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Project Report

Open Questions and Research Needs in the Adoption of Conservation Agriculture in the Mediterranean Area

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Abstract: This article aims to provide a review of major challenges and research needs for the diffusion of conservation agriculture (CA) and the improvement of crop–soil–water conditions in Southern Europe and Northern Africa. A multidisciplinary study and a participatory approach are at the basis of an international project of research and innovation action, "Research-based participatory approaches for adopting conservation agriculture in the Mediterranean Area-CAMA". It aims to understand the reasons and the research needs that limit a large CA diffusion in the Mediterranean countries. CAMA aims to provide significant advances to CA through multidisciplinary research at the field and farm scales (with main emphasis on smallholder), encompassing a socio-economic analysis of the reasons that obstacle the CA diffusion, legume crop improvement as a component of improved CA cropping systems, and a network of long-term experiments on CA and soil characteristic modification. Its results will be available to scientific and farming communities.

Keywords: conservation agriculture; socio-economy; participatory approach; cropping systems; legume crops; nitrogen and water use efficiencies; soil fertility; dissemination; training

1. Introduction

Conservation agriculture is based on three key principles, namely, minimal soil disturbance with no or minimum tillage, soil cover with crop residues, and use of crop rotations [1,2]. Crop residue disposal on the soil surface is expected to increase soil carbon content, compared to conventional, intensive tillage-based cropping, where residues are generally removed from the field. This is seen as an important process explaining the increased soil productivity over time under CA compared to conventional systems. Moreover, on the basis of experimental evidence of increased water productivity under sub-optimal rainfall conditions [3], reduced soil erosion [4], and better soil moisture content [5,6], CA has been attributed the potential for mitigating negative effects from future climate change, when rainfall is projected to decrease and be more unreliable [7].

The capability of CA techniques to mitigate the climate change effects has been reported by several authors. An important effect is the reduction of machinery use and consequently the abatement of energy from fossil sources and greenhouse gas emission; secondly, the greater carbon sequestration into the soil for the organic matter content increase; and thirdly, the reduction of soil erosion due to extreme events for the surface residue mulching [8,9].

This article presents an overview of major challenges for the diffusion of CA and the improvement of crop–soil–water conditions in Southern Europe and Northern Africa. Moreover, it provides information on "Research-based participatory approaches for adopting Conservation Agriculture in the Mediterranean Area–CAMA", a 3-year project that started in April 2020, whose ambition is to understand and alleviate the obstacles—social, economic, agronomic, and technological—to the diffusion of CA in eight target countries of the Mediterranean basin. This will be carried out with the involvement of local farmers' associations, technicians, stakeholders, field research, and a participatory approach aimed to evaluate the best genotypes, crops, and soil management techniques in CA adoption.

2. The Conservation Agriculture in the Mediterranean Basin

In semi-arid rainfed contexts, there seems to be a consensus that conservation agriculture may perform better than conventional agriculture if all three principles can be implemented [10]. The experimental trials in the last decades showed positive effects of CA on crop yield, but in specific conditions, weed control and residue management need precise adjustment to lead to a complete success [11]. In the same way, the implementation of the three principles of CA, especially residue retention and appropriate crop rotation, are often challenging, especially amongst smallholders [12]. In fact, the high cost of direct seeding machinery, the competition for crop residues with animal feeding, and the difficult-to-find valuable crops in the rotation are the main obstacles in CA adoption amongst smallholders.

In Mediterranean areas, CA is a clear strategy to sustain agricultural production [13]. In these areas, soils are prone to severe degradation processes [14]. Intrinsic properties and characteristics such as low soil organic matter, high pH, heavy textures due to predominant silt and clay fractions, and the presence of significant amounts of calcium carbonate exacerbate soil degradation processes in Mediterranean areas, with soil erosion being the most relevant constraint. Concurrently to the intrinsic soil types and properties, historical agricultural management practices, led by intensive tillage systems and long bare fallowing periods between crops, has triggered soil degradation processes in Mediterranean agroecosystems. In fact, the extent of degradation of rainfed cropland is greatest in the many countries of this region: Algeria (93%), Morocco (69%), and Tunisia (69%) [15].

A thorough review paper on the long-term effects of no-tillage on soil properties is that of Strudley et al. [16]. Overall, an extensive literature review showed stable and detectable improvements of soil properties when CA has been properly adopted [17–19]. Such improvements should be achieved about a decade after conversion to CA [20,21]. However, with a view of reducing both agronomic inputs and production costs, a substantial equivalence in the performance between traditional agriculture and CA was suggested as a valuable option to minimize soil degradation in the transition of cropping systems under climate changes [22,23].

Crop diversification and the adoption of reduced/no-tillage systems boost soil organic matter accrual. Under conservation tillage systems, crop residues remain on the soil surface, thus slowing down the decomposition by soil microorganisms.

Soil organic carbon (SOC) is the most reported soil property from tillage experiments since it is the keystone soil quality indicator, being inextricably linked to other soil attributes. SOC is also a crucial contributor to food production, mitigation and adaptation to climate change, and the achievement of SDGs [24]. Several studies conducted in Mediterranean soils showed that soil organic matter (SOM) content in the topsoil increased significantly under conservative compared to conventional tillage [25–27]. The increase in SOM in those agro-systems has a double benefit: on the one hand, it improves the soil aggregation and overall physical status of the soil system, providing resistance to soil erosion; on the other hand, conservation tillage has positive effects on the natural fertility status of the soils and, thereby, to maintain the same crop yield level, it lowers the need for mineral fertilizers, avoiding negative impacts of nutrient surpluses on natural ecosystems. The challenge measured in France (source ARVALIS) of increasing soil fertility expected in CA is represented by a better nitrogen uptake by wheat, of 40 to 60 kg N/ha deriving from previous crop and SOM mineralization, and this can lead to an increased yield by 5 to 10%. These beneficial effects were only confirmed in cases where the legume cover has been grown well in autumn–winter and has been efficiently destroyed or heavily regulated in spring so as not to compete with wheat.

Agriculture is the predominant user (75–80%) of the available freshwater resources. At present, most of the **water used** to grow crops is derived from rainfed soil moisture, with non-irrigated agriculture accounting for some 60% of production in developing countries. The FAO predicts that agricultural water withdrawals will increase by approximately 14% up to 2030 to meet the food demand [28]. An increase in the productivity of rainfed agriculture can be achieved by means of (i) water accumulation and maintenance, (ii) reducing runoff and evaporation and increasing water infiltration and retention, and (iii) improving water use and water use efficiency [29]. Under semiarid rainfed conditions, soil water storage increases with the use of CA systems that leave crop residues on the soil surface. Moreover, this effect escalates as the degree of aridity of the site increases. Inversion tillage should be avoided in these conditions, especially in soils prone to crust formation, because it can have deleterious effects on infiltration, reducing their capacity to store water and leading to reduced crop yield [30]. Mulching is an important component of conservation agriculture. Mulching influences soil evaporation, transpiration, crop yield, and WUE. There is a reduction of 23 and 45 mm in evaporation in mulched winter wheat and maize fields, respectively, compared to non-mulched fields [31].

