Review Article

Climate and Environmental Changes: Reflections and Prospects for the Future of the Mediterranean Area — Food Security and Climate Change: Agricultural Considerations

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The Mediterranean region, renowned for its rich biodiversity and complex interplay of cultures, faces significant challenges due to climate change, population growth, and socio-economic shifts. The region's agricultural system, integral to its economy and food security, must adapt to meet the demands of a growing population while preserving environmental sustainability. This paper explores the main threats to Mediterranean agri-food systems, such as unsustainable practices, water scarcity, and soil degradation, and emphasizes the need for collective strategies to build resilience. The analysis includes three case studies from the Mediterranean area, that illustrate diverse approaches to sustainable agricultural development and adaptation, highlighting both shared challenges and innovative solutions.

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Introduction and Main Challenges

The Mediterranean region, with its intrinsic peculiarities, diversity, and similarities, is one of the world's most biodiverse areas. It is home to a complex mosaic of cultures, economies, climates, and agricultural systems. The countries bordering the Mediterranean have been the cradle of ancient civilizations that created and exported knowledge, influencing one another and remaining interconnected to this day [1].

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For these reasons, addressing the challenges of climate change is complex and requires the collective effort and shared strategies of all Mediterranean states. The way these nations tackle these challenges will shape the future they continue to share.

This multidimensionality of the Mediterranean system is also evident when analyzing the various food systems. Viewed as a whole, they represent the Mediterranean agri-food sector, connecting producers to consumers. Specifically, the virtuous and rich dietary styles of the Mediterranean region are globally recognized for the health benefits of the so-called "Mediterranean diet." Like the cultures that have adopted them for centuries, these dietary styles are equally complex, encapsulating the sociocultural, economic, nutritional, and environmental aspects of the Mediterranean territory [2].

In 2010, UNESCO inscribed the Mediterranean diet on the List of Intangible Cultural Heritage of Humanity, defining it as "a set of skills, knowledge, rituals, symbols, and traditions, stretching from landscape to table."

The capacity of Mediterranean agriculture to meet the needs of its populations has increasingly been threatened, particularly in recent decades, by various factors linked not only to climate change and pollution but also to population growth, urbanization, and shifts in socioeconomic trends.

Population growth is undoubtedly a significant factor strongly influencing the sustainability of agri-food systems and food security across the Mediterranean region [3][4].

The Food and Agriculture Organization (FAO) has recently estimated, based on current trends in income, population, and consumption, that by 2050 it will be necessary to produce approximately 70% more food to meet global demand.

In the Mediterranean region, estimates for the current year 2020 indicate approximately 530 million inhabitants to be fed. For this reason, agriculture remains a crucial economic sector, employing about a third of the active workforce in the region and representing over 10% of GDP in many Mediterranean countries [5].

Among the various climate-change-related challenges affecting the Mediterranean agricultural system are:

- Unsustainable agricultural production practices.
- Limited agricultural diversification.
- Overexploitation of natural resources (soil fertility loss, depletion of agricultural biodiversity and pollinators, etc.).

- Depletion of water resources often linked to poor management.
- Decreases in agricultural yields, leading to diminished nutritional value in food products and diets.
- Significant food waste.
- Declines in food culture and sovereignty.
- Limited access to innovations, particularly among rural producers.

The most pressing modern challenge for the entire Mediterranean region lies in producing more food for a growing population—food that is of higher quality and safer, provides fair incomes, and comes from a more sustainable agricultural system resilient to climate change.

While the Mediterranean Sea physically delineates spatial boundaries, the challenges facing the region transcend borders, remaining common to all Mediterranean countries.

Historical Development of the Agri-Food System

The first human communities in the Mediterranean region began relying on hunting approximately 13,000 years ago. Only years later did they start livestock breeding and eventually land cultivation. The primary cereal crops cultivated in the Mediterranean were wheat, barley, millet, and spelt, alongside significant production of sesame and olives.

The spread of olive cultivation in the Mediterranean had substantial socioeconomic repercussions. Olives were utilized in agriculture as well as in various other activities, becoming a highly profitable crop for the ancient "industries" of the time in the Mediterranean [6].

Agricultural traditions have thus been an integral part of Mediterranean countries since the dawn of time, with knowledge passed down from generation to generation. Unlike modern times, ancient irrigation depended on natural sources such as rivers and rainfall. The Nile, for example, fertilized and shaped the primitive landscape of ancient Egypt. Between the 16th and 11th centuries BCE, agricultural production ranged from 1.5 to 2.5 million tons, with an annual gross yield of wheat amounting to approximately 500 kilograms per person.

Over centuries, crops developed and diversified throughout the Mediterranean region, with new varieties introduced, particularly following the discovery of the Americas. The Arab influence played a significant role in the development of Mediterranean food history. Unlike the Romans, who standardized agriculture of the time, the Arabs introduced new products and cultivation methods. These innovations led to the spread and development of agronomic sciences in the Mediterranean region.

The most significant changes in the agricultural sector occurred in the 1900s, when agriculture experienced substantial productivity increases. Human labor was supplemented and replaced by mechanization, supported by synthetic fertilizers, pesticides, and selective breeding. Until then, food production cycles had harmonized with natural resources, available technologies, and societal needs.

