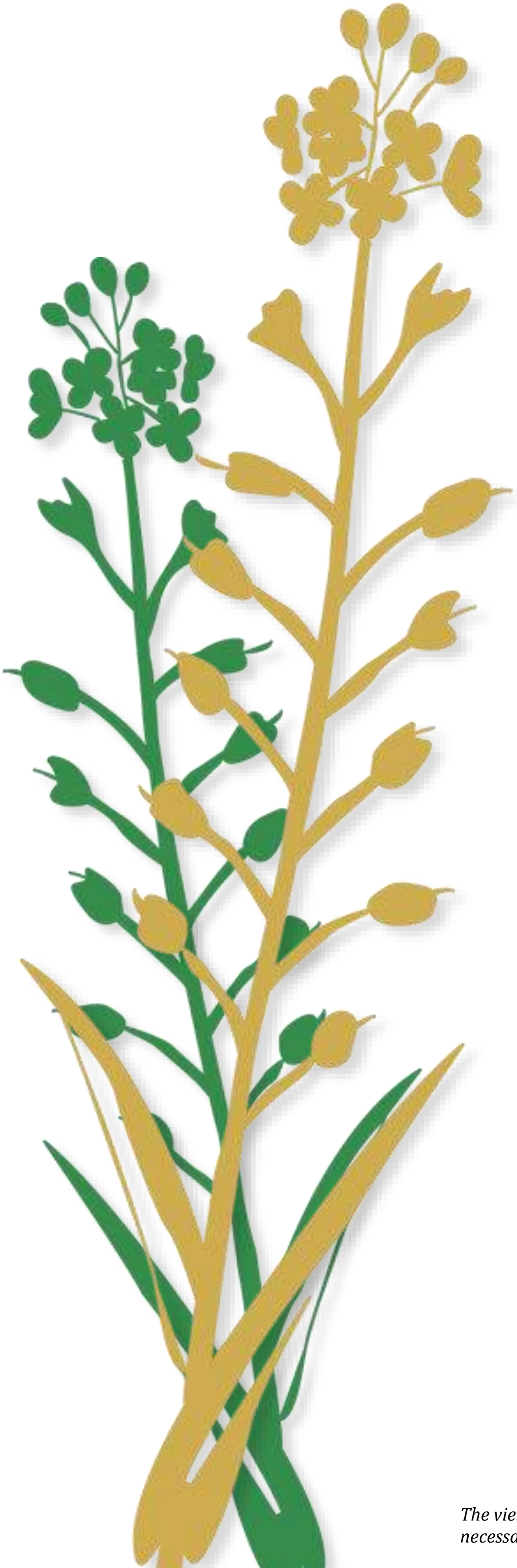
Camelina:
a Cash Cover Crop Enhancing
water and soil conservation
in MEDiterranean
dry-farming systems



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Abstract

Mediterranean dry-farming systems mostly rely on cereal production, often on sole crops, due to a lack of alternatives. These farming systems are intensive in terms of agronomic inputs, thus highly impacting on the environment, and more vulnerable to the pitfalls of climate change. Conservation agriculture (CA) which relies on the three core principles of i) minimum mechanical soil disturbance, ii) maintenance of permanent or semi-permanent soil cover and iii) crop diversification, offers the opportunity to reduce soil erosion and nitrogen leaching, increasing water availability, soil organic matter and biodiversity. CA is still poorly widespread across the Mediterranean due to a lack of knowledge of the benefits associated with its application. In this context, 4CE-MED project has developed innovative solutions to preserve water and soil conservation in Mediterranean dry-farming systems, by including camelina, a promising oilseed crop for Europe and the Mediterranean region, a cash-cover crop, in the cereal-based cropping System. Training of local stakeholders, including farmers, extension workers, , agronomists, and students is one of the key activities under this project, with the aim to transfer practical knowledge on the possible adoption of the 4CE-MED solutions identified in Work Packages 1 to 3. In this context, this easy-to-use training material was developed containing the key information of the new 4CE-MED solutions for distribution to students, farmers, agronomists and other stakeholders. This training material contains information on the following:

- Soil health and land degradation;
- Conservation agriculture;
- Conservation agriculture with camelina as a Cash Cover Crop, including practical sessions.

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1 Objectives of this manual

4CE-MED project has capitalized on a highly experienced and competent team of partners located in the 7 PRIMA countries (Italy, France, Greece, Spain, Algeria, Morocco and Tunisia) and developed innovative solutions to preserve water and soil conservation in Mediterranean dry-farming systems. 4CE-MED solutions are built on previous and on-going similar projects to take advantage from achieved results and to increase their impacts beyond completion. Training and capacity building are the integral part of the project. Training of local stakeholders, including farmers, extension workers, agronomists and students is one of the key activities, with an aim to transfer practical knowledge on the possible adoption of the 4CE-MED solutions identified in work packages 1-3. In this context, this easy-to-use training material was developed, containing the key-information of the new 4CE-MED solutions for distribution to students, farmers, agronomists and other stakeholders.

2 Soil health and land degradation

Sustainable farm productivity depends on soils. Healthy soils are important to ensure the sustainability of crop production. In most cases, however, intensive farming systems such as ploughing, frequent tillage and monocultures can degrade the soils. This requires farming methods that satisfy the needs and desires of farmers and farming communities, but also preserve natural resources, especially soil, water and organic matter[1].
To better understand the importance and benefits of sustainable agriculture, it is important to understand soil health and related concepts[1].
Soil health is defined as the capacity of soil to act as a living system, enough to support the life of plants and animals. A soil is considered healthy if it can store or hold enough water and nutrients for plants to grow. It is deep enough for the roots of the plant to enter deeper into the soil[1].

2.1 Properties of a healthy soil

A healthy soil is characterized by three main properties: physical, chemical, and biological[1-6].

Physical

The physical properties of soil refer to the structure and texture of the soil and how air and water moves in and out of it. Physical properties of soil include color, texture, structure, porosity, density, consistence, aggregate stability, air, and temperature.

Chemical

The chemical properties of soil refer to the nutrients in it and its ability to provide nutrients to plants as influenced by its acidity and alkalinity.

