 43% and 46% in the almond inter-cropped with caper and with winter thyme, respectively) while no annual changes were observed in the almond monocrop. In addition, aggregate stability also increased in the diversified plots, associated to increases in TOC. After three years, the topsoil organic carbon content only enhanced in the almond inter-cropped with winter thyme, while a significant increment in the particulate organic carbon (POC) content was observed in the subsoil of both crop diversification systems (Figure 3). Soil water content was also increased in diversified systems compared to the monoculture. The fact that topsoil organic carbon only increased in the almond inter-cropped with winter thyme could be explained by the higher plantation density of winter thyme compared to that of caper but also by phenological differences between both secondary crops. While winter thyme provides a permanent plant cover in the inter-tree rows and continuous leaf-litter C inputs to the soil from its establishment, caper shoots are lost annually from November to April, when it re-sprouts, and therefore leaf-litter inputs from this crop can be assumed to be negligible during half of the year (Almagro et al. 2023).

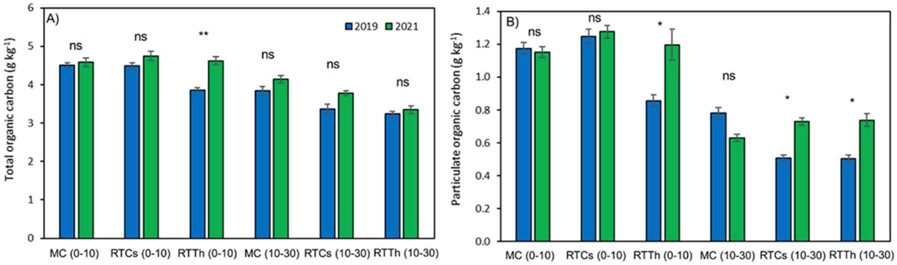

Figure 3. Total organic carbon (left) and particulate organic carbon (right) in the almond orchard. MC: monoculture; RTCs: reduced tillage and intercropped with caper; RTTh: reduced tillage and intercropped with thyme; (0-10): 0-10 cm soil depth; (10-30): 10-30 cm soil depth.

Regarding CS2, melon crop yield was significantly highest under intercropped systems compared to monocrop, with no significant difference between intercropping patterns (Figure 4). Cowpea crop yield showed significantly highest values in the monocrop system owing to higher plant density. Mixed intercropping and row intercropping 1:1 showed the lowest cowpea yields. Land equivalent ratio (LER) ranged between 1.45 and 1.92 in the three crop cycles, with no significant differences between intercropping patterns, confirming the efficiency of the intercropping, with values higher than 1.

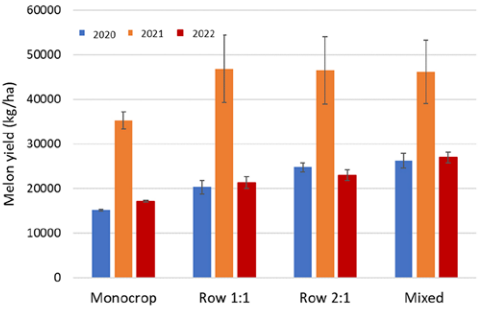

Figure 4. Melon yield in CS2 for the three crop cycles for melon monocrop and intercrop patterns.

TOC was significantly affected by crop diversification, with higher values in cowpea monocrop and melon/cowpea associations, compared to melon monoculture. Total nitrogen also showed significantly highest values in cowpea monocrop and intercropped systems compared to melon monocrop, despite reducing N fertilization under intercropping. Furthermore, available phosphorus and water content were significantly higher in intercrops than in the melon and cowpea monocrops (Figure 5).