Initially, these advancements positively impacted productivity, the volume of production, and product quality. However, they subsequently contributed to today's challenges in the agricultural sector, requiring study and intervention to address them effectively.

The Mediterranean Area Today

A closer examination of the current Mediterranean region reveals significant agricultural challenges, particularly from an environmental perspective. The area suffers from severe and prolonged water stress, coupled with considerable salinization of water resources [7].

More than 60% of freshwater is used for agricultural activities, reaching up to 85% in southern Mediterranean countries. This poses an increasing risk of higher consumption due to exacerbating drought conditions caused by climate change. Future scenarios predict a global reduction in water availability of approximately 30%.

Although the Mediterranean accounts for around 7% of the global population, its inhabitants have access to only 3% of the world's freshwater resources for their activities. This creates a significant imbalance, with approximately 100 million people currently living with less than 1,000 cubic meters of water per year. By 2025, with an estimated population of 160 million, per capita water availability will decrease even further.

Irrigated agriculture represents one of the sectors with the highest potential for water savings. This can be achieved by adopting methods aimed at reducing losses and increasing efficiency. Currently, only about 1% of wastewater (from agriculture, industry, and domestic use) is recycled. However, this trend is increasing across much of the Mediterranean region [8].

The graph (Figure 1) illustrates projections of water requirements for key crop samples by the end of the century. It compares the current water demand in millimeters per year (green bars) with future water demand (blue bars), highlighting a marked increase, which in some cases reaches 40% [9].

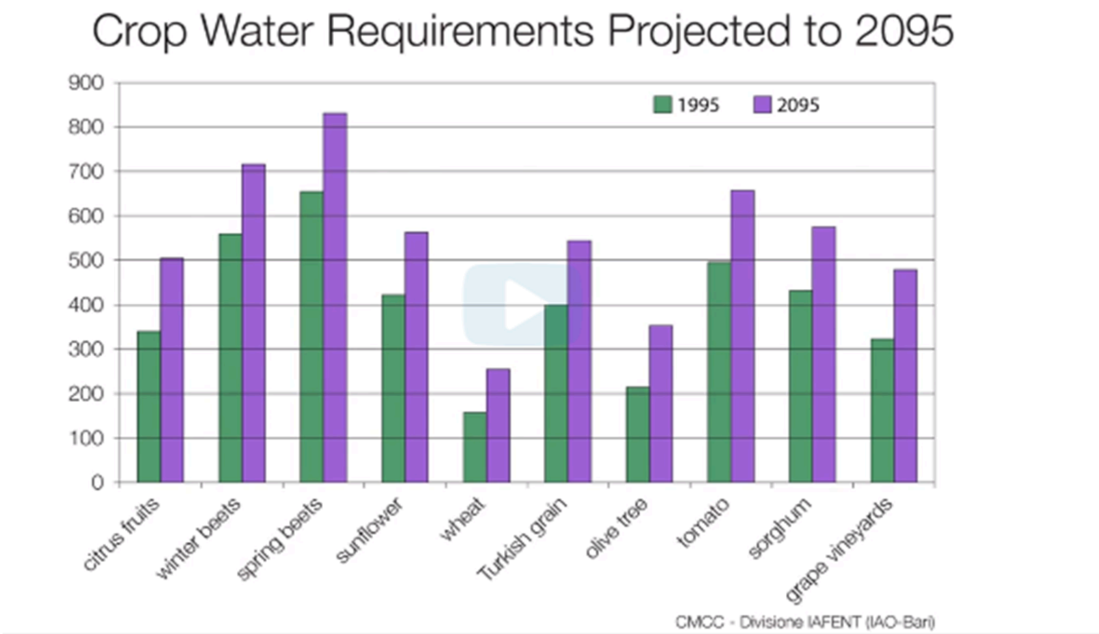

Figure 1. Irrigation Water Demand in the Agricultural Sector of the Mediterranean, Source CMCC.

The Mediterranean region faces significant agricultural challenges, including a marked decline in biodiversity and ecosystem services, as well as issues such as soil erosion, reduced soil fertility, and diminished carbon storage capacity in the soil [10].

The agricultural sector urgently requires the adoption of more sustainable practices across the board, as the ecological footprint of the Mediterranean region dangerously exceeds its biocapacity.

These challenges are not only environmental but also social, often rooted in demographic imbalances. The southern Mediterranean experiences rapid population growth, while the north faces a slow decline. Additionally, consumer habits and dietary choices have evolved over time. On the one hand, it is crucial to ensure food availability and maintain food security; on the other, healthier food production is necessary to combat the rise of diet-related diseases such as obesity, diabetes, and cardiovascular issues.

An increasing number of consumers are paying close attention to the quality, origin (traceability), and sustainability of the food they purchase. This trend must be taken into account when planning agricultural activities and policies.

Food value chains also require examination. The entire agri-food system — encompassing the production, processing, and transportation of food — significantly impacts the environment as well as human and ecosystem health.