Agri-environmental measures are key elements for the integration of environmental concerns into the Common Agricultural Policy. They are designed to encourage farmers to protect and enhance the environment on their farmland by paying them for the provision of environmental services. The public incentive for the adoption of conservation agriculture should only be considered as a decisive support for the task undertaken by farmers to protect the environment [32].

3. Obstacles and Research Need for CA Diffusion

Adoption rates of CA in Mediterranean countries, however, remain low, despite more than three decades of research [13,33]; development investments; and, in the EU countries, economic subsidies (Table 1), representing about 2% of the arable crop area for EU countries and 0.8% only for African countries. This is in huge contrast, for example, with the situation in South America, where about 50% of the cropped area is cultivated without tillage in CA systems. However, adoption of CA in that part of the world is predominantly successful in mechanized, medium–to-large-scale farms, and by far less in smallholder farms where *"a defining characteristic of smallholder is that they struggle to be competitive and hence to provide an income to support themselves and their families, they [...] produce at least part of their product for self-consumption"* [34].

Table 1. Diffusion of conservation agriculture in some Mediterranean countries [35].

Countries	Hectares
Spain	900.000
France	300.000
Italy	283.000

Table 1. *Cont.*

Countries	Hectares
Portugal	32.000
Greece	24.000
Tunisia	10.500
Morocco	12.000
Algeria	5.600

Adoption of CA is conditioned by its technical performance, subject to the opportunities and trade-offs that operate at farm and village scales and constrained by different aspects of the context in which the farming system operates, including market, socio-economic, institutional, and policy conditions defining the innovation system and the variability inherent to the physical environment (e.g., climate change). Therefore, a challenge that demands some research is to identify where and how a particular CA practice may fit best and which farmers in any given community are likely to benefit the most [36]. Answering these questions will help in directing the investment efforts in CA dissemination.

Since the availability of crop residues is limited in several farming systems of the Mediterranean basin, especially those of the semi-arid regions, strong competition exists among different uses (feeds for livestock, energy production, etc.). For example, the traditional common right of free grazing in many farms of North Africa (i.e., Algeria, Morocco, and Tunisia) makes the crop residues non-private products for farmers. Keeping crop harvest residues on the field as soil cover with CA and not feeding them to livestock leads to significant trade-offs with livestock production [37]; however, some opportunities regarding grazing could be considered for these systems [38].

The adoption of CA in the Mediterranean basin is also hindered by the widespread use of wheat monoculture. Legume crops are at the crossroads of agricultural sustainability, mitigating climate change and reducing nitrogen pollution and energy costs [39] via higher biologic nitrogen fixation and achieving greater self-sufficiency of feed proteins. Insufficient profitability arising from low yields is the main reason for low legume cropping [40]. Lucerne is the most grown legume in the Mediterranean basin, whilst pea has a remarkable potential as a high-protein feed grain legume (while being usable also as a forage crop).

The practice of CA has the potential to conserve soil moisture through a soil cover of crop residues, which makes it an effective technology to mitigate the negative effects of less and more erratic rainfall due to climate change [9]. With CA, crop yields are expected to progressively increase in time because of the gradual improvement of soil quality. With the absence of immediate positive yield responses, CA is unlikely to result in immediate increases in farm income, which is a major constraint for the rapid adoption of CA. The ex-ante identification of appropriate situations for adapting and implementing CA is a challenge that demands active research and development from a multi-stakeholder, multi-scale, and interdisciplinary perspective.

4. The CAMA Project

The project aims to:

Identify the major social, economic, and agronomic barriers to CA implementation by smallholders of Mediterranean countries;

Improve innovative cropping systems on the basis of legumes in rotation with cereals;

Develop new agronomic management practices to maintain soil fertility, improve crop residue management, reduce soil erosion, and enhance nitrogen and water use efficiencies;

Increase the end-user's technical knowledge to effectively face the new challenges in the agriculture of the third millennium in Mediterranean countries.

The research activities are articulated on three levels:

At the scientific level: (1) identifying the relevant barriers to CA adoption in Mediterranean countries; (2) creating a network of CA users and testing a new crop yield diagnostic method; (3) testing selected new legumes' genotypes for stress tolerance; (4) assessing the effect of CA on soil N and water balance and use efficiencies; (5) evaluating changes in the soil characteristics focusing on water retention, erosion, and fertility; (6) development and application of crop simulation models.

At the technological and industrial levels: developing and validating novel technical approaches, such as (1) optimal settings sowing in CA; (2) new agronomic techniques for weed control and crop residues management; (3) improved cropping systems; (4) genome-based selection of novel legume varieties adapted to arid and semi-arid environments.

At the farming level: fostering cooperation with farmers and other value chain actors to (1) establish a participatory approach; (2) favor the dissemination of the results to technicians, farmers' associations, and extension services; (3) build farmer organizations', advisers', extensionists', and researchers' capacities for the development and application of adapted practices for the conservation of soils and water in dry land agriculture.

CAMA is structured in five research work packages (WP2 to WP6); one outreach, dissemination, and technology transfer work package (WP7); and one project management work package (WP1), all of them interacting strongly with each other (Figures 1 and 2).

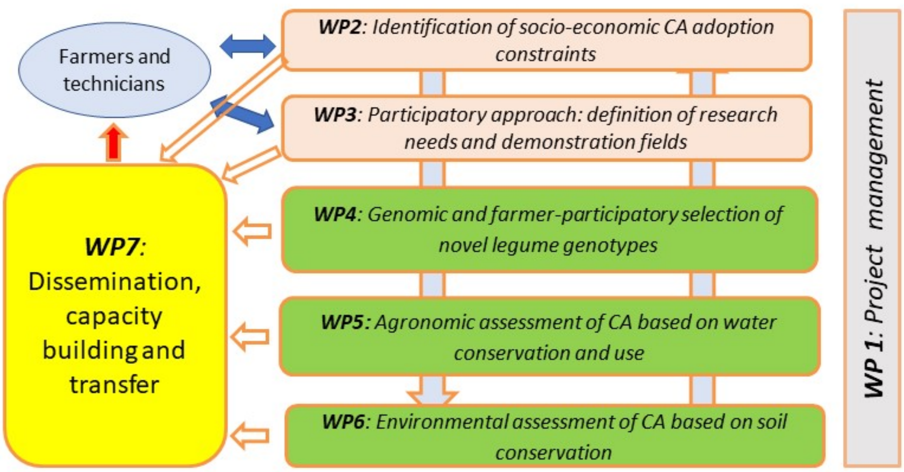

Figure 1. Interrelationships between Work-Packages (WP) in the CAMA project.