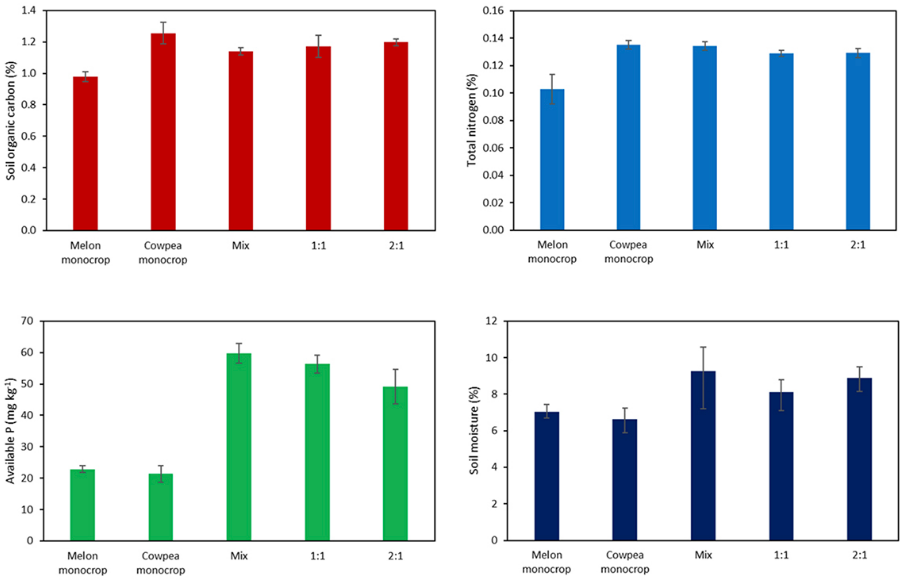

Figure 5. Soil organic carbon, total nitrogen, available phosphorus and soil moisture under melon monocrop, cowpea monocrop and intercrop patterns the last crop cycle.

Thus, our investigation indicates that intercropping can effectively reverse the decreasing trend of SOC content seen under melon monocrop cultivation. By integrating practices such as reduced tillage and crop residue incorporation, these systems can, not only prevent the loss of SOC attributed to vegetable production under a Mediterranean climate, but also increase it. This loss has been known to have detrimental effects on the sustainability of agroecosystems.

CONCLUSIONS

The establishment of crop diversification combined with conservation management practices in almond and melon crops can significantly improve soil health at short-term compared to monocrop systems, related to carbon sequestration and storage, aggregates stability, water storage and nutrient cycling. This finding demonstrates that the establishment of a conservation agriculture with diversified crops and reduced tillage is one strategy for achieving the improvement of the soil health and thus productivity and sustainability, contributing to climate change adaptation and mitigation with carbon sequestration and storage.

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Two examples of sustainable strategies for the management of agro-industrial and livestock organic wastes: the projects LIFE-AGROWASTE and LIFE-MANEV

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ABSTRACT

In a context of increasing world food demand due to the global population and income growth, climate change constitutes one of the principal challenges for the sustainable agricultural and livestock production. Thus, the main objectives of the projects LIFE-MANEV (LIFE09 ENV/ES/000453) and LIFE-AGROWASTE (LIFE10 ENV/ES/000469) were to design, evaluate and implement different environmentally-friendly strategies and/or systems for the management of manure and fruit and vegetable wastes, respectively. Both projects involved the participation of partners coming from European regions and were coordinated by Spanish public institutions, Aragonese Society of Agro-environmental Management (SARGA) and Centro de Edafología y Biología Aplicada del Segura (CEBAS-CSIC), respectively. In general, both projects have provided the know-how of the main technologies available for the management of manure and fruit and vegetable wastes, as well as corresponding tools to support decision-making when it is implemented the best system or technology for the management of these wastes in specific areas, adapted to its needs, at European level.

Keywords: waste management, manure, agricultural waste, environmental assessment, decision making support, food production.