Biological

The biological properties of soil refer to the living organisms in it, such as earthworms, microorganisms, and insects. These organisms support plant growth through recycling nutrients, forming channels that enable water and air to move, and preventing pests and diseases in plants, among others.

Optimal physical and chemical soil properties lead to optimal soil biological properties and ideal soil health and productivity.

Fig. 1. The three main soil properties: physical, chemical, and biological

2.2 Indicators of soil health

As mentioned earlier, a soil is healthy if it can hold water and nutrients and make them available to the crops. The most common indicators of soil health are:

Soil organic matter. Soil organic matter content is key for a healthy and high-quality soil[2]. Soil organic matter is considered the most apparent measure of soil quality. Soil organic matter is the organic component of soil. It consists of organic material from plants and animals, and material that has been converted by microorganisms in the soil at different stages of decomposition. Soil organic matter is a primary source of carbon (C) which gives energy and nutrients to soil organisms. Soil organic matter supports soil functionality because it improves the activity of microorganisms in the soil and it can enhance biodiversity. Healthy soils with stable levels of organic matter are also better equipped to prevent and fight soil-borne diseases. Soil organic matter supports organisms, improves soil structural stability and provides plants with nutrients. Soil organic matter has direct benefits for agricultural and forestry production. Therefore, the more organic matter in the soil, the more fertile it is. Generally, soils with higher levels of organic matter have improved soil structure and faster infiltration rates of rain water, resulting in a greater resistance to erosion.

Water-holding capacity. Water holding capacity is the amount of water a soil can hold for crops to use. Water is the most common limiting factor for many crops[3]. Many factors affect the soil's ability to hold water, such as its texture, structure and depth[4]. Soil texture refers to the proportion of mineral particles (such as sand, silt and clay) in its composition. A certain texture of soils physically hold water against the force of gravity. It does this by soil particles holding water molecules by the force of cohesion. This affects not only the water holding capacity of the soil, but also its ability to retain and exchange nutrients. Soil structure is the distribution of these mineral particles into lumps. Soils with high silt and clay content are more productive and have better water and nutrient retention. Sandy soil has larger sand particles and pore space so water can easily pass through. This results in low water holding capacity and limited protection of soil organic matter.

In addition, the deeper the soil, the better its water retention capacity[4]. Organic matter should be added to the shallow soil to increase water retention and nutrient supply. Soil cover by mulches and cover crops also influences soil water holding capacity and water infiltration capacity, thereby soil health.

- ***Soil pH****.* Soil pH is a measure of the acidity or alkalinity of the soil. Having the correct pH is important for healthy plant growth[5]. The relative acidity or alkalinity of soil is indicated by its pH. The pH scale runs from 0 to 14. Any pH reading below 7 is acidic and any pH above 7 is alkaline. A pH of 7 indicates neutral soil. The pH is important because it influences the availability of essential nutrients[5] by determining soil solubility, which measures how nutrients easily dissolve and become available to plants. Also, the pH of the soil affects the activity of living organisms in the soil. High acidity lowers the activity of bacteria, which slows down decomposition and the release of nutrients in the soil. High alkalinity levels also reduce biological activity, leading to soil crusting and the accumulation of toxic sodium and other minerals. Most soils are either acidic or alkaline, while most plants require a relatively neutral pH. However, some crops have more specific pH requirements
- ***Soil organisms.*** Since soil provides important ecosystem services to various communities of organisms, the presence or absence of organisms, including microorganisms, can also be used as biological indicators of soil health[6]. In addition to the presence of organisms, the abundance, biomass, spatial distribution, morphology, activity and behavior of organisms can be used as important biological characteristics of soil health. Soil fauna can be broadly and generally classified into three different groups according to their functions and ecological services. They are 1) ecosystem engineers 2) biological regulators and 3) chemical engineers[6]. Ecosystem engineers such as earthworms, ants and beetles improve soil structure by digging furrows and creating nests through which air and water can be transported. Ecosystem engineers also mix the soil profile and absorb and release organic and mineral matter, contributing to nutrient and organic matter cycling and distribution. It creates valuable habitats for other organisms and microbial communities, for further transformation and contributes to nutrient cycles and soil fertility. The presence of organisms increases the water- and nutrient-retention qualities of the soil. Biological regulators such as protists, nematodes, springtails, mites, isopods, and millipedes control the work of the chemical engineers. They fragment and displace organic material, exposing it to microbes and creating more surface area, thus boosting the release of nutrients by the chemical engineers. Chemical engineers such as bacteria, fungi, and algae that can decompose organic matter and are able to break down and transform complex compounds containing carbon and nitrogen into carbon dioxide and the nutrients that plants need.

2.3 Land degradation

Land degradation is defined as the deterioration or loss of the productive capacity of the soils for present and future, owing to natural or human causes[7]. It is a global challenge that affects everyone through food insecurity, higher food prices, climate change, environmental hazards, and the loss of biodiversity and ecosystem services[7]. Land degradation includes, soil erosion by water and wind, deterioration in soil physical, chemical and biological properties, waterlogging, and the build-up of toxicities, particularly salts, in the soil[8].

2.3.1 Soil erosion

Soil erosion is a naturally occurring process that affects all landforms. In agriculture, soil erosion refers to the removal of a field's topsoil by the natural physical forces of water and wind or through forces associated with farming activities (such as tillage), overgrazing, deforestation, industrial activities, etc[9]. Climate change further aggravates soil erosion, in relation to the higher occurrence of erosive rainfalls, which are often alternated with prolonged drought period.

Fig. 2. Soil erosion due to water (a), wind (b), and tillage and cultivation practices using animals (c) and tractor (d). (Photos credit: Courtesy of ICARDA)

Tillage and cultivation practices that reduce soil organic matter content can cause poor soil structure or soil compaction and an increase in soil erosion[9]. For example, compacted subsurface soil layers can reduce infiltration and increase runoff of water or nutrients. The formation of a soil crust, which tends to "seal" the surface, also reduces infiltration. In some areas, a soil crust can reduce soil loss due to the impact of splashing of raindrops. However, the corresponding increase in runoffs can contribute to more serious erosion problems[9].The steeper and longer the slope of a field, the greater the risk of erosion. Soil erosion caused by water increases with increasing slope length due to the greater accumulation of runoff[9]. The possibility of soil erosion increases when there is no or very little vegetative cover of plants and/or crop residues[9].