For several years, the Mediterranean region has been advancing sustainability projects in the agri-food sector through the adoption of tailored programs and techniques. Various Mediterranean countries have successfully implemented best practices, leveraging innovation in conjunction with local values and knowledge. However, challenges to their effective adoption often arise from a lack of integration and dialogue among stakeholders, including vulnerable groups such as farmers, businesses, institutions, and the research community.

From an economic perspective according to Eurostat, greater investments in research and development (R&D) are essential to promote the development of sustainable agricultural practices. Currently, only a few Mediterranean countries allocate more than 2% of their GDP to R&D. Moreover, the lack of effective collaboration among stakeholders often leads to overlapping and fragmented initiatives, limiting their overall impact.

To address these diverse challenges, it is first necessary to clearly define the characteristics of a sustainable and climate-resilient agri-food system.

Recently, an expert group on food security and nutrition was established as part of the reform of international governance on food security. Its goal is to provide guidance to the Committee on World Food Security (CFS), the principal intergovernmental body on food security and nutrition since 1974.

The CFS equips policymakers with the tools to act decisively on global food security issues, promoting more stable, nutritious, and sustainable food systems.

Among its various functions, one is to provide policymakers with the tools to act decisively on global food security issues, promoting more stable, nutritious, and sustainable food systems.

A sustainable food system comprises a range of elements that must always be considered in strategy definition and implementation. Specifically, these elements include: land, natural resources, people, inputs, processes, infrastructure, institutions, production, transformation, distribution, food preparation and consumption, equity, and sustainability.

A sustainable food system takes all these elements into account to ensure food security and nutrition through the three pillars of sustainable development promoted by the United Nations' 2030 Agenda [11].

Agricultural productivity growth, developed with a sustainability perspective, is essential to addressing food price volatility, reducing dependency on imports, and improving living conditions in rural areas through better governance and social inclusion [12].

While Mediterranean countries share many commonalities, there is also significant diversity, especially concerning the economic development of each country and the prioritization of their goals. Beyond national political and institutional frameworks related to sustainable development, agriculture, and climate change, there are multiple supranational tools designed to protect the Mediterranean's environmental system.

These include the United Nations' Mediterranean Action Plan, established in 1975, and the Mediterranean Strategy for Sustainable Development 2016-2025, adopted by the Barcelona Convention COP 19, which sets out a political and strategic framework to ensure a sustainable future in line with the Sustainable Development Goals (SDGs).

Both tools aim to harmonize interactions between states and between socioeconomic and environmental objectives, adapt international commitments to regional conditions, guide national sustainable development strategies, and foster regional cooperation among stakeholders [13].

It is important to understand and measure the impacts of climate change on agriculture and water resources to develop appropriate actions in the Mediterranean region.

Land availability and use are also crucial topics, as there is a growing trend of urbanization and rural depopulation in the Mediterranean area. By 2050, it is estimated that eight out of ten people will live in cities, leading to the abandonment of rural areas. This raises concerns about territory protection, land management, and cultivation. Per capita land availability has decreased from about 1.7 hectares per person in 1950 to 0.3 hectares today [14].

However, the flip side of this issue is the growing demand for food, particularly animal feed, which links our dietary choices directly to land availability.

It is necessary to produce more food for a growing population, and we must do this within the constraints of climate change, which impacts and limits food production. At the same time, sustainable food production practices must be employed to avoid contributing to pollution that would exacerbate climate change [15].

The challenge for the agricultural sector is demanding, and to date, various sustainable agricultural practices have been developed throughout the Mediterranean region.

The Mediterranean is also considered a climate change hotspot by climatologists. Historical temperature data (as shown in Figure 2) illustrates a clear upward trend in the region, which is warming at a rate higher than the global average. This marked trend has serious consequences for agricultural systems, increasing their vulnerability.

Not only are rising average temperatures and water scarcity major factors to consider in agriculture, but also the unpredictability of extreme weather events (e.g., heavy rainfall, flooding, heatwaves, diseases, etc.), as short- and long-term forecasts become more difficult and targeted interventions less effective. For example, studies show that temperatures sustained above 35°C for more than five days can completely destroy wheat crops, leading to significant economic impacts for farmers [16]. Additionally, heavy rainfall and flooding can cause serious damage to crops, as can the increased spread of diseases linked to fungal, viral, and bacterial pathogens.