INTRODUCTION

Agriculture constitutes one of the principal economic sectors in Europe. As an example, the agricultural goods had a gross value that amounted up to 370 billion € in 2014. Almost 50% of all agricultural production is provided by the livestock sector, which is one of the main economic sectors in the European Union, generating 160.000 million Euros in revenues (Bernal et al., 2015; Albiac Murillo et al., 2016). However, livestock production is also associated to the environment and the use of natural resources, such as land and water resources, also consuming an important share of agricultural crops. Additionally, this sector generates in Europe around 1,400 million tonnes of manure per year and the major intensification of the livestock farming (e.g. EU-28 has one of the greatest livestock densities in the world) has generated large amounts of manure located in very specific areas, making it more difficult to manage (Bernal et al., 2015). Thus, this intensification combined with an improper management of the manure may produce important environmental impacts, such as the contamination of soils (accumulation of metals and phosphorous and spreading of pathogens), in water bodies (groundwater nitrate contamination and eutrophication of surface waters) and atmosphere, with the emissions of ammonia and greenhouse gases (GHG). In this sense, the livestock sector is a significant source of GHGs, accounting for 15% of global emissions and 10% of emissions in Europe (Albiac Murillo et al., 2016).

On the other hand, the food and agricultural industry constitutes the principal activity of the European manufacturing sector, representing 14.6% of its output (more than 1,048,000 million €) (MAGRAMA, 2015). The production processes of this industry involve high water consumption, generating by-products and organic wastes, which constitutes approximately 50-70% of the starting materials (Morales et al., 2016). Currently, these wastes are managed by an authorized manager or used for animal feed. However, this final use is not the most appropriate, not only due to the high amounts of wastes generated, but also because animal-diet based only in these wastes is not varied enough, which could affect human health (Layman's Report LIFE10ENV/ES/469, 2014).

In this context, climate change is one of the main challenges for the sustainable agricultural, agri-food and livestock productions. Climate change not only threatens agricultural production, but also the natural environment and the services provided by ecosystems. For this, the design, assessment and implementation of different strategies and/or systems for the sustainable management of livestock manures and of the wastes from the fruit and vegetable transformation industry, respectively, were conducted by the projects LIFE-MANEV (LIFE09 ENV/ES/000453) and LIFE-AGROWASTE (LIFE10 ENV/ES/000469).

THE PROJECT LIFE-MANEV

The management of livestock manures is required in order to avoid or at least minimise the negative environmental impacts, such as air, water and soil quality deterioration, as well as social nuisance and health impacts, derived from an improper management.

There is a wide variety of manure treatments available in the market, but there is also a lack of unified criteria for their implementation. Moreover, the strategies selected must consider not only the management of manures, but also the recycling of the nutrients present in these wastes, also adapting these strategies or systems to the local characteristics. In this context, the environmental technologies and management strategies are often interfered by the variations in regulations among EU countries and the absence of well-defined market conditions.

Therefore, the main purpose of the LIFE-MANEV project (*Evaluation of manure management and treatment technology for environmental protection and sustainable livestock farming in Europe*, ref. LIFE09 ENV/ES/000453) was to improve the sustainability of livestock farming by promoting the use of treatment technologies in different saturated or surplus areas in the production of livestock manure across Europe. The project was focused on joining the available knowledge and expertise in manure management at European level and providing it to the stakeholders with a guidance to choose the system that better fits every agricultural scenario.

This project involved the participation of eight partners coming from European regions (Figure 1.3) with a major livestock production, coordinated by the Spanish public company SARGA, attached to the Department of Rural Development and Sustainability of the Government of Aragon (Fig. 1).