Soil erosion has negative effects on the farm where the eroded soil came from (on-site) [10] and where it goes (off-site)[10]. On-site effects of soil erosion include loss of nutrients in the upper layer of the soil, resulting in lower quality and reduced water-holding capacity.

Off-site impacts of soil erosion include silting of dams, contamination of water sources, movement of agricultural pollutants into water resources,flooding, and siltation of bodies of water like creeks, streams, rivers, and oceans.

2.3.2 Decline in soil fertility

In addition to soil erosion, soil compaction, monocropping, complete removal of crop residues, continuous cropping systems, inadequate fertilizer use, nutrient imbalance, pollution, acidification, water logging, loss of soil biodiversity and increasing salinity have been affecting soil across the globe, reducing its ability to support plant life and so grow crops[11, 12]. These factors contribute to various forms of physical, chemical and biological degradationof soils[10]:

- A decrease in soil organic matter, which leads to lower biological activity and a deterioration in soil structure and water retention.
- Changes in soil nutrients due to depletion and/or imbalance of key nutrients.
- Accumulation of toxic compounds, usually due to improper use of chemical fertilizers and pesticides.

3 Conservation agriculture

3.1 Cereal-based farming in Mediterranean region

Currently, in the Mediterranean region, the cropping systems are dominated by cereal-based cropping systems under intensive tillage[12-16]. In many countries in the Mediterranean area, especially in eastern and the southern regions, cereal monocropping (wheat, barley and in some cases maize)[16] and intensive tillage have marked negative impacts on soil[17], and increased pressure from diseases, weeds and pests resulting in decreased profit margins from agriculture[18]. These current agricultural models in many of these countries based on mechanical soil tillage, uncovered soils, and/or continued monocropping, speed up loss of agriculture productivity, soil and biodiversity. As a result, large share of the potentially available land in the region is either degraded or in a process of degradation[19].

The Mediterranean agricultural sector is also heavily dependent on water using an astounding 75% ground water resources (IUCN 2022)[20]. The combination of climate change, soil loss and unsustainable use of water for irrigation can lead to increased water shortages and droughts. This kind of unsustainable exploitation of soil and water is very concerning and is having severe consequences on the region's biodiversity[20]. Unsustainable use of fertilizers and pesticides also leads to soil degradation and contributes to pollution and biodiversity loss[20].

Therefore, crop production in the region should focus increasingly on raising production per unit area of farmed land, through improving soil health, soil cover, improving soil organic matter, sustainable use of natural resources and fertilizers, and decreasing use of irrigation water and energy.

3.2 Conservation agriculture

Conservation agriculture, as defined by the United Nations' Food and Agriculture Organization (FAO), is "a farming system that promotes maintenance of a permanent soil cover, minimum soil disturbance, and diversification of plant species. It enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production"[21]. The IPCC special report "Climate Change and Land" (2019) includes conservation agriculture among the incremental adaptation options to address climate risks[21].
Conservation agriculture is an increasingly common approach to sustainable agriculture. It is a combination of farming methods aimed at optimizing yields and profits while also preventing land degradation. It aims to minimize the decline of a soil's structure, composition, and natural biodiversity[10].

3.3 Core principles

Conservation agriculture (CA) treats the soil as a living body, vital for agriculture and sustaining life. It underscores the importance of protecting the topsoil (upper 0–20 cm of soil),which is the layer with the most activity and also the most prone to erosion. The following three core principles of conservation agriculture help to protect the environment and to reduce both the impacts of climate change on agricultural systems (adaptation) and the contribution of the agricultural practices to greenhouse gases (GHG) emissions (mitigation) through sustainable land management[21].

3.3.1 Minimum mechanical soil disturbance

The core of this principle, is the use of the direct seeding technique that consists in growing crops without mechanical seedbed preparation and with minimal soil disturbance since the harvest of the previous crop[22]. The term direct seeding is understood in CA systems as synonymous of no-till farming, zero tillage, no-tillage, direct drilling, etc[23]. Planting refers to the precise placing of large seeds (maize and beans for example); whereas seeding usually refers to a continuous flow of seeds as in the case of small cereals (wheat and barley for example). The equipment penetrates the soil cover, opens a seeding slot, and places the seed into that slot. The size of the seed slot and the associated movement of soil are to be kept at the absolute minimum possible. Ideally, the seed slot is completely covered by mulch again after seeding and no loose soil should be visible on the surface[23]. A direct planter could be either hand-operated or by a tractor or an animal.

Fig 3. A pictorial representation of core principle 1: Minimum mechanical soil disturbance[23] (Courtesy FAO of UN)

Land preparation for seeding or planting under no-tillage involves slashing or rolling the weeds, previous crop residues, or cover crops; spraying herbicides for weed control, and seeding directly through the mulch[23]. Crop residues are retained either completely or to a suitable amount to guarantee the complete soil cover and fertilizer and amendments are either broadcast on the soil surface or applied during seeding[23].

3.3.2 Maintenance of permanent or semi-permanent soil cover

Soil should be covered by crop residues and/or cover crops (e.g. pulses, cereals, oilseed crops such as camelina or other plants planted between main crops mainly for the benefit of soil, but in some cases even with the possibility of harvest and profit) that allow adaptation to climate change by reducing soil erosion and degradation, which can be exacerbated by the impact of extreme weather conditions (e.g. extreme precipitations, droughts and periods of soil saturation, extreme heat, strong wind events) and improving the stability of the conservation agriculture system[21]. In addition, cover crops improve soil properties (fertility and quality), help to manage soil erosion, conserve soil moisture, prevent soil compaction, control some pests and diseases, and increase agroecosystem biodiversity[21].