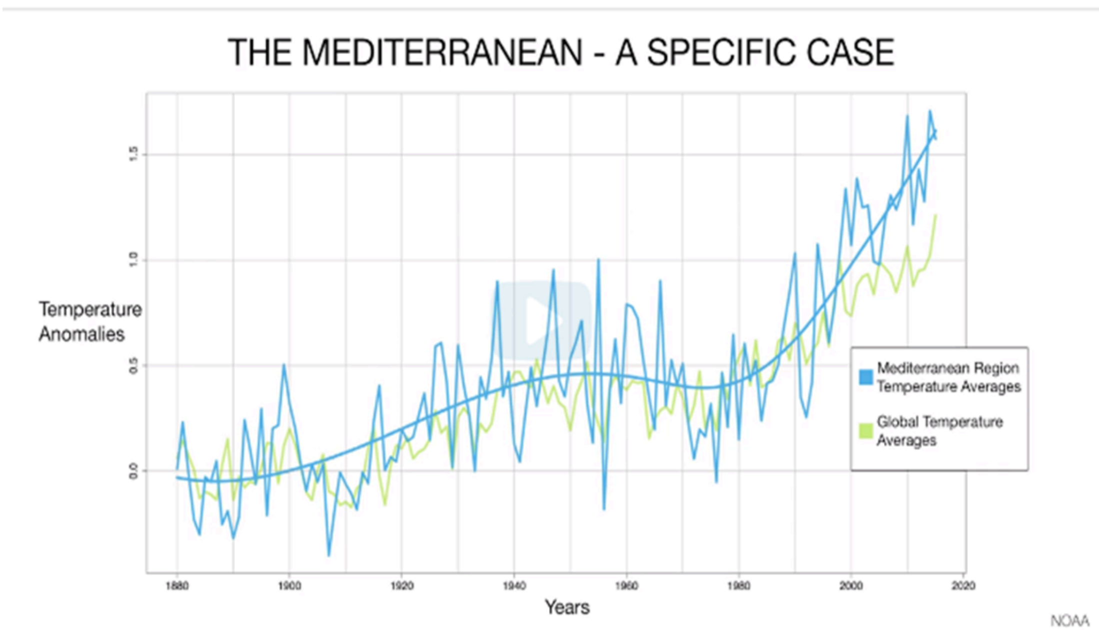

Figure 2. Temperature Variation in the Mediterranean, Source NOAA

The global agricultural sector emits more than 5 billion tonnes of CO2 equivalent into the atmosphere, primarily producing methane, nitrous oxide, and nitrogen. In the Mediterranean, emissions related to the agri-food sector, including production, processing, and transportation, account for up to 70%, with an additional 7% if land-use changes are included.

The agricultural sector needs the joint adoption of sustainable farming practices to reduce the impacts and greenhouse gas emissions produced by agricultural activities. Key sustainable actions include soil conservation practices, organic farming, minimal soil tillage, reforestation, agroforestry, the use of

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organic fertilizers derived from waste valorization, precision farming, conservation agriculture, and so on. All these practices aim to make the agricultural system more efficient and less vulnerable.

Efficiency is a key term for all agriculture in the Mediterranean, and ancient knowledge combined with new available technologies is essential for climate change mitigation and adaptation efforts. It has also been shown that such development and growth activities in agriculture are the most effective and equitable strategies for addressing the increasing demands of society and social and environmental costs, with the goal of protecting natural resources and adapting to climate change [17].

To achieve sustainable development goals, it is necessary to strengthen agriculture that can also generate income, create jobs, and contribute to territorial development and cohesion. Sustainable agriculture places these conditions at the center of the transition towards a resilient system that ensures food security through mitigation and adaptation actions.

Climate-Smart Agriculture (CSA) is an approach that integrates the three dimensions of sustainable development—economic, social, and environmental—to guide and define actions in the agricultural sector [18].

The concept of CSA was introduced by the FAO in 2010 during the Hague Conference on Agriculture, Food Security, and Climate Change, and it is one of the FAO's 14 themes for sustainable development. The CSA approach encompasses a range of targeted and adaptable actions that cater to the specificities of different territories and is not a fixed, standardized protocol. Instead, it is an integrated system based on the three pillars of sustainable development, aiming to achieve food security through climate change adaptation and mitigation actions, guiding the management of agriculture and food systems within the context of climate change at various levels: from small farmers to landscapes, traditions, innovation, and collaboration among stakeholders.

In the Mediterranean region, agriculture requires rapid transformation to face the challenge of climate change and food security, through actions that involve both national and international cooperation as well as local or regional initiatives. For this purpose, CSA is considered an effective and widely adopted approach.

To limit the effects of climate change on agriculture, the Paris Agreement (COP21) also promotes greenhouse gas emission mitigation actions, strengthening the capacity of individual countries to address climate impacts [19].

In the Mediterranean area, each country must activate actions primarily aimed at: developing sustainable and less vulnerable territories, reducing carbon emissions, supporting stakeholders in the ecological transformation of economic activities, transforming the economy and social model towards green growth, directing research and innovation in production towards ecological transition, educating, training, and raising awareness among various sector actors, developing collaborations between the research world and the agricultural sector, activating risk management policies, and promoting investments.

To concretely analyze some of the strategies and projects developed in the Mediterranean area, best CSA practices from particularly exemplary Mediterranean countries will be examined.

Morocco

As previously mentioned, climate change forecasts for the Mediterranean region predict significant reductions in rainfall and considerable increases in temperatures over the next two decades, with very dramatic consequences for food security and natural resources. Therefore, it is crucial to anticipate the impacts of climate change on territories by improving the efficiency of agricultural systems and enhancing their resilience. In more vulnerable Mediterranean regions, such as Morocco, where agriculture is often practiced in arid areas by small groups of farmers in rural zones, the increasing incidence of extreme climate events combined with a lack of reliable and predictable weather models represents one of the main issues related to seasonal-dependent, low-yield agricultural systems [20].