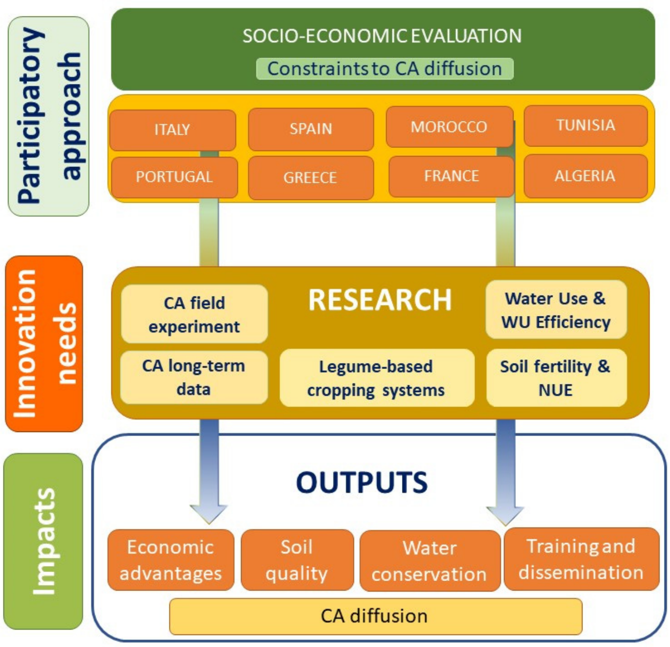

Figure 2. Overall approach adopted within the CAMA project.

The CAMA Consortium (Table 2) consists of 13 partners highly experienced in CA, wherein some of them have been working together in previous research projects.

Table 2. Partners of the CAMA project.

ORGANISATIONS	ACRONYMS	COUNTRIES
Council for Agricultural Research and Economics	CREA	Italy
AGROMNIA	AGROMNIA	Italy
Institut du végétal	ARVALIS	France
Mediterranean Agronomic Institute of Saragoza	IAMZ-CIHEAM	Spain
University of Lleida	UdL	Spain
Spanish National Research Council	CSIC	Spain
Portuguese Association for Mobilization of Soil Conservation	APOSOLO	Portugal
Instituto Nacional de Investigação Agrária e Veterinária	INIAV	Portugal
Hellenic Agricultural Organization-"DEMETER"	HAO-Demeter	Greece
Institut National de la Recherche Agronomique de Tunisie	INRAT	Tunisia
Association for Sustainable Agriculture	APAD	Tunisia
High National School of Agronomy	ENSA	Algeria
Institut National de la Recherche Agronomique de Morocco	INRA	Morocco

The creation of CAMA Consortium (CA) was based on the complexity of the agricultural production system requiring a multi- and inter-disciplinary approach to exploit positive synergies and achieve sustainable innovations. This involved approach aimed at optimizing nutrient and water use efficiency, improving cropping systems' resilience to climate change, and reducing agro-environmental and socio-economic pressures.

The multidisciplinary character, with the presence of researchers in all main disciplines (economics, genetics and breeding, agronomy, soil science, microbiology, modelling) will represent an important added value.

Three partners are farmers' associations, seven are research institutions, two are universities, and one is an International Organization specialized in agricultural post-graduate training and cooperation. The 13 partners belong to 8 countries, 5 EU Member States (France, Greece, Italy, Portugal, and Spain), and 3 Mediterranean countries (Algeria, Morocco, and Tunisia) (Figure 3).

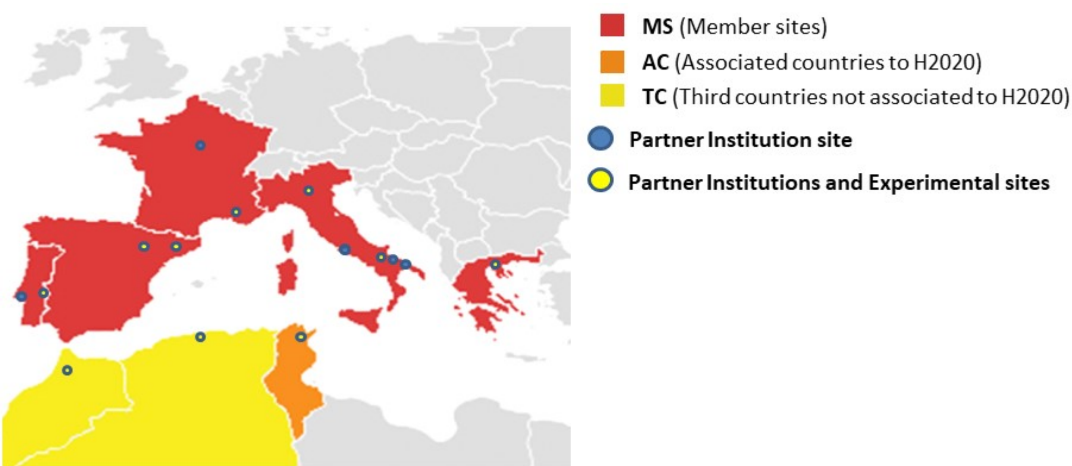

Figure 3. Map of countries and experimental fields involved in the CAMA project.

5. Research Participatory Approach

The large variety of Mediterranean pedological, social, and climatic environments need to define target regions/areas, with a regional characterization and a necessary set of data to be collected by each country. These data were classified into two categories: environment and territory/pedo-climatic data and socio-economic factors (Table 3).

Table 3. Country region/area characterization and selection. Example of data to be collected.