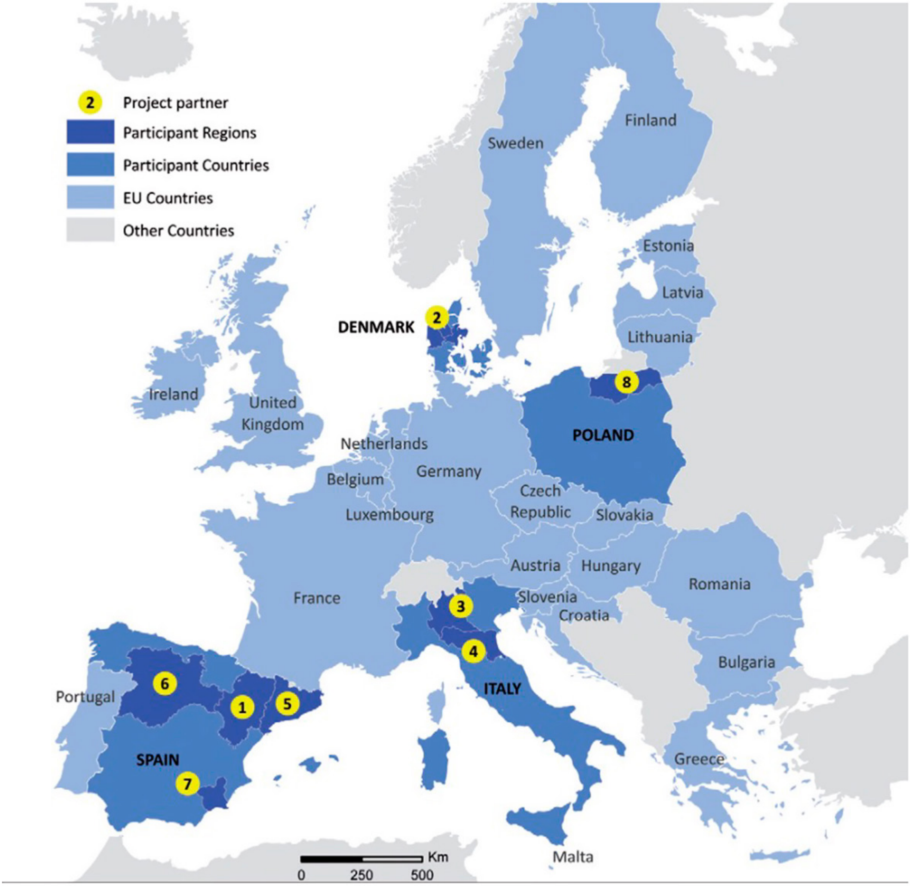

Figure 1. Partners involved in the project and the corresponding regions (Bernal et al., 2015).

The main objectives of the project were to (Bernal et al., 2015):

- Demonstrate that both the use of treatment technology and an adequate management scheme of manure can contribute to a reduction of GHG emissions, while at the same time improving the situation of farmers.
- Improve environmental protection and the sustainability of livestock farming by increasing the use of manure treatment technology in various livestock-dominated areas of Europe.

- Unify criteria for the evaluation of different manure treatment technology systems and management schemes.
- Develop a common protocol among European regions for the evaluation of manure treatment technology and management schemes that consider environmental, technological, energy, economic, legal and health factors.
- Develop and test a decision supporting and planning tool to evaluate different manure treatment and management strategies in various European countries: Italy, Denmark, Poland, and various sites in Spain.
- Define the fertilising properties of directly applied manure and of treated waste in order to provide a real value in the market.
- Evaluate the know-how related to the treatment technologies and management methods, its strengths and weaknesses, within the different countries and areas in Europe.

The tasks conducted to achieve these objectives were the following (Bernal et al., 2015):

1. Collection of the studies on manure treatment technologies carried out in the different European regions with the objective of gathering all the knowledge and expertise available so far.
2. Creation of a Common Evaluation and Monitoring Protocol (CEMP) that unified the criteria and parameters in order to be able to evaluate and compare different manure treatment plants and management systems. This protocol was a guideline to establish the methodology for the assessment of different manure management systems in a defined scenario to obtain comparable data around Europe and included environmental, agronomic, energetic, economic, social, sanitary and legislative criteria (Fig. 2) to determine the impact from a global point of view.
3. Based on this protocol, thirteen operating treatment plants were assessed in different European scenarios. These evaluations enabled to understand better the performance of each technology and its different possible impacts.
4. Development of the MANEV tool, to support decision-making for implementing at European level the best manure management system adapted to the local characteristics of a specific area. This tool included more than 20 treatment technologies that are available

on the market, which can be classified in four main groups depending on their objectives: a) Facilitate the manure handling (separation technologies); b) Recovery treatments (composting, anaerobic digestion); c) Nutrient concentration (ammonia stripping, acidification, evaporation and thermal drying); d) Nutrient removal (nitrification/denitrification treatment).