In Morocco, various studies have been conducted by the government in collaboration with the International Fund for Agricultural Development (IFAD) to assess the vulnerability of water resources and the performance of major crops (e.g., winter wheat and sunflower) to the impacts of climate change in some of the most sensitive areas of northwestern Mediterranean regions with agro-silvo-pastoral systems. One pilot area in Morocco that exhibits such characteristics is Oued R’dom, where it is estimated that with increased temperatures and decreased rainfall, there will be a 26.4% reduction in the basin's water yield and a 44.7% decrease in crop water productivity [21].

The adoption of adaptation strategies to improve the productivity of water-dependent crops has proven necessary to preserve hydrological resources over the long term. Among the models used, adaptation strategy modeling through the SWAT (Soil and Water Assessment Tool) model has shown a 57.1% increase in crop productivity and a 6.4% rise in yields in the R’dom region.

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According to IFAD, agriculture plays a key role in Morocco's economy, as agriculture and fisheries provide 80% of the income and represent more than 14% of the GDP, with nearly 42% of the population living in rural areas and working in the sector. To address national and international challenges and sustainably increase farmers' incomes, the Moroccan government launched the "Green Plan for Morocco 2008-2020."

The plan includes strategies to increase cereal crop production by 44% while reducing land use by 22% through improved production efficiency. The primary interventions planned and implemented under the Green Plan target the most vulnerable areas, often located inland and at the foot of mountain ranges where the rural population resides. The activities focus on small landholders, landless farmers, small livestock producers, women, and unemployed youth in the country's poorer areas [22].

Such interventions promote community participation in the development process through skill-building and encourage organizational and management capabilities through inclusion and participation activities. Special attention is given to the most vulnerable segments of the population, particularly women and youth, by facilitating access to sustainable financial services such as microcredit and fostering partnerships with local development associations, agricultural water user associations, women's groups, and microfinance cooperatives. Promoting agriculture as a local enterprise is developed through a value chain approach both upstream in production and downstream in marketing [23].

Another project, with similar characteristics but different areas of intervention, is carried out by Morocco in collaboration with IFAD and focuses on developing agricultural value chains in the mountain regions of Taza. The goal of the project is to improve the agricultural system and make it less vulnerable, involving youth, promoting microcredit access, and increasing profits. The main crops modeled are olive and almond trees, which benefited from an approximately 88% increase in yields through the use of more efficient irrigation systems.

Climate change adaptation actions aim to diversify and enhance local agricultural production by sustainably converting cereal-growing areas to sectors that are more suitable for the land and more profitable for the population. The development of irrigated olive and almond plantations using water-saving systems has allowed the project to achieve its objectives. These two specific crops are more resilient to climate variability than cereals and have a more profitable market.

Additionally, the project has led to the activation of a new supply chain network through cross-cutting actions and the creation of pastoral infrastructure, such as plantations, canal rehabilitation, the installation of irrigation support channels, and the establishment of water points and snow shelters, all contributing directly to strengthening the population's capacity.

Egypt

In Egypt, as part of the Regional Nexus Dialogue Program for the Middle East, a project was implemented for irrigating agricultural land using solar energy, through collaboration with GIZ (German development organization), FAO, the Arab Organization for Agricultural Development (AOAD), and the League of Arab States (LAS).

The project aims to mitigate the effects of climate change by limiting greenhouse gas (GHG) emissions through the use of renewable energy sources, specifically solar energy, and to combat drought and soil erosion through no-tillage and minimum-tillage practices [8].

In Egypt, it is estimated that 85% of water is consumed by agricultural activities, making it crucial to rationalize water use for irrigation through more sustainable practices such as solar-powered irrigation systems (SPIS) in the Arab region, which has significant potential for use (Figure 3).

Access to water for irrigation is fundamental for farmers' livelihoods, but irrigation systems often require reliable and efficient energy supplies to function. In many rural areas, the lack of reliable electricity is often compensated for by using fossil fuels, resulting in costs for farmers and substantial pollutant emissions into the atmosphere. Although initial investment costs are high, solar energy offers significant environmental benefits and low maintenance costs, plus the principle that solar energy is free and inexhaustible.

In addition to the implementation of national credit access systems and subsidies for farmers wishing to transform their operations, integrated actions can be promoted, such as using the generated energy for other farm activities, selling excess solar energy, or sharing costs among farmers.

Egypt adopted this innovative irrigation system following an initial trial phase that began in Tunisia in 2015, which showed that after adopting the system, farmers significantly improved their working conditions by increasing soil productivity and reducing field labor costs through the use of SPIS, which directly contributed to lowering electricity and diesel demand.

The SPIS system has proven highly effective in rural areas but can also be used in broader areas such as those with sprinkler irrigation. The more extensive use of solar energy in crops could ensure Arab food security by expanding vertically and horizontally in plantations through sustainable water resource management. As part of the project, farmers receive technical assistance and training, and the Egyptian government facilitates access to financial structures for using solar-powered pumps. However, increasing awareness among farmers about the importance of adopting such modern irrigation systems is crucial. Information should be made easily accessible, farmers should be sensitized to the potential benefits, and the research community should collaborate with institutions to provide more solutions regarding technical issues.