Fig. 4. A pictorial representation of core principle 2: Maintenance of permanent or semi-permanent soil cover[23] (Courtesy FAO of UN)

3.3.3 Crop diversification

The crop diversification consists in the cultivation of more than one species of crops in a given agricultural area in the form of crop rotation and/or combination (mixtures). Diversification of cultivated species increases the adaptability of agricultural systems to climate change by improving soil fertility and structure, soil water holding capacity, and the distribution of water and nutrients throughout the soil profile, helping to prevent pests and diseases and increasing crop yield stability. Diversified cropping systems are indeed more stable and sustainable than monoculture systems. Crop diversification provides a range of ecosystem services, helps improve crop productivity and the sustainability of agricultural systems, and reduces greenhouse gas emissions from agriculture[21]. The inclusion of legumes, energy crops like camelina, deep-rooted crops, and crops with high residues in the crop diversification, maximizes benefits to the soil[10,23]. Cropping different species also helps clean weeds and fight diseases. Cultivating continuously the same species reduces crop yield and favours the persistence of the pests and diseases that affect it.

Fig. 5. A pictorial representation of core principle 3: Crop diversification[23] (Courtesy FAO of UN)

3.3.4 Key features

These three core principles of conservation agriculture can be summarized in the following do's and don'ts[10].

Do's

- Keep crops and crop residues on the soil surface.
- Apply fertilizer on the surface, as necessary, without incorporation.
- Direct seeding or planting.
- Grow multiple crops in a season.
- Use specialized equipment for seeding and mulch management.

Don'ts

- Burning crop residue or spontaneous vegetation
- Fertilizer application without rain and incorporation could increase volatilisation
- Ploughing or disking
- While direct seeding or planting ensure good seed-soil contact
- Monocropping
- Uncontrolled grazing

4 Conservation agriculture with camelina

4.1 Camelina is an ancient oil seed crop

Camelina *(Camelina sativa L.* Crantz*)* is an ancient oilseed crop that has been grown in Europe[24-28] as early as 4 000 BC[24]. Camelina was mostly forgotten as a crop and replaced by other oilseed crops such as canola, but was recently re-discovered for its unique characteristics[24]. The crop's possible centre of origin is located in Europe between Ukraine and Russia, since the genetic diversity hotspot was identified in this region[29]. Camelina has been developed as a crop due to its high oil content (30-40%) and protein content (27% to 32%), its unique oil properties[27]. The oil from camelina is suitable for a variety of feed and food uses and for biodiesel production[27]. The oil is composed by 30% monosaturated fatty acids and 64% polyunsaturated fatty acids[24,27]. Omega -3 fatty acids comprise 39% (alpha linolenic acid 38%) of the oil[24]. The α-linolenic acid (C18:3, ALA) accounts around 28-50% while linoleic acid (C18:2, LA) can reach up to the 23% of the total fatty acid profile. Camelina oil, differently from flaxseed oil, has a much longer shelf life and can be stored without special conditions, due to high levels of gamma-tocopherol (Vitamin E)[27]. The oil content of camelina varies with cultivar and seasonal growing conditions[24,27].

4.2 Botany of camelina

Camelina sativa (L.) Crantz, also called gold-of-pleasure, false flax, or linseed dodder, is an oilseed crop belonging to the tribe *Camelineae* of the mustard family (*Brassicaceae*) [25,27,28]. Plants are erect and typically reach heights between 30 and 110 cm. Rosette leaves are not lobed and are withered by the time of flowering. The stems are branched, woody when mature, and can be sparsely hairy[28]. The leaves alternate on the stem and are lanceolate with a length of 2–8 cm and a width of 2–10 mm[28]. Inflorescences are racemes with small flowers in terminal clusters, primarily self-pollinating[28]. The flowers are pale yellow with four spatulate petals. The siliques are 7 to 9 mm long, leathery, smooth, and contain golden brown seeds. Seeds are small, generally 2 to 3 mm long, light brown in colour, rough, and have a rippled surface[25,27,28].

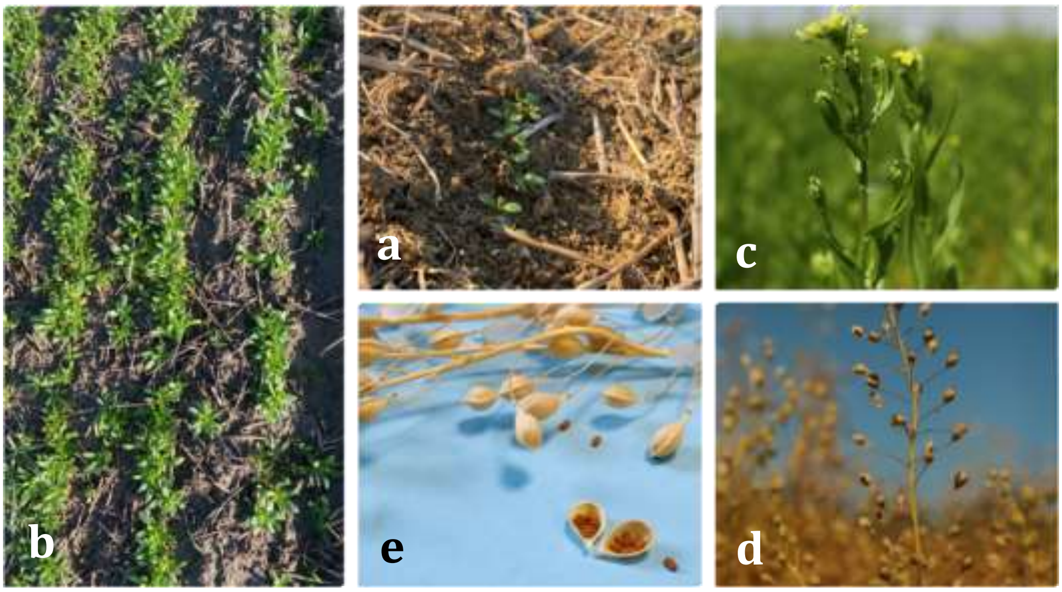

Fig. 6. Main developmental stages of Camelina sativa under conservation agriculture practices: a) emergence, b) rosette, c) full flowering d) full maturity and e) camelina seeds (Photos credit: Courtesy of University of Bologna)