Environment and Territory Pedo-Climatic Data	Socio-Economic Factors
Average annual temperature (°C) and precipitation (mm)	Agricultural holdings (n.) and utilized agricultural area (hectare)
Forecasted maximum temperature and precipitation anomalies (°C)	Utilized agricultural area per use (crop use) (hectare)
Relative air humidity (%)	Irrigated utilized agricultural area (hectare and % of utilized agricultural area)
Extreme weather events—maximum and minimum temperature, drought or heavy rain, strong winds (°C, mm, km h^{-1})	Agricultural sole producer age class
Land use (hectare)	Agricultural sole producer education level (basic, secondary, and higher)
Soils FAO classification Soil chemical, physical, and biological characterization	Total agricultural labor force per time dedicated (% of time—full-time and part-time)
Orography	Information and communication technology use (% or total number of farmers)
Estimated soil erosion by water (t ha^{-1} $year^{-1}$)	New machinery/technology available (total number)
Areas susceptible to desertification (Aridity Index-ratio of Precipitation and Potential Evapotranspiration P/PET)	Contractors' availability (total number)
Topsoil organic carbon content (g kg^{-1})	Soil cover—residue management (seeding) and cover crop seed availability (% of farmers that were referred)
Potential and actual soil erosion risk (from low to high)	Good markets for new crop availability—crops rotation (total number)
Land quality (from low to high)	Input and machinery costs (% of farmers that referred)
	Training and advice service availability (% of farmers that were referred)
	Sources of information about farmers' work (e.g., researcher, other farmers, internet)
	Weed, pest and disease control
	Fertilization
	Agri-environment measure (EU + National Funds)—soil conservation, no-till, and strip-till (number of beneficiaries and area in hectares)
	Other measures related to CA (number of beneficiaries and area in hectares)

According to the characteristics of these target areas inside the countries involved in the project, a range of factors hampering CA adoption were investigated. These factors belong to the following thematic categories:

- Natural conditions such as agro-climatic, soil, weed, and pest disease incidence;
- Socio-economic conditions and agronomic data such as farming households (number, size, gender, age, and level of education of the main decision maker; land tenure), crops, rotations, production, products and input prices, national and EU policies, existence of farmers' organizations;
- Resource constraints such as cash, credit, input, labor, machinery, and contractor's availability;
- Farmers' goals—income increase by production increase and/or cost decrease, better practice of CA technology, wanting to adopt CA if there is an extension/assistance service; having practiced CA but rejected it;
- Possible farming system interactions—not practicing CA, as for some crops there is no solid know-how yet and they cannot afford different machinery;
- Identification of limiting factors or farmers´ constraints for using CA technology;
- Farmer's adoption of new technologies and crops in the past that may characterize their level of risk aversion or avoidance;
- Farmers being open to innovations, having developed or improved their own technologies.

To overcome the limitations on the adoption of CA, a participatory approach is adopted in this research that was based on the use of field experiments and pilot case studies. The first step is a social and economic analysis in all CAMA partner countries in order to understand the reasons for low adoption of CA in the eight Mediterranean countries and identify the obstacles to be overcome by on-farm experiments in farmers´ fields.

Meetings, demonstration field-days, and living-labs will be organized in the Mediterranean countries, with the help of the involved farmers' associations, in order to detect the main research needs.

A structured **survey** was produced (https://docs.google.com/forms/d/1UTpD5VRfF17-Kh9S8DDmGxZjfEWK4ujVvBCpkOqdmrs/viewform?edit_requested=true) (accessed on 26 April 2022), with two specific target farmers groups: users and non-users of CA. Information about the famers, the farm, the cropping systems, the level of technology adopted, experience on CA, positive and negative aspects experienced by the users, and doubts and worries of the non-users will be collected and analyzed in the different countries.

From the outcomes of the project, some improvements will be suggested and proposed to the involved farmer associations, with the main focus on **weed control improvements**—use of cover crops with allelopathic or competitive properties; crop residue management: use of rollers or other mechanical equipment; **no-till seeding** special machinery; **use of CA-adapted monitoring tools**; use of controlled-release fertilizers; low N volatilization products; **introduction of new crops in the rotations** (i.e., legumes), considering local market, climate change, farmer's attitudes, farmer's equipment, and agronomic issues in the different countries.

An example of tools to overcome yield limitation in conservation agriculture is the methodology "Diagchamp field diagnosis" (Figure 4): it was designed by ARVALIS partner, and it is based on an experimental approach. It is not analytical but is diagnostic, trying to understand and explain the phenomena that are occurring. Four variables are considered very relevant to improve CA management: weed control, sowing, fertilization, and crop rotation. The Diagchamp method helps to "rank" limiting factors on the basis of their significance (yield loss compared with expected potential) and their extent in the plots under study.

Understanding the mechanisms involved using diagnostic tools and assessing performance on the basis of multiple criteria will help to improve direct sowing into green cover systems, as well as to make them more readily accessible to most farmers, with design methods, suggested practices, and development of special management tools that take into account specific conditions during the season.

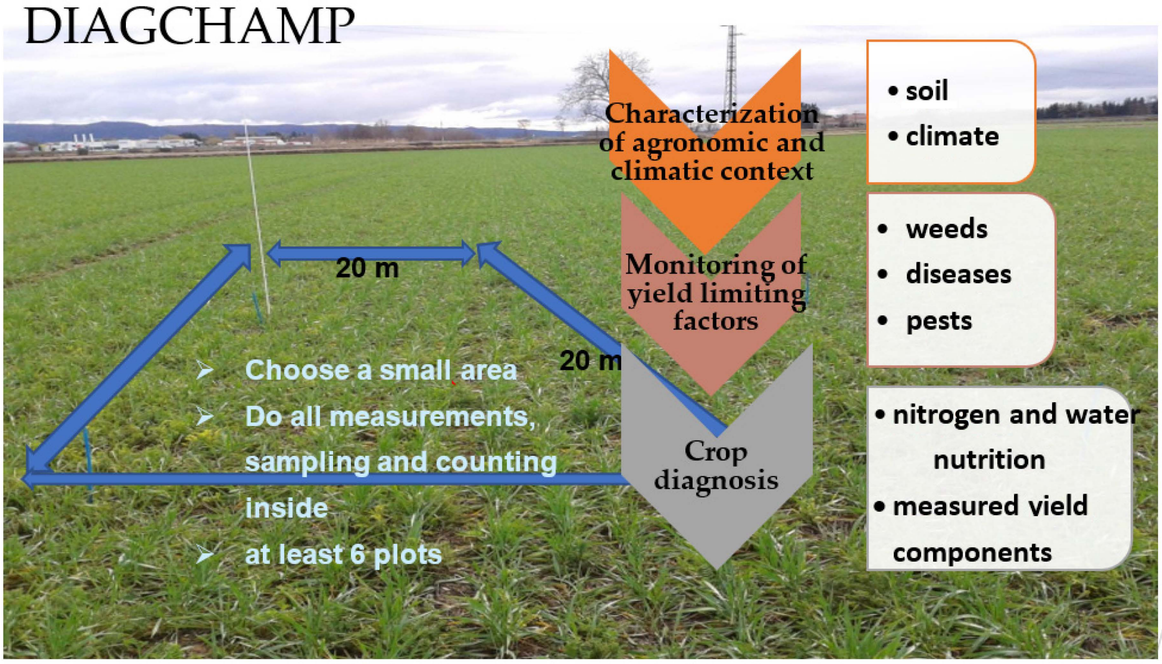

Figure 4. Diagchamp method scheme.