An additional point for consideration is the issue of unregulated solar energy supply, which, given its high availability and low cost, can lead to excessive use of groundwater and resulting waste of water and energy resources. The widespread use of such innovative systems therefore requires careful assessment of technical-economic feasibility, social and environmental impacts, policies and regulations, and cultural contexts where solar irrigation will be used. A solution may lie in adopting combined systems, such as drip irrigation, alongside proper use of subsidies and regulations for solar energy use.

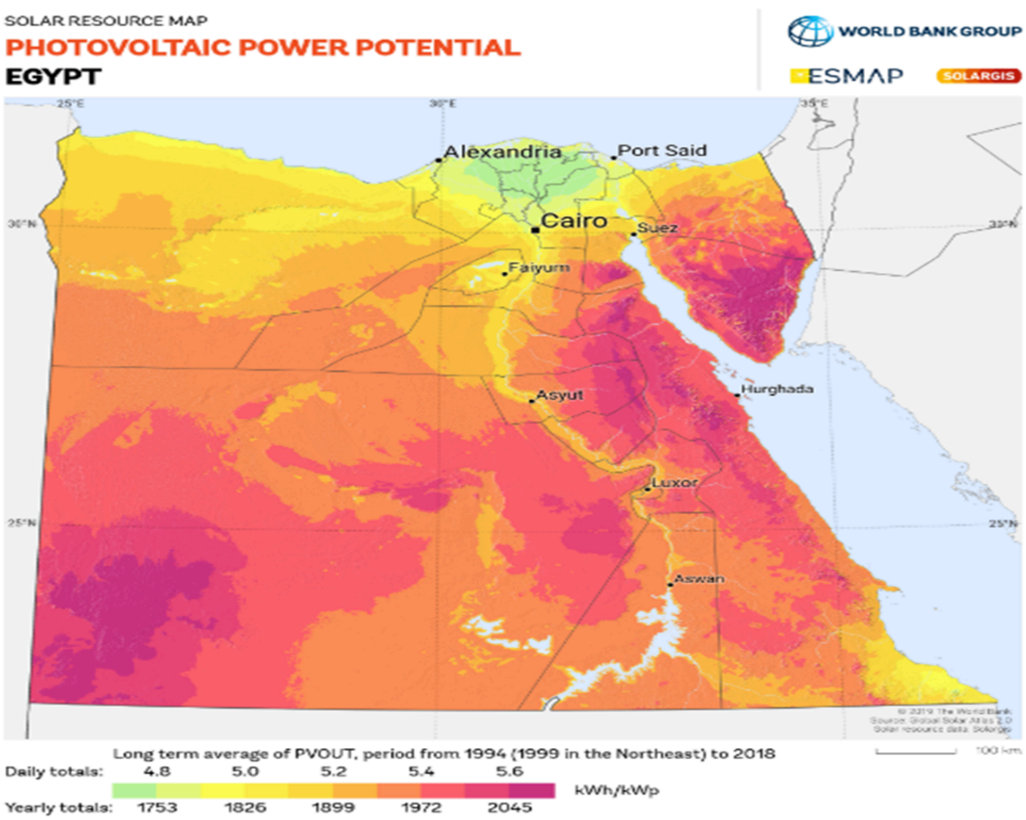

Figure 3. Solar Resource in Egypt (Source: Global Solar Atlas 2.0, Solargis, The World Bank, 2019)

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Spain

In Europe, drought exacerbated by the effects of climate change is also drawing the attention of countries. The INTERREG-MED Program promotes sustainable growth in the Mediterranean region through cooperation and the sharing of good practices in innovation and climate change mitigation among participating funding countries.

As part of this program, and more specifically in the Agri-Adapt project, Spain is leading an initiative in the region around Segovia to diversify crops for better soil management and adaptation to climate change through cross-fertilization principles and dissemination of good practices [24].

The project aims to test sustainable adaptation measures to improve the resilience of farms to climate change, reducing greenhouse gas emissions and enhancing market competitiveness. The pilot area of the project is located in Melque de Cercos, on an organic farm using rainwater with 110 hectares of agricultural land [25].

The main crops cultivated on the farm are barley, rye, sunflower, winter soft wheat, and forage vetch, grown on sandy-clay soil without flooded areas. The main climate change challenges affecting all farms in the region include high temperatures and heatwaves, drought, desertification, soil degradation, pest infestations, and biodiversity loss caused by increasingly extreme weather conditions.

A series of adaptation measures have been implemented on the farm to counter the harmful effects of climate change. Key interventions include cultivating local crop varieties that show greater resistance to climate stress, improving crop rotation, growing legumes and cereals alongside forage crops, and adjusting planting dates to avoid periods of high climate risk.