4.3 Importance of camelina in EU and Mediterranean agriculture

Promoting crop diversification in European and Mediterranean agriculture is a key pillar of the agroecological transition. Diversifying crops generally enhances crop productivity, quality, soil health and fertility, and resilience to pests and diseases and reduces environmental stresses[25]. Moreover, crop diversification provides an alternative means of enhancing farmers' income[25]. Camelina re-emerged in the background of European agriculture approximately three decades ago, when the first studies on this ancient native oilseed species were published. Since then, a considerable number of studies on this species have been carried out in Europe. The main interest in camelina cultivation is related to its (1) broad environmental adaptability, (2) low-input requirements, (3) resistance to multiple pests and diseases, and (4) multiple uses in food, feed, and biobased applications[25]. Further studies showed that camelina has high adaptability to conservation agriculture (CA) practices[26], yielded seeds of 1.9 t /ha with a very low fertilisation rate[26]. It has the potential to increase the cropping intensity in certain dryland cropping systems.

In this context, the 4CE-MED project has developed innovative, diversified, and resilient cropping systems, through a participatory approach, consistent with the principles of CA. These cropping systems include Camelina, an emerging oilseed cash cover crop enabling enhanced soil and water conservation. Camelina is particularly interesting due to its environmental sustainability and the quality of its oil rich in omega-3, as indicated earlier. Camelina is currently grown on a commercial scale in the USA and Canada where it is commonly grown as a no-till cover crop replacing fallow between two summer crops, whereas in Europe and the Mediterranean region, it is still virtually absent. The 4CE-MED project has investigated the opportunity to develop camelina as a cash cover crop or double crop in the Mediterranean area, in cereal-based cropping systems.

4.4 Agronomy of camelina

Camelina is a short-season crop that takes approximately 85 to 100 days to mature when sown in spring, and about 150-80 days when sown in autumn, and has low irrigation demands It has typically been grown in in rotation with other short-season crops, such as wheat, barley, peas and lentils[27]. Camelina can be a good fit for intensifying the barley or wheat-fallow rotation in some regions as it has a short growing season, is drought and cold tolerant, and is resistant to most pests that affect other *Brassica* oilseed species[27].

4.4.1 Cropping Strategies

Three cropping strategies have been identified as the most suitable for growing camelina in Europe and Mediterranean region as reviewed by Zanetti et al. (2021)[25]:

A) as the main crop in marginal soils where there is no possibility to grow alternative staple species, apart from winter cereals, as the sole crop;

This type of cultivation strategy is being adopted with both spring and winter camelina cultivars. In milder environments of the Mediterranean basin such as Spain, Italy, Greece, Morocco, Algeria and Tunisia, spring camelina adapts well to be grown with an autumn cycle in marginal soils.

B) as a cover crop, with both winter and summer cycles, between two main crops in double cropping systems (= form of sequential cropping in which two crops are grown in sequence within a year on a piece of land, one after the harvest of the other, FAO definition);

In recent studies conducted together with farmers, adopting a participatory approach, camelina was identified as a possible summer cover crop in double cropping systems in northern France. This type of approach tremendously widens the opportunities of camelina to pass from the status of niche crop to cash cover crop in Europe[25]. Cash cover crops have been defined by Gesch et al. (2014) as cover crops able to reach seed maturity before the establishment of the main crop, thus providing an additional income to farmers. In the milder environments of northern Italy and central Greece, Zanetti et al. (2019) demonstrated the feasibility of growing camelina as a winter cover crop before maize[25]. Reported results confirmed the suitability of camelina to fit as a preceding crop before typical summer cereals, but other alternative succeeding crops such as sunflower or soybean can also be sown after camelina. The choice of the crop to match camelina should be carried out locally to fulfil farmers' expectations and needs. One of the main advantages of camelina toward other competing crops, also belonging to the Brassicaceae family (i.e., *Crambe abyssinica, B. napus*), is the shorter cycle, allowing the sowing of a second crop and likely aiding in reducing nematodes[25].

C) as mixed cropping systems (= growing two or more crops simultaneously in the same field, FAO definition) or relay cropping (= form of intercropping growing two or more crops in a sequence usually planting the succeeding crop after the flowering, but before the harvesting of the preceding crop, FAO definition) in combination with legumes or grasses.

Several studies demonstrated that camelina can be successfully grown when mixed with peas, lentils, and lupins without consistent seed yield losses in both species and without the need for any chemical weed control. Unfortunately, the majority of the abovementioned studies are part of spring-sown camelina. Hence more studies on these issues are needed considering camelina as a winter crop. Mixed cropping is highly valuable for organic farming systems where experiences with camelina grown together with soybean and lentil are reported in France[25].

Included in any of the three abovementioned systems, camelina will promote biodiversity, decrease soil erosion, improve water infiltration, and foster the sustainable intensification of cropping systems. Furthermore, option C) can be particularly valuable in organic farming to help overcome weed pressure[25].

4.4.2 Camelina crop management

Key points for crop management of camelina for the EU and Mediterranean region are presented below (Source: Camelina Company, Spain):

4.4.2.1 Autumn sowing

Sowing date: October to December

Nutrients in soil: Guarantee minimum nitrogen availability (60 units/ha)

Herbicides: Check residual herbicides (mainly ALS & PDS)

Field selection: Avoid fields with poor drainage or a tendency to flood. Fields prone to forming a superficial crust, with a pH lower than 5.5 or a pH higher than 8.5; and residual herbicides: ALS (Chlorsulfuron and Metsulfuron-methyl) and PDS (Diflufenican).

Land preparation: If there are heavy cereal straws in the field, partial removal of straw is recommended. By doing so, better seed-to-soil contact could be established for better germination, establishment, and nutrient utilization. Pass the roller before sowing to facilitate a shallow sowing & better seed-soil contact. Rolling after sowing is only recommended if there has been a crust problem. Perform sowing with no tilling. Otherwise, perform a shallow land preparation (minimal tillage) to avoid reducing soil moisture.