6. Breeding of Legume Crops

The marked insufficiency of high-protein feedstuff, the overexploitation of forage resources, the increasing costs and/or the decreasing availability of irrigation water and mineral fertilizers, and the increasing drought stress arising from climate change are threatening the crop–livestock systems that have a remarkable socio-economic importance in the Mediterranean region. The use of nitrogen-fixing forage and feed legumes with genetically improved tolerance to drought will enhance the economic and environmental sustainability of Mediterranean agriculture, thereby contributing to tackling these challenges [41,42] while playing a role in strategies of climate change adaptation and mitigation. The cultivation of legume crops favors the diversification and flexibility of farming systems, the biodiversity of cultivated germplasm, and a more efficient nutrient cycling, thereby improving the resilience of farming systems relative to cereal monoculture-based systems [43].

Aiming to design new farming systems in conservation agriculture for the Mediterranean area entailing the introduction of legumes in crop rotations, the main objective is to select and make available new varieties of lucerne (*Medicago sativa* L.) and pea (*Pisum sativum* L.) for innovative and diversity-based cropping systems oriented to CA by means of genomic and farmer participatory approaches. It is strongly rooted on the past ArimNEt project REFORMA.

Lucerne is the main forage crop in southern Europe and in Morocco. Its cultivation in the Maghreb countries is traditionally limited to oases or frequently irrigated conditions, but recent results have highlighted the good adaptation to severely drought-prone environments of germplasm that evolved in stressful conditions [44]. The outcome of previous work has enabled the establishment of a genetic base that is used in the current project. **Pea** is the main feed grain legume along with faba bean (*Vicia faba* L.) in southern Europe, being mainly grown in a mixture with a cereal in the Maghreb, wherein recent work has highlighted the high yield potential and appreciation of farmers for this species [45].

Multi-environment forage yield testing work for lucerne revealed an outstanding genotype × environment (GE) interaction of cross−over type (implying rank changes) across agricultural or managed drought−prone environments, both for cultivars, as in [44], and for half-sib progenies of candidate parents for new synthetic varieties, as shown in Figure 5 for a subset of top-performing progenies sorted out from a set of 128 test progenies. This kind of germplasm response emphasizes the importance of breeding distinct varieties for different target regions (although breeding for wide adaptation may entail larger market opportunities).

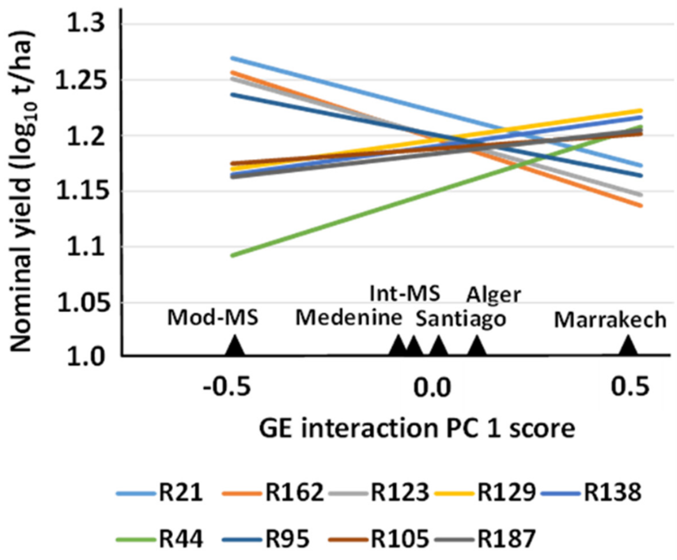

Figure 5. Nominal forage dry matter yield of nine top−yielding lucerne half−sib progenies as a function of the first "genotype × environment" (GE) interaction principal component (PC) across a managed stress (MS) environment in Lodi, Italy (with moderate or intense drought stress), and stress−prone agricultural environments (Médenine, Tunisia; Santiago del Estero, Argentina; Algiers, Algeria; Marrakech, Morocco) in an additive main effects and multiplicative interaction (AMMI) analysis. Source: [46].

Remarkable GE interaction of cross−over type was also be found for the grain yield response of pea lines across two severely drought-stressed environments (represented by a Moroccan sites or managed stress in Italy) and one moderately drought stress site of Algeria (Figure 6), suggesting specific breeding for either of these conditions.

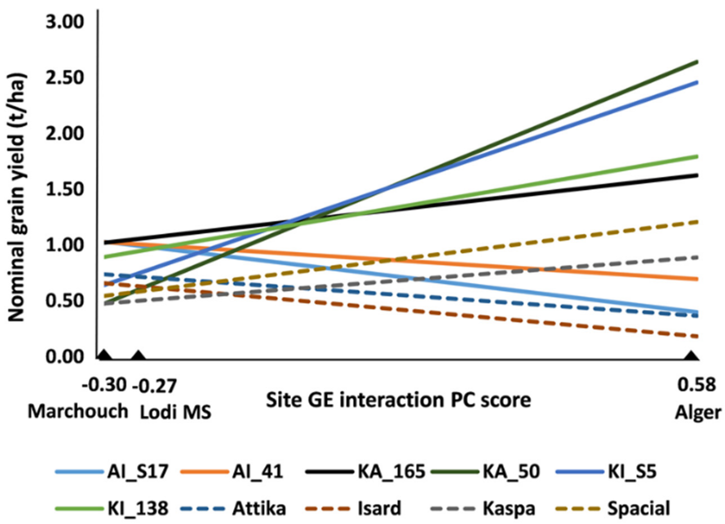

Figure 6. Additive main effects and multiplicative interaction (AMMI)−modeled nominal grain yield of six top-performing pea lines out of 288 lines belonging to three connected RIL populations, including the two top−ranking lines in each site or over sites, three parent cultivars (Attika, Isard, and Kaspa), and one recent control cultivar (Spacial), grown in a managed drought stress (MS) environment of Lodi (Italy) and two rainfed agricultural environments of Marchouch (Morocco) and Alger (Algeria). Source: [47].

Phenotypic selection (PS) typically features very low rates of genetic yield gain in lucerne, urging the development of more cost-efficient marker-based selection. Genomic selection (GS) is a tool for predicting breeding values for complex, polygenic traits using a statistical model built by combining phenotypic and genome-wide marker data. Pioneering results in lucerne provided promising estimates of genotype breeding values for forage yield under moderately favorable conditions [48]. Genomic predictions were less encouraging for drought-prone environments in a preliminary study [46] but still of some interest compared with opportunities offered by PS.

Promising GS results also originated from pioneer studies for pea. The mean GS predictive ability for grain yield in three recombinant inbred line (RIL) populations (i.e., the correlation between genomically-predicted and observed data, with predictions assessed in environments and material independent from that used to construct the GS model) achieved 0.30 for material grown in climatically contrasting Italian environments [49]. In a proof-of-concept study, the application of genomic selection for pea yield in severely drought-prone environments provided actual yield gains comparable to PS, suggesting greater gains per unit of time or cost when considering the quicker evaluation time and lower evaluation cost per genotype of GS relative to PS [47].