Among the agricultural practices implemented by farmers, who receive training, is the use of cover crops, a practice used in Climate-Smart Agriculture (CSA). This involves using ground cover, in this case with straw, to prevent soil exposure and reduce the need for additional work and machinery. This practice, combined with more frequent soil fertilization using manure, helps restore and increase organic matter in the soil, improves the soil's ability to store CO2, and limits the use of machinery for soil processing [14].

Agroforestry practices are also employed in the project, which involve the joint cultivation of trees and/or perennial shrubs with crops and/or pastures on the same land unit to enhance soil fertility and biodiversity.

Lastly, field margins have been created or rehabilitated in a multifunctional way to reduce soil erosion and improve local biodiversity, particularly benefiting pollinators. The vegetation in these margins includes predominantly local species and shrubs that, along with stone walls, provide nesting and refuge sites for reptiles and arthropods.

After the first two years, which allowed for the implementation of CSA practices and overcoming the challenges of the transition period, the pilot project proved successful in terms of increased resilience and economic impact, with other farms starting to benefit from these practices.

Italy

In Italy, several projects related to CSA have developed in recent years across different regions. Particular attention is given to soil conservation, as there is significant erosion in Italian farmland, caused not only by the geomorphological characteristics of the territory but also by climate conditions and improper land management that promote soil mineralization. This leads to a gradual reduction in soil thickness and, consequently, a decrease in physical and chemical fertility, negatively impacting biodiversity and crop yields.

Special focus is given to minimal or no-tillage practices and direct seeding, which, as shown by scientific literature, are particularly effective in reducing the cost of mechanical soil treatments, including energy consumption, machinery wear, and labor costs. Compared to conventional agricultural practices, these innovative approaches offer significant economic, social, and environmental benefits, resulting in substantial increases in farm efficiency and productivity.

For example, in Puglia, the "Stratega" project (Experimental and Transfer of Innovative Techniques for Conservation Agriculture), funded by the Puglia region with the active participation of the Council for Agricultural Research and Agricultural Economics (CREA), implements conservation agriculture practices such as no-tillage to improve soil structure. Thanks to crop residues left on the surface, the first few centimeters of soil—the most biodiversity-rich part—are restored, and water content is increased compared to tilled soil, especially during critical periods for winter crops (April and May).

The target crop of the project is durum wheat planted directly on soil with surface residues (no-tillage), which benefits from higher yields compared to durum wheat planted on tilled soil (minimum-tillage).

One of the main objectives of this two-year project, which began in 2017, is to promote the adoption of an innovative agronomic pathway that combines efficiency, protection, competitiveness, and income, while safeguarding soil fertility and preventing erosion.

Through life cycle assessment (LCA), it was estimated that durum wheat production in characteristic agricultural areas of southern Italy, using no-tillage, had a significantly lower environmental impact compared to conventional agricultural practices.

Conservation agriculture achieved more favorable results in terms of wheat productivity and the overall environmental impact per kilogram of wheat produced, reducing greenhouse gas emissions by about 78%. [26]. Energy consumption was also examined, comparing the innovative system with conventional methods. The energy analysis results showed that the most efficient energy-consuming practices for durum wheat cultivation included reducing nitrogen fertilizers, such as introducing legumes and reducing fuel use through conservative soil management practices. With these CSA practices, energy consumption required to produce 1 kg of wheat can be halved, improving the environmental and economic sustainability of durum wheat cultivation with positive implications for the entire supply chain.

In the Marche region, several agroecology projects, soil regeneration, and the rediscovery of ancient seeds more resilient to climate change are underway in collaboration with the Universities of Camerino and the Marche Polytechnic University (e.g., Isea Agroservice). These projects align with CSA principles through a combination of local knowledge, research, and innovation.

Specifically, in the project "Transfer and Adaptation of the Organic Conservation Agricultural Model in Marchigian Cropping Systems," presented to the FAO in 2019 during the Global Symposium on Soil Erosion, a prototype system was developed for the objective measurement of soil erosion. The device aims to conserve and improve soil functionality, biodiversity, and ecosystem services through bioconservative agricultural techniques applied mainly to organic farming and crop rotations [27].

From a technical perspective, the device consists of a mobile unit that can be applied to various terrains and geomorphological situations and captures and separates debris that accumulates in runoff after each rainfall. The debris is then collected, weighed, and the filtered water is channeled into a device that measures the flow rate and periodically releases a known amount of water. A small sample of water is taken at regular intervals, analyzed in a laboratory for dissolved chemicals, and connected to a data logger that transmits the water flow data via radio to a concentrator. Information from the erosion sensor and rainfall intensity data are combined with data from a local weather station to determine the water balance of the experimental fields.

The two best practices presented are concrete examples of sustainable soil management practices that enable those in the agricultural sector to adopt real climate change mitigation and adaptation practices, even through the use of innovative, accessible, and user-friendly systems.

A crucial aspect of implementing CSA projects that address climate change impacts in agriculture is the decisive involvement of institutional bodies in a country.

A significant example is the work carried out by the Emilia-Romagna region through the development of a high-quality agri-food system. The agri-food system of Emilia-Romagna is characterized by the high value of its production chains, symbolized by the 45 Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI) products, as well as numerous certified wines, which thrive on the collaboration between producers and processors.