Weed management: It is highly recommended to destroy weeds before planting using herbicides or through minimal tillage.

Sowing depth: Shallow sowing, less than 1 cm, on plots without weeds. In the case of CA, the seed should touch the soil beneath the straw, so that seeds can germinate and establish itself. Superficially: <1 cm. Ensure good seed-soil contact.

Seed rates: The seed rate for drilling with separation between rows of 12.5 -15 cm, is 8 kg/ha. In Italy, Morocco and some other countries, for broadcasting, 10kg/ha. For planting, locally available cereal planters (Fig.7) were used with minor modifications in settings, for small grains. In Morocco, camelina seeds were mixed with barley semolina with 1:1 proportion by weight in order to increase the quantity to use in locally available seeds (Fig. 6). In some location in Morocco, seeds were broadcasted manually and obtained good stand of the crop.

Fig. 7. Mixing camelina seeds with barley semolina, 1:1 proportion by weight to increase the volume suitable for use with local cereal drill for planting. (Photos credit: Courtesy of ICARDA)

Fig. 8. Camelina planting in Oued Ghilane village in Morocco using locally available cereal planting drill. (Photos credit: Courtesy of ICARDA)

Fig. 9. Camelina crop at an on-farm trial in Souk El Arbaa in Morocco. (Photos credit: Courtesy of ICARDA)

Fig. 10. Camelina was manually harvested and transported to threshing yard (in Souk El Arbaa, Morocco). (Photos credit: Courtesy of ICARDA)

Fig. 11. In the North Africa region, usually, threshing done in threshing yard by passing tractor on harvested camelina plants (upper photo). The seeds were separated by winnowing using local methods (lower photo). (Photos credit: Courtesy of ICARDA)

Fertilization:

Minimum fertilization requirements:
N: 60-80 FU/ha
P: 30-40 FU/ha

K: 40-50 FU/ha
S: 12-24 FU/ha

Basal dose/Background fertilization: apply P & K and 30 % N & S of recommended units. Top-dressing fertilization at rosette status, applying 70 % N & S of recommended units. Local regulations for the application of fertilization can be followed, depending on the period

Weeds: In case of proper crop establishment, camelina competes well with weeds, showing an allelopathic effect. In case of grassy weeds infestation, ACCase inhibitors are recommended, especially quizalofop and cletodim.

Insect pests: No major pests have been detected so far. Although there can be the presence of flea beetles and *Meligethes Aeneus*, it generally does not impact production.

Diseases: Camelina is generally resistant to *Alternaria*, black spots, and blackleg of crucifers. However, it can be susceptible to clubroot and white rust. Downy mildew can appear, with limited damage, generally.

Fig. 12. Camelina ready for harvest at Camelina Company, Madrid, Spain

Maturity: When the siliques have turned from lemon yellow to brown. Do not delay harvest more than 7-10 days to avoid losses (Fig. 12).

Combiner settings: Adjust to small seed harvest, in the EU, whereas in Morocco and other developing countries manual harvesting threshing was followed.

Moisture status of seeds: Optimal is 8-9% and should not exceed 13-15%.

Husk content: Typical at harvest is about 10-20%

Achievable yield: 1,000 – 2,000 kg/ha.

Post-harvest operations: Maximum moisture for storage is 8-9%. Cleaning is recommended when humidity is 8-10%. Drying is recommended when moisture is more than 10%.

Common errors:
-Sowing in fields with residual herbicides.
-Sowing out of the recommended date, especially too late.
-Sowing in plots with low fertility (insufficient nitrogen).

-Sowing too deep & in soils too wet.
-Sowing in plots with weed infestation.
-Late harvest, with consequent possible seed losses.

4.4.2.2 Spring sowing

It's more a late spring and beginning of summer depending on the area. Spring sowing could be from February to June (after energy cover crop or forage crop).

Previous crops:
-Pulses and cereals are most recommended as preceding crop.
-Pea is the best suited, especially with early harvest and little regrowth.
-Winter cereal is also possible, requiring a good camelina establishment to avoid regrowth issues
-In the case of pulses as the previous crop, the straw collection is not necessary, and also, residual herbicides are typically not a problem. However, in France, problems encountered with residual herbicides applied in spring to winter peas
-In the case of cereals as a previous crop, straw collection is strongly recommended. Cautious about residual herbicides, such as ALS & PDS, and depletion of soil nitrogen.

Field selection: Avoid fields with poor drainage or a tendency to flood. Fields prone to forming the superficial crust, with a pH lower than 5.5 or a pH higher than 8.5; and residual herbicides: ALS (Chlorsulfuron and Metsulfuron-methyl) and PDS (Diflufenican).
Irrigation: In case irrigation is available, provide 20 mm of irrigation immediately after sowing ensures good emergence.

Land preparation: If there are heavy cereal straw in the field, partly removal of straw is recommended. By doing so, better seed-to-soil contact could be established for better germination, establishment and nutrient utilization. Pass the roller before sowing to facilitate a shallow sowing & a better seed-soil contact. Rolling after sowing is only recommended if there has been a crust problem. Perform sowing with no-tilling. Otherwise, perform a shallow land preparation (minimal tilling) to avoid reducing soil moisture.

Weed management: It is highly recommended to destroy weeds before planting using herbicides or through minimal tillage.

Sowing depth: Shallow sowing, less than 1 cm, on plots without weeds. In case of CA, the seed should touch the soil beneath the straw, so that seeds can germinate and establish itself. Superficially: <1 cm. Ensure a good seed-soil contact.

Seed rates: Seed rate for drilling with separation between rows of 12.5 -15 cm, is 8 kg/ha. For broadcasting, 10kg/ha

Fertilization: Sowing after pulses is recommended, as no fertilizer is required (e.g. as in Spain) or reduced to 20U of nitrogen (e.g. as in France). If sowing after cereals, a nitrogen addition of 40-50 units is required.