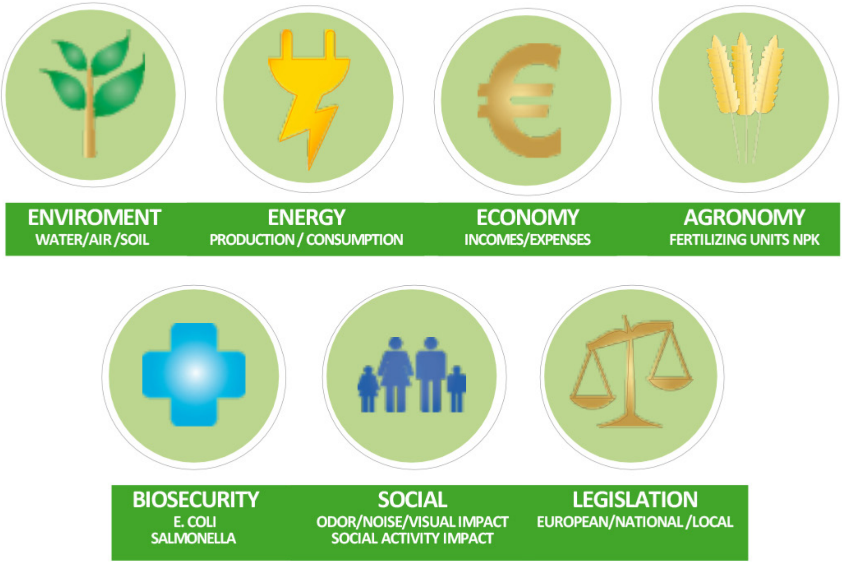

Figure 2. Criteria established in the Common Evaluation and Monitoring Protocol (CEMP) (Bernal et al., 2015).

The results of the project have shown that manure management has no unique solution and the treatment of the manure is not a solution in itself, but it is part of a proper management system. There are different technological options, but the selection of one treatment of other will depend on the characteristics of the agro-farming scenario. Thus, the solutions should be tailored to local conditions, ensuring the financial feasibility, manure land application as organic fertiliser being the first management option if it is possible. Moreover, the different technological options constitute a good management strategy for the surplus areas for reducing the nitrogen and phosphorus quantity. In this sense, the nutrient removal treatments are an option only if there is no reuse or recycling alternative, anaerobic digestion being able to support the feasibility of nutrient removal treatments. Manure management system has to be balanced between the costs and the environmental benefits, ensuring its sustainability, being of great importance for the technology and innovation to reach the final users. Further works concerning the development and optimisation of the treatment technologies are necessaries from the economic point of view, rather than to improve the treatment efficiency, which has already been demonstrated.

Finally, the homogeneous evaluation based on the common protocol established (CEMP) achieved to unify the know-how of the principal and current technologies available for manure management at full scale. With the MANEV tool was possible to gather the state of the art of the different technologies and manure treatment systems, putting all this knowledge at the disposal of every stakeholder for their profit with the aim of minimising the environmental impacts and strengthening the livestock sector in Europe.

THE PROJECT LIFE-AGROWASTE

In the last decades, the intensification of the activity of the agri-food industry has produced an increase in the by-products and organic wastes generated that can produce a negative effect on the environment if these materials are not properly managed. For this, it is necessary to implement measures that prevent, or at least minimise, the potential impacts derived from the disposal of these organic waste streams (Pascual et al, 2018). Concretely, in the case of the organic wastes generated from fruit and vegetable transforming industries, there is a lack of clarity about the best treatment processes for their management. Thus, it is necessary to carry out specific actions that incorporate best management practices for any type of fruit and vegetable waste and residues in order to increase the effectiveness of the different community and national sustainability.

Thus, the project LIFE-AGROWASTE (*Sustainable strategies for integrated management of agroindustrial fruit and vegetable wastes*, ref. LIFE10 ENV/ES/000469) aimed to design an integrated management system, using environmentally-friendly technologies, and to demonstrate the proposed technologies, for the valorisation of the organic residues and by-products of the fruit and vegetable transformation industry of the Autonomous Community of the Region of Murcia (Spain).