For this reason, the Emilia-Romagna region, in coordination with agricultural organizations, decided to allocate substantial economic resources—about 136 million euros, corresponding to 11% of the total Rural Development Program (RDP) 2014-2020—to support projects across various sectors of the Italian agri-food industry that unite farms, processing, and marketing companies.

The allocated funds have facilitated integrated interventions that have triggered investments exceeding 370 million euros, increasing the competitiveness of the entire agri-food system according to two main action priorities: maintaining high quality and enhancing innovation within the system.

This approach has also materialized through the adoption of tools aimed at innovation, ensuring that investment support was complemented by pilot projects within the region to develop new products, practices, processes, and technologies in the agricultural and agri-industrial sector.

The 51 supply chain projects funded under the RDP were thus enhanced by an equal number of innovation pilot projects, which focus on the relationship between research entities and farming businesses. These businesses, which often risk being disadvantaged in value distribution along the supply chain, represent the cornerstone of an essential sector of Made in Italy and a strong point for export capacity and competitiveness in national and international markets.

A fundamental aspect in implementing the various projects in the RDP was the political and institutional will to create direct collaboration among multiple sectors, which were involved from the start in the design, planning, and subsequent implementation of the program. Among the main innovations introduced were the development of measures and actions that facilitated the adoption of innovative systems through collaboration between farmers. Specifically, 50 million euros were allocated to create

Operational Groups (OGs) to find appropriate solutions in various thematic areas, such as climate change, water use efficiency, precision agriculture, soil quality, organic farming, animal welfare, antibiotic-free livestock farming, and organic waste recovery. All activities carried out by the OGs were conducted in coordination and collaboration with research centers and universities, farmers' cooperatives, the private sector, and local and regional governments.

Another form of collaboration between stakeholders and the research community was established through the Italian Regional CSA Hub, which since 2015 has strengthened cooperation between the scientific community and institutions by creating a network of climate experts to foster possible alliances and structure data collection activities and the adoption of best practices for sharing.

Conclusions

The examples analyzed so far, related to exemplary CSA projects in the Mediterranean region, were chosen to provide a snapshot of the current climate change mitigation scenario in the area. The presented practices enable the transformation and redirection of agricultural development in response to the new and difficult realities posed by climate change, through the implementation of medium- and long-term actions involving stakeholders across multiple sectors and levels.

Policies related to sustainable development and climate change mitigation require a bottom-up approach to be effective and replicable. They must also be designed and developed through the consultation and participation of all stakeholders, aligned with both international and national policies, and adapted to the unique characteristics of each territory.

Only through the development of policies and actions focused on the conservation of natural resources, biodiversity, and local knowledge, combined with research and innovation, can the vulnerability of the Mediterranean region be reduced from a perspective of development and capacity sharing.

In particular, the integrated approach of CSA results in sustainably increasing agricultural productivity and incomes (food security), enhancing the resilience of agri-food systems to climate change (adaptation), and reducing and/or removing greenhouse gas emissions (mitigation). The resulting equation positions climate-smart agriculture as: CSA = Sustainable Agriculture + Resilience – Emissions [28][29].

The main aspects to consider for maintaining healthy agricultural soil are:

- Complete vegetation cover of the soil.

- Adequate levels of carbon in the soil, within limits determined by soil type and regional climate.
- Minimal loss of essential nutrients from the soil due to leaching.
- Minimal or no soil runoff and erosion.
- No accumulation of soil contaminants.
- Agriculture that does not overly rely on fossil energy, including mineral fertilizers.
- Good soil permeability for water storage.

However, a resilient agricultural system also requires attention to the entire agricultural network, from farmers and producers to laborers, processors, and the most vulnerable groups (youth and women), who must have the means to be trained and participate in decision-making processes.

It is also essential to develop active collaboration between the research community and institutions, as well as with the private sector and civil society.

The Mediterranean agricultural system also needs the implementation of climate information services, as these are an effective tool for acquiring climate data, storing it, and transforming it into specific products needed by various users in vulnerable sectors. According to the World Meteorological Organization, climate services encompass a range of activities aimed at generating and providing information on past, present, and future climate, as well as on impacts on natural and human systems. These services, coupled with the availability of funding and appropriate policies, are vital for significantly reducing farmers' vulnerability.

The increasing instability in Mediterranean countries, particularly in the agricultural sector, requires targeted interventions to reduce the risk of failure in climate change-related projects. The main limitations to the adoption of sustainable practices lie in difficulties accessing credit, short-term production declines (even when long-term production may increase), investment risks during transition, a lack of information, knowledge, and skills, insufficient funding and appropriate policies, a lack of participation in decision-making processes, a lack of cooperation with the research community, and, not least, a lack of trust in the system and innovation.

Consumers also play an important and active role in the Mediterranean agri-food sector, as their level of awareness regarding climate change and nutrition, along with their food choices, can influence future agricultural policies.

In this difficult historical period, the Mediterranean region needs to reassess its priorities, place greater focus on the agricultural sector that ensures subsistence, and pursue socio-economic and environmental sustainability to protect social and environmental heritage.

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