CAMA will provide for lucerne and pea a thorough comparison of GS versus PS in terms of actual yield gains per unit of time or cost, adapting both strategies to the specific-adaptation prospect that is needed across countries of the Mediterranean region (particularly those with contrasting drought stress level). Material selected from GS and PS will undergo multi-environment testing inclusive of farmer participatory evaluation and selection, according to a participatory plant breeding (PPB) approach considered as a component of a "system-based" breeding approach [50], which is consistent with the knowledge exchange and mutual learning between researchers and farmers, a key feature of CAMA. In a recent study of pea targeted to organic systems, PPB produced greater yield gains than ordinary breeders' selection, even in countries with advanced agriculture such as Italy [51].

7. Field Experiment Network

Regardless the limitations in water and nutrient resources in the Mediterranean cropping systems, the improvement of several indicators will be used to assess the agronomic and environmental performance of the proposed techniques of CA and cropping system development for smallholder sustainability.

Yield crop and water use efficiency by crop will be the main and more important indicators to assess the agronomic performance of CA. Other soil parameters will be used for environmental assessments, including the soil erosion risk that will also be assessed with proxy measurements of pedologic characteristics and the change in soil organic carbon stocks. Moreover, soil and crop data obtained from long-term experiments will be used to parametrize and evaluate soil–crop models. The main aim of the use of simulation models is to predict the long-term changes in crop performance and productivity, water and nitrogen balances, and soil organic carbon stocks under different management and climate conditions. The information obtained in this modelling exercise will help to understand the future performance of CA agricultural practices in the Mediterranean basin under a global warming scenario.

Four tasks of the agronomic work-package (WP5) will focus on activities related to the assessment of crop yield and water use efficiency of different CA agricultural practices in Mediterranean countries, the assessment of soil infiltration and water-holding capacity, and in the evaluation of the role of different management and climate scenarios on CA-based crop yields and water use efficiency using simulation models (i.e., carbon (C), water (H), and nitrogen (N)-CHN and Simulateur mulTIdisciplinaire pour les Cultures Standard (STICS) models).

Three tasks of the WP6 will pay specific attention to the assessment of CA on soil conservation and environmental quality. Different CA systems across the Mediterranean basin will be tested to evaluate their performance in terms of soil fertility, soil erosion, and soil organic carbon sequestration.

To develop these assessments, a network of 11 medium-to-long-term field experiments in seven countries (eight partners) will be used (Table 4). These field experiments provide an extensive set of scenarios in a range of climate conditions from 200 to near 700 mm of annual rainfall and soil types. The experiments account for different cropping systems from monocropping to 3-year crop rotations including different legume crops (faba bean, pea, chickpea, lathyrus) and grain sorghum in rainfed conditions or maize and soybeans under irrigation. Different soil management systems in combination with other agricultural practices such as N fertilization will be tested.

Table 4. Experimental network of the CAMA project.

Partner n. and Country	Field Experiment n./Location	Beginning of the Experiment and Crops Involved	Water Regime and Annual Avg Rainfall	Compared Treatments
P1 CREA Italy	EXP 1. Foggia	2013 durum wheat–broad bean rotation	Rainfed 550 mm	No-till vs. minimum till
	EXP 2. Foggia	2002 monoculture of durum wheat (wheat–chickpea rotation from 2021 onwards)	Rainfed 550 mm	idem
P3 ARVALIS France	EXP 3. Oraison On-site farm scale	2013 durum wheat–legume rotation (drought part)	Rainfed 650 mm	No-till, living crop, and irrigation treatments
	EXP 4. Oraison On-site farm scale	2013 durum wheat, maize, or soybean–legume rotation (irrigated part)	Irrigated 650 mm	idem
P5 UdL and P6 CSIC Spain	EXP 11. Senés de Alcubierre	2010 barley–wheat–pea crop	Rainfed 330 mm	No-till vs. intensive till combinations of N fertilization dose and type of product (mineral vs. organic)
P9 HAO-Demeter Greece	EXP 5. Drimos-Thessaloniki	2019 two-year crop rotation with winter–summer crop of barley–Panicum miliaceum (June 2020), Lathyrus sativus (autumn 2020)–sorghum bicolor (end of spring 2021) and barley (autumn 2021)	Rainfed 450 mm	Minimum till vs. intensive till
P10 INRAT Tunisia	EXP 6. Kef Kef Region	2010 faba beans–durum wheat–barley in three rotation types in three rotations: wheat monocropping, faba bean–wheat, and faba bean–wheat–barley	Rainfed 450 mm	No-till vs. moderate tillage vs. intensive till
P11 ENSA Algeria	EXP 7. Algiers	2018 intercropping: chickpea/wheat vs. monocropping	Rainfed 450 mm	Conventional tillage; combination of N fertilization levels
	EXP 8. Mezloug	2018 intercropping: chickpea/wheat vs. monocropping	Rainfed 300 mm	idem
	EXP 9. Baida Bordj	2018 intercropping: chickpea/wheat vs. monocropping	Rainfed 200 mm	idem
P12 INRA Morocco	EXP 10. Merchouch	2004 wheat or barley–legumes	Rainfed 300 mm	No-till vs. intensive till

Soil management in CA application may affect the hydrodynamic soil properties, including saturated hydraulic conductivity; porosity and pore connectivity; and, as a consequence, the water and solute movement into the soil [20]. Moreover, it is expected that CA may affect the soil water retention and the degree of soil compaction [23]. These main soil properties will be investigated in field experiments, especially in soils characterized by preferential flows. A new method named BEST-2K, recently developed by Lassabatere et al. [52], will be applied to characterize the hydraulic functions of dual permeability (see Figure 7 for BEST-2K application in the field), while standard laboratory methods (i.e., evaporation and UHG methods) will be applied to investigate the impact of CA on soil water retention [53].