Canned vegetables Frozen vegetables Juices

Figure 3. Map of distribution of the companies of the fruit and vegetable transformation sector in the Region of Murcia (Spain) (Layman's Report LIFE10ENV/ES/469, 2014).

The project involved the participation of Spanish public and private entities, such as the Centro de Edafología y Biología Aplicada del Segura (CEBAS-CSIC), the Centro Tecnológico Nacional de la Conserva y Alimentación (CTNC) and the Agrupación de Conserveros y Empresas de Alimentación de Murcia, Alicante y Albacete (AGRUPAL).

The main activities developed to achieve this objective were the following (Layman's Report LIFE10ENV/ES/469, 2014):

1. Free online access database of organic wastes and by-products generated by the fruit and vegetable transformation industry of The Region of Murcia, as well as the most appropriate technological options for their management and valorisation.
2. Free online Decision Support System (SDD) with a simple and flexible user access, which allowed the selection of the most appropriate technology for each type of residues and by-product, according to parameters previously defined by the user in a way.
3. Practical field demonstrations in the agricultural (aerobic digestion (composting), energy (anaerobic digestion) and Food (interesting compounds) sectors.

4. Dissemination of the designed tools to achieve the maximum number of possible users.

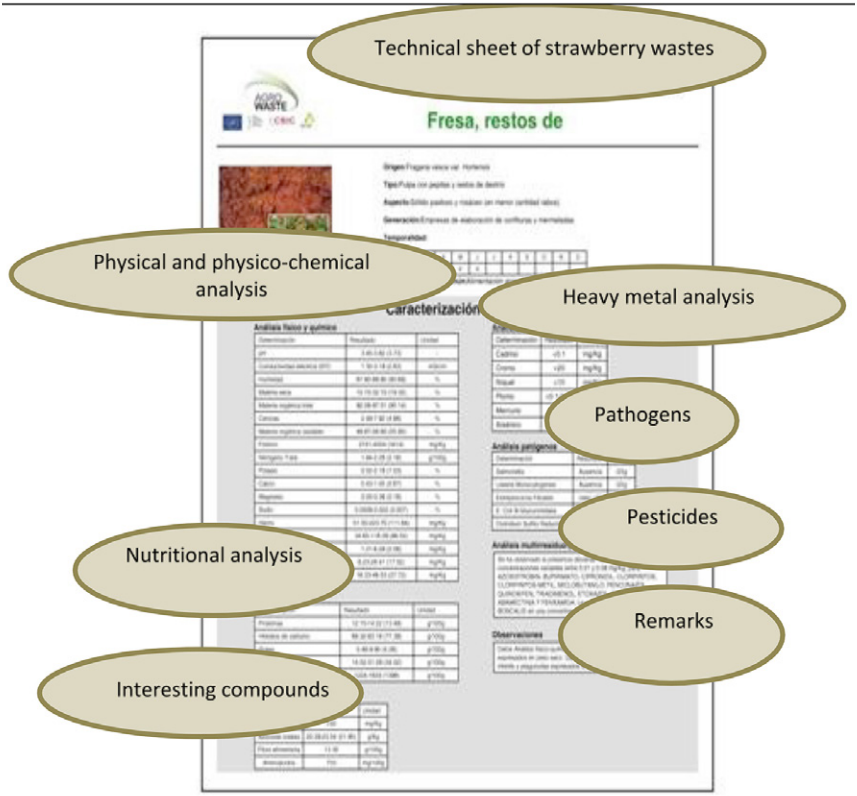

Figure 4. Example of by-product sheet included in the database developed (Layman's Report LIFE10ENV/ES/469, 2014).

As a result of the project, an integrated management system for fruit and vegetable wastes was designed, adapted to the region of Murcia (Spain), but with good potential for being adapted and replicated in other European regions, especially those in the Mediterranean area. For this management system, the project developed a web-platform that included a database of the main sustainable strategies for the valorisation of this type of organic wastes, as well as an intelligent Decision Support Software (DSS) that provided advice on the most suitable valorisation technology for specific scenarios.