Weed management: In case of proper crop establishment, it is not recommended to apply herbicides, as camelina will compete well with weeds. In case of grassy weeds infestation, ACCase inhibitors (quizalafop & cletodim) are recommended.

Insect pests: No major pests have been detected so far. Although there can be the presence of flea beetles and *Meligethes aeneus*, it generally does not impact production.

Diseases: Camelina is generally resistant to Alternaria, black spots, and blackleg of crucifers. However, it can be susceptible to clubroot and white rust. Downy mildew can appear, but damage is generally not significant.

Harvest: The crop is matured when the siliques have turned from lemon yellow to brown, the crop is matured. Do not delay harvest more than 7-10 days to avoid losses (Fig. 13).

Fig. 13. Camelina ready for swathing (left) and ready for harvest (right) at Camelina Company, Madrid, Spain.

Swathing: Swathing should be done when 75% of siliques are turning yellow or about 2-3 weeks after losing the last flower. Harvest should be done approximately 1 week later.

Combiner setting: Adjust to small seed harvest.
Moisture levels: Optimal level is 8-9%. However, moisture should not exceed 13-15%.
Husk content: Typically husk content is of 10-20% after harvest.
Expected yield: 1,000 – 2,000 kg/ha.
Post-harvest: Maximum moisture for storage is 8-9%. Cleaning is recommended when humidity is 8-10%. Drying is recommended when moisture is more than 10%.
Common errors: Sowing in plots with residual herbicides; Sowing out of the recommended date, especially too late; Sowing in plots with low fertility (insufficient nitrogen); Sowing too deep; Sowing in plots with weed infestation and Late harvest.

5 Practical sessions: Some guidelines

Topic to be discussed: cultivation of camelina under conservation agriculture

Target stakeholders: The training course is expected to target farmers, farm workers, extensionists, agronomists, students, small-scale enterprises, members of farmers and farm women cooperatives, NGOs, private sectors, policy makers in agriculture departments and other levels, researchers and technicians.

Overall objectives: To disseminate, popularize and train on practices of conservation agriculture in general and with camelina in specific as a Cash Cover Crop for enhancing water and soil conservation in Mediterranean dry-farming systems

Specific objectives:
Specifically, the training aims to:

- enhance their understanding and knowledge of conservation agriculture practices
- enable them to identify the practices suitable to their conditions, capacities, and regions;
- enhance adaptation of the practices in farmers' fields (both small and large farmers) with active cooperation of other major stakeholders.
- to get feedback from the stakeholders including farmers and redesign the practices accordingly to enhance adaptation of the practices in farmers' fields (both small and large farmers) with the active cooperation of other major stakeholders.
- to enhance the dissemination of the practices to a larger stakeholder base.

Resources:

- ■Identify a venue with the help of an extension agent and lead farmer, which should be located within the target region/major cropping region and well connected with local transport systems;
- The selected venue should have basic facilities and amenities, facilities for PowerPoint presentations and discussions;
- ■The on-farm trial/demonstration sites should be nearby of the venue location and able to reach within an hour or two duration by the drive for organizing hands-on training and other field demonstrations of the practices;
- ■The selected demonstration sites should have adequate equipment used for conservation agriculture and camelina.
- ■The selected venue should have better visibility within the village and town so that the local population and local press and news agencies are also aware of the events. This will help in wider publicity of the events.

Methods:

- ■PowerPoint presentations and lectures
- ■Video presentation of new practices
- ■Handouts of the presentations and lectures with logos of donors and other stakeholders' organizations/agencies
- ■Actual demonstration and hands-on training /farmers' field schools
- ■Short oral presentation/discussion session by the lead farmer and/or early adaptor giving the background of the crop and the new practices and technologies; If possible, a demonstration even could be led by the lead farmer.

Number and duration of training events or discussion sessions: The reasonable number of training events should be fixed during cropping duration/season, with the aim to disseminate critical technologies/practices at the right stage of the crop (for example, for camelina, planting, and harvesting could be critical stages for the learning; the flowering stage could be a good stage for learning the morphology of the crop). The number of events should not be too low (which fails to disseminate the practices) or too high, which may danger loss of interest of farmers and the stakeholders, since they are busy with their ongoing crops, at that time. Duration could be fixed based on need and type of stakeholders, with due consultation.

For example, for farmers, the training event duration could be one day, which can cover the theoretical part in the morning session (Fig. 14), followed by field visits (Fig. 15) for hands-on training or demonstration events. On the other hand, for extension agencies, the duration of the events could be a little longer; and two days may be optimal in most cases, which allocates the first day for lectures and the second for the demonstration/hands-on training events. The individual lecture sessions by an expert should not exceed 2.5 to 3 hours for farmers and other stakeholders, and the session should be a discussion session rather than a typical university-like lecture session. The discussion sessions should consider the goal and aspirations of the individual participating farmers and stakeholders and address their questions and inquiries adequately.

Fig. 14. A theoretical session on camelina at Rommani, Morocco (Photos credit: Courtesy of ICARDA)

Fig. 15. On-farm demonstration event at Souk El Arbaa, Morocco (Photos credit: Courtesy of ICARDA)