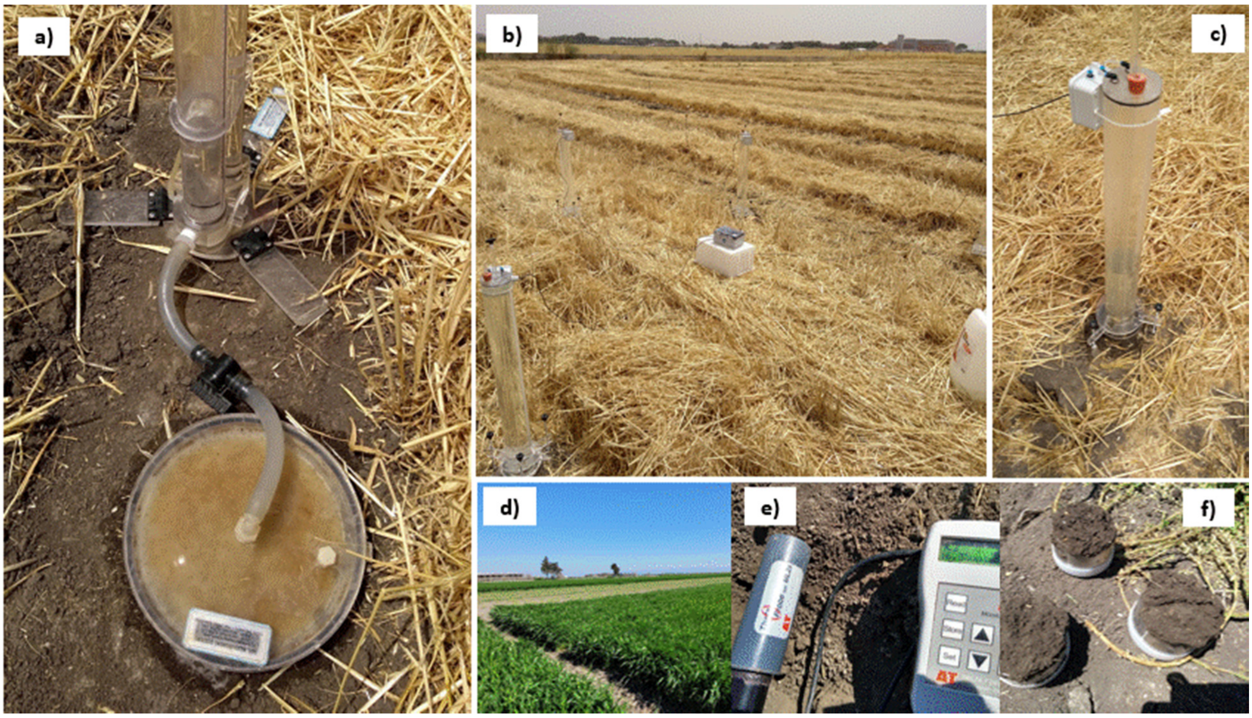

Figure 7. Images of the instruments used and methods applied at CREA experimental farm in Foggia (EXP 2. Foggia; Table 3): (**a**) tension infiltrometer, (**b**) automated Beerkan infiltrations with view of four simultaneous infiltration experiments and (**c**) detail of a single infiltration, (**d**) a view of the field under durum wheat, (**e**) the theta-probe sensor to measure the soil water contents, and (**f**) undisturbed soil cores collected to determine the soil water retention in the laboratory.

Moreover, adoption of CA systems may have significant effects on soil erosion rates and C and N dynamics. It has been reported that the maintenance of crop residues on soil surface under CA systems results in greater resistance to soil particle detachment and subsequent soil transport by water or wind [54]. This response towards soil conservation converts CA as an interesting option to mitigate soil degradation by soil erosion in Mediterranean areas. Another possible benefit of CA adoption is the accumulation of soil organic carbon, particularly in the soil surface where most crop–soil interactions result. Increases in soil organic carbon levels are positively related to many soil functions and ecosystems services and with and overall enhance of crop growth and yield [55]. Consequently, the CAMA project brings us an excellent framework to evaluate the response of a variety of CA systems under different soil and climate conditions in crop growth, yield, and associated environmental impacts.

8. Dissemination and Training

Dissemination and communication are crucial aspects in a research and innovation action, as is the case with CAMA; therefore, the research results and the innovations need to be transferred to local farmers by means of farmers' associations, extension services, field days, and demonstration activity tools; scientific results will follow the usual scientific dissemination channels.

Well-targeted dissemination, communication, and capacity building contributes to achieving a maximum impact of project findings and activities to relevant audiences. More specifically, the communication, dissemination, and training activities will aim to

- ensure that the results from CAMA reach all the relevant stakeholders with appropriate communication and dissemination tools and channels.
- transmit project results that can be of relevance for the stakeholders involved in the transition to CA in the Mediterranean countries, namely, the community of farmer advisors, the farmers' organization, and the applied researchers who support the farmers.
- contribute to the capacity building of Mediterranean farmer advisors and agronomists working in cropping systems innovation, with a special emphasis on young professionals.
- reaching the scientific community with project results of scientific and technical relevance.
- increasing the awareness of the potential and benefits of CA in Mediterranean agroecosystems among farmers, advisors, technicians, and policymakers.

CAMA has firstly developed a logo (Figure 8) that has been inspired by some characteristic traits of Mediterranean agriculture (e.g., the sun and the cereal spikes), integrating the soil, water, and crop (three color lines) as the basic layers of the cropping system that CA aims to preserve and improve. A project brochure and a poster that summarizes project goals, activities, partners, and networks has been prepared in Arabic, English, Greek, Italian, French, Portuguese, and Spanish, being used for dissemination by every partner. These materials are available on the project website.

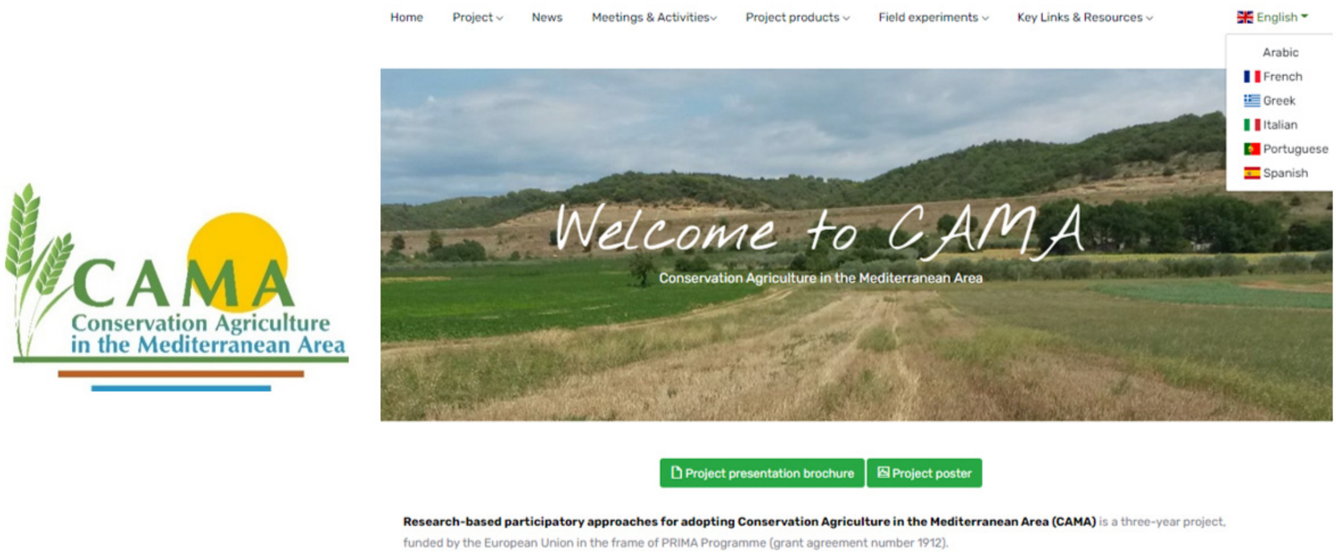

Figure 8. Logo and website of the CAMA project.