The data was analysed to quantify the by-products and the amount of recoverable waste generated in the region of Murcia. The web-platform was used to disseminate the results of the analysis, to enable stakeholders to identify the best available technology for a specific fruit and vegetable wastes and a report was also delivered on the technological opportunities for valorising these organic wastes. Furthermore, the project performed pilot-scale demonstrations of some of the best innovative technologies for the management and valorisation of this type of organic wastes, focused on valorising them in three main target areas:

1. Food: identifying and adding value to bioactive compounds extracted from fruit and vegetable wastes as multifunctional food ingredients (e.g. for artichoke, a cynarine-enriched extract was obtained with antioxidant activity, and for lemon rind, onion and garlic by-products, and strawberry leftovers and leaves).
2. Energy: obtaining biogas through anaerobic digestion of industrial wastewater and organic solid wastes with high organic content, with positive results in terms of quality and feasibility of use.
3. Agriculture: obtaining mature organic soil amendments through an aerobic process that can be used both for improving soil quality and as a substitute for non-renewable peat.

In conclusion, the results obtained by the project LIFE-AGROWASTE demonstrated that all types of fruit and vegetable wastes in the region of Murcia (Spain) could be converted into a resource. Thus, the implementation of the approach of this project could improve the environmental sustainability and the economic competitiveness of the companies in the fruit and vegetable transforming sector. Additionally, adopting the concept of waste to resource, and the application of new technologies for the recovery of materials from fruit and vegetable wastes, opens up new business opportunities and, consequently, the possibility of job creation.

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Sustainable soil management to unleash soil biodiversity potential and increase environmental, economic and social wellbeing

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ABSTRACT

By 2024, the status of soil biodiversity will be defined for multiple biogeographic regions and its contribution to the economic and social value of the most relevant soil-mediated ecosystem services will be quantified. the effects of climate change stressors on soil biodiversity and multifunctionality will be assessed. Operationalizing chains of evidence through modeling approaches will enable forecasting of soil management effects on soil biodiversity and welfare responses in future climate scenarios. This information will be collected in one easy to use application.

Keywords: Soil, Biodiversity, Climate Change, Sustainable Management.

INTRODUCTION

Land degradation is a major threat for the development of the society, where the losing healthy and productive lands is related with unsuitable soil management practices (Bouma, 2019; Lal, 1997; Minasny et al., 2017). Since a soil is a non-renewable resource in human period, safeguarding its biodiversity and multifunctionality is critical for the maintenance of our societies (Bouma, 2019; Fan et al., 2023; Keesstra et al., 2016; Manning et al., 2018; Várallyay, 2007).

Soil biodiversity plays a crucial role in maintaining ecosystem health and functioning (Blum, 2005; Delgado-Baquerizo et al., 2020). It encompasses a diverse array of organisms, including bacteria, fungi, protists, and invertebrates, which collectively contribute to essential ecosystem services. These services include nutrient cycling, organic matter decomposition, pollutant degradation, and pathogen control. Thus, understanding soil biodiversity is essential for sustainable land management and addressing environmental challenges such as land degradation and climate change (Steffen et al., 2015).

The safeguarding of soils is not only necessary, but urgent to mainstream sustainable soil management practices and the perception of soil biodiversity as a key nature-based solution to face land degradation and climate change stressors (Delgado-Baquerizo et al., 2020; Fan et al., 2023; Lal, 1997). The effects of climate change are more tangible year with year, so it is a stressor which is added to the actual threats of soil biodiversity. Therefore, soil biodiversity assessment emerges as a key challenge to be overcome (Guerra et al., 2020).

Urgent action is thus required on addressing major knowledge gaps related to biodiversity and soil-mediated nature contributions to people. The Horizon 2020 SOILGUARD project arose to assess the soil biodiversity status in different countries and the effects of climate change, this work shows part of the Spanish case under different degradation and management scenarios.