6 References

1	Corsi S. and Muminjanov H. (2019) Conservation Agriculture: Training guide for extension agents and farmers in Eastern Europe and Central Asia. FAO, Rome
2	EIP-AGR (2016) Soil organic matter matters: Investing in soil quality for long-term benefits. EIP-AGRI network, available at https://ec.europa.eu/eip/agriculture/sites/default/files/eip-agri_brochure_soil_organic_matter_matters_2016_en_web.pdf (accessed on 21-Jul-2023)
3	Ohio State University Extension (2023) Water holding capacity. Ohio State University at https://soilhealth.osu.edu/soil-health-management/water-holding-capacity (accessed on 21-Jul-2023)
4	Koops D. (2023) Know Your Water Holding Capacity. Crop Quests, Inc. at https://www.cropquest.com/know-your-water-holding-capacity/# (accessed on 21-Jul-2023)
5	Jauron R. (2023) The Meaning and Importance of Soil pH. ISU Extension and Outreach. https://hortnews.extension.iastate.edu/2002/5-24-2002/soilph.html (accessed on 21-Jul-2023)
6	Davies E. (2022) Biological Indicators of Soil Health. Farming Connect. At https://businesswales.gov.wales/farmingconnect/news-and-events/technical-articles/biological-indicators-soil-health (accessed on 21-Jul-2023)
7	GEF (2023) Land degradation. Global environmental Facility. At https://www.thegef.org/what-we-do/topics/land-degradation (accessed on 21-jul-2023)
8	FAO (1994) Chapter 2 - Types of land degradation, In: Land degradation in south Asia: Its severity, causes and effects upon the people. FAO of UN, Rome. At https://www.fao.org/3/v4360e/V4360E03.htm (accessed on 21-Jul-2023)
9	OMAFRA (2023) Soil erosion: causes and effects. Ontario Ministry of Agriculture, Food and Rural Affairs. At https://www.ontario.ca/page/soil-erosion-causes-and-effects (accessed on 21-Jul-2023)
10	Mercado A, Noza Z, and Piñon C. (2020) Conservation agriculture with trees: a training manual. World Agroforestry (ICRAF), Los Baños and Department of Environment and Natural Resources, Asian Development Bank, Green Environment Facility, Los Baños, Department of Environment and Natural Resources, Asian Development Bank, Green Environment Facility, Los Baños, Phillipines.
11	Gray R. (2019) Follow The Food: Why soil is disappearing from farms. BBC Publication in association with Corteva Agriculture. https://www.bbc.com/future/bespoke/follow-the-food/why-soil-is-disappearing-from-farms/
12	Balogh A. (2021) The rise and fall of monoculture farming. Horizon at https://ec.europa.eu/research-and-innovation/en/horizon-magazine/rise-and-fall-monoculture-farming
13	Ryan, J., Ibrikci H., Sommer R., McNeill A. (2009) Chapter 2 Nitrogen in Rainfed and Irrigated Cropping Systems in the Mediterranean Region, Adv. Agron., 104:53-136 https://doi.org/10.1016/S0065-2113(09)04002-4.
14	Gibbon D., (1981) Rainfed farming systems in the Mediterranean region. *Plant Soil* 58, 59–80 (1981). https://doi.org/10.1007/BF02180049 (accessed on 23-Jul-2023)
15	Grigg D. B. (1999) Mediterranean agriculture, The Agricultural Systems of the World An Evolutionary Approach, pp. 123 - 151 https://doi.org/10.1017/CBO9780511665882.008
16	Mørch H. F. C.(1999) Mediterranean agriculture - an agro-ecological strategy. At https://tidsskrift.dk/geografisktidsskrift/article/view/42446/49355 (accessed on 24-Jul-2023)
17	Kassam A.H., Basch G., Friedrich T., Shaxson F., Goddard T., Amado T., Crabtree B., Hongwen L., Mello I., Pisante M. (2013)Sustainable soil management is more than what and how crops are grown. In Principles of Soil Management in Agro-Ecosystems, 1st ed.; Advances in Soil Science; Lal, R., Stewart, B.A., Eds.; CRC Press; Taylor & Francis Group: Boca Raton, FL, USA,Chapter 14; pp. 338–399.
18	Lal R. (2004) Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. Science, 304, 1623–1627.

19	Ferreira C. S. S., Seifollahi-Aghmiuni S., Destouni G., Ghajarnia N., & Kalantari Z. (2022). Soil degradation in the european mediterranean region: Processes, status and consequences. *Science of the Total Environment, 805*, 150106. doi:10.1016/j.scitotenv.2021.150106(accessed on 24-Jul-2023)
20	IUCN (2022) Biodiversity and Agriculture in the Mediterranean. At https://www.iucn.org/sites/default/files/2022-06/biodiversity-and-agriculture-factsheet.pdf (accessed on 24-Jul-2023)
21	Climate-Adapt (2022) Conservation agriculture. https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/conservation-agriculture (Accessed on 24-Jul-2023)
22	UNEP (2016) MEDITERRANEAN STRATEGY FOR SUSTAINABLE DEVELOPMENT 2016-2025 https://wedocs.unep.org/bitstream/handle/20.500.11822/7700/-Mediterranean_strategy_for_sustainable_development_2016-2025_Investing_in_environmental_sustainability_to_achieve_social_and_economic_development-20.pdf?sequence=3
23	FAO of UN (2023) Conservation Agriculture. at https://www.fao.org/conservation-agriculture/en/ (accessed on 25-Jul-2023)
24	CEITEC (2019) Genome Origin and Evolution of an Important Crop, Camelina sativa, and its Relatives Uncovered by Czech Scientists. Press Release. at https://www.ceitec.eu/genome-origin-and-evolution-of-an-important-crop-camelina-sativa-and-its-relatives-uncovered-by-czech-scientists/t10213 (accessed on 26-Jul-2023)
25	Zanetti F., Alberghini B., Jeromela A., Grahovac L., Rajkovic D., Kiprovski B., Monti A. (2021). Camelina, an ancient oilseed crop actively contributing to the rural renaissance in Europe. A review.ASD. 41. 10.1007/s13593-020-00663-y.
26	Avola G., Sortino O., Gresta F. (2021) Low-input cultivation of camelina (Camelina sativa (L.) Crantz) in a Mediterranean semi-arid environment. Ital. J. Agron., vol 16, at https://doi.org/10.4081/ija.2021.1728
27	AgMARC (2022) Camelina. At https://www.agmrc.org/commodities-products/grains-oilseeds/camelina (accessed on 26-Jul-2023)
28	Ghidoli M, Ponzoni E, Araniti F, Miglio D, Pilu R. (2023) Genetic Improvement of *Camelina sativa* (L.) Crantz: Opportunities and Challenges. Plants. Jan 27;12(3):570. doi: 10.3390/plants12030570
29	Ghamkhar K., Croser, J., Aryamanesh N., Campbell M., Kon'kova N., Francis C. (2010) Camelina (Camelina sativa (L.) Crantz) as an Alternative Oilseed: Molecular and Ecogeographic Analyses. Genome, 53, 558–567.

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