The multilanguage CAMA website (http://www.camamed.eu/en/, Figure 8, accessed on 26 April 2022) has been designed and managed to be used as a key channel of communication to external audiences as well as amongst partners. The website has a restricted intranet area designed to enable the exchange of information and documents between partners. The web will be maintained for up to 5 years following project completion.

Social media are also important channels for communicating news and results about the project and for facilitating wider interaction with external audiences. Facebook, Twitter, ResearchGate, and YouTube accounts have been opened (Table 5).

Table 5. CAMA web page and social links.

Project website	http://www.camamed.eu/en/ (accessed on 26 April 2022)
Facebook	https://www.facebook.com/CAMAproject (accessed on 26 April 2022)
Twitter	https://twitter.com/cama_med (accessed on 26 April 2022)
ResearchGate	https://www.researchgate.net/project/Research-based-participatoryapproaches-for-adopting-Conservation-Agriculture-in-the-Mediterranean-Area-CAMA (accessed on 26 April 2022)
YouTube	https://www.youtube.com/channel/UC3twVsFUmyuR_HdlsIpuI2Q (accessed on 26 April 2022)

The local extension service activity aims to transfer the research results and innovations to local farmers, farm associations, and advisory and extension services in the participant countries, by means of field days, demonstration activity on-field experiments, and a participatory research farm network. This task is linked to the activities of WP3, intended to facilitate the sharing of the experiences developed throughout CAMA and the spread of them to a wider number of farmers and advisors to catalyze the adoption of the CA approach and techniques.

Dissemination and transfer materials will be created upon the results of the scientific and participatory activities of CAMA. A series of fact sheets, practice abstracts, short guidelines, and videos on field experiences will be created and disseminated. These materials will be translated into relevant languages (Arabic, Greek, English, French Italian, and Spanish). A collection of videos presenting the project workpackages has been started. The WP3 team has created special tutorial videos on the Diagchamp method to be used in the field experiments. These videos are available in the project YouTube channel (https://www.youtube.com/channel/UC3twVsFUmyuR_HdlsIpuI2Q, accessed on 26 April 2022).

With the aim to enhance the capacities and to transfer knowledge from the research activities to agronomists and researchers committed to consultancy and extension services in the Mediterranean countries, CAMA organized an international advanced course on "Recent trends in conservation agriculture in Mediterranean environments" from 14 to 19 February 2022 (https://edu.iamz.ciheam.org/ConservationAgriculture/en/) (accessed on 26 April 2022).

9. Conclusions

In Mediterranean rainfed cropping systems, the agronomic management practices are finalized to use rainfall more efficiently. Most soils have low soil organic content, due to low water availability, high temperature, and tillage intensity. CA could reduce the risk of soil quality degradation and improve nutrient and WU efficiencies while providing a more stable yield, supporting smallholder agriculture.

Overall, the CAMA project aims to understand and overcome the barriers that prevent the adoption of CA in the Mediterranean basin.

Among the most relevant scientific challenges faced by CAMA are

- Identification and adoption of new techniques within the CA system to improve soil water and nutrient conservation and reduce runoff, which will be obtained by participatory research on CA application;
- Selecting and testing of new legume varieties, more oriented to drought stress, with special interest in crop–livestock cropping systems;
- Optimization of natural resources, with attention to N and WUE, hydrological properties, soil water holding capacity, soil fertility, and soil erosion control that will be obtained by the adequate use of the CA soil management practices in combination with effective crop diversification and other cropping practices in a range of Mediterranean scenarios.

The presence of farmers' associations, research institutes, and a post-graduate education international center as partners will guarantee a strong interaction among final users.

The main outcomes derived from the first activities carried out in the project and from the training course can be summarized as follows:

- A large body of scientific research and direct experiences of farmers with conservation agriculture over the years in the Mediterranean area demonstrate the positive effects of this farming system on yields, soil health, water conservation, biodiversity, and economic performance of farms. These benefits are observed in very different ways depending on the agroecology of each location, and the transition processes between conventional and conservation agriculture can be long and adapted to the conditions.

- It is important to respect as much as possible the three main pillars of conservation agriculture to achieve good results. However, the practice of agriculture requires adaptation and flexibility of cultivation operations according to the agronomic state of each field, and the farmer must be able to opt—in some cases and especially at the beginning of the transition process—for different alternatives that may include, for example, vertical tillage for decompaction.
- Crop rotation is essential to control weeds, pests, and diseases, as well as to maintain a good level of soil fertility. It is necessary to search for profitable crops adapted to local conditions, as well as to improve varieties and ecotypes of alternative crops to cereal monoculture, especially legumes; seed availability is a limiting factor in many cases. Cover crops, well known in woody crops, can be difficult to establish in Mediterranean arable crops, although there are alternatives, especially in wetter drylands or when there are long periods between crops (e.g., in spring sowings).
- In weed control, an important question is whether there is a chemical or physical alternative to glyphosate because of all kinds of uncertainties about this herbicide, and because of its poor public image. Research and testing of mechanical weeding tools and herbicides that can be used as an alternative to glyphosate is ongoing.
- In some areas, particularly in southern and eastern Mediterranean countries, there is a conflict between livestock and conservation agriculture over the use of crop residues and the reported problems of trampling and soil compaction. The choice and establishment of fodder crops can mitigate this conflict, allowing livestock to be fed without relying so much on stubble and other residues of low nutritional value.
- There are some technical and economic barriers, but above all, social and cultural ones that must be overcome to promote conservation agriculture in Mediterranean countries, especially among small producers. Applied research, advice and support, learning, and training are essential, along with participatory and collective approaches, which are more successful, as has been seen in many areas. Regarding the specific machinery for direct seeding, it is important to have cheap seed drills adapted to small farmers, but also to promote systems of collective ownership or provision of direct seeding services that do not require heavy investments by each producer.
- Public support in the form of financial subsidies can play an important role, although many farmers are already practicing conservation agriculture without any need for it, simply by conviction, observation, practice, and learning. In some countries, such as Spain and Morocco, support from agricultural policies will have great potential in the short term to expand conservation agriculture.

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