MATERIAL AND METHODS

We worked on 10 cereal croplands with traditional management and 10 with organic management, inside the NUTS-2 Region of Murcia zone (RM). This area is placed in southeastern Spain, it has a Mediterranean climate with 130 continuous sunshine days, maximum temperatures above 40 °C during the summer months and precipitation below 350 mm, concentrated in intense rain episodes during the winter and part of the spring.

RM is considered the Garden of Europe due of its for its intensive cultivation of fruits and vegetables. Despite the arid conditions, crops like tomatoes, lettuce, citrus fruits, and melons thrive in the fertile soils. Cereals are also produced, whose products are mainly used as raw material for animal feed.

For sampling design, there were considered plots with an organic management those without using inorganic fertilization for more than five years, otherwise there were considered traditional management plots. Land degradation was included as a covariable with two degradation levels according to soil aggregate development and presence of surface crusts: high and low. During the summer of 2022, soil samples were taken from each plot and analyzed for the following soil properties: organic matter content (Walkley & Black, 1934), microbial biomass carbon (SIR method), basal soil respiration, enzymatic activities as β-Glucosidase, Urease and Phosphatase (Tabatabai, 1982), available phosphorus, soil color (Munsell Color, 2000), bulk density, and coarse fragments.

During the crop season of 2022 (May – July), two of the above-mentioned plots were selected and climate change simulations were performed, using three open greenhouses called rainout shelters (ROS) per management practice to force drought simulations according to the climate change RCP 4.5 scenario for this region. The ROS allowed to exclude the rain, but not the wind so the temperatures were similar inside and outside them. We simulated a drought with 80% less rainfall for three-months, however we had to irrigate 18 l/m^2 outside the shelters due to an abnormally hotter and drier summer. Humidity, air, and soil temperatures (12 cm and 0 cm above soil surface, and 6 cm below soil surface) were measured.

RESULTS AND DISCUSION

As preliminary results, there were found differences between organic and traditional management when degradation levels were included. Soil organic matter, bulk density, microbial biomass carbon, and basal soil respiration were the sensible soil parameters. The first one was related with the interaction between management and degree of degradation ($p<0.05$, d.f. = 3, F= 5.45), the second and third ones with the soil color ($p<0.001$, and d.f. = 2 in both, F= 6.76, and F = 8.18, respectively), and the last one just with the degradation level ($p<0.05$, d.f. = 1, F= 7.30).

In high degraded lands, soil organic matter concentrations of organic plots were significantly higher than in traditional ones. By other hands, low degraded lands didn't show clear differences between the type of management, so the carbon storage function isn't clearly affected.

As expected, the air temperatures at 12 and 0 cm above the surface didn't show any significant differences for the drought simulations ($p > 0.05$, F < 4.1, d.f. = 1 in both cases). However, the drought and management factors didn't produce any clear significant differences in the soil temperature (p = 0.12, F = 6.95, d.f. = 1 for management and p = 0.86, F = 0.04, d.f. = 1 for drought) and volumetric water content (p = 0.08, F = 11.26, d.f. = 1 for management and p = 0.57, F = 0.37, d.f. = 1 for drought). The actual droughts and heatwaves that RM experimented on 2022 were unexpected weather alterations that biased the field experiment. The stronger presence of climate change may increase the bias for this kind of simulations in the region.

Finaly, it is important to remark that understanding the changes in soil biodiversity and multi-functionality will make possible to establish more precise recommendations for the establishment of agricultural management policies for Mediterranean environments. Whether organic or conventional the management, urgent actions are needed to stop soil biological degradation.

CONCLUSION

The management and the degradation had clear impacts for the organic matter content in the soils from the RM zone. The management and the simulated drought showed differences in some properties specially the soil under organic management improve the parameters as organic matter content, carbon biomass, and basal soil respiration, during the 2022 Summer season in RM. The Spanish case inside the SOILGUARD project will form part of the required knowledge to fill the European gap for soil biodiversity and multi-functionality.

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