Advanced Sustainable BIOfuels for Aviation BIO4A

Deliverable D2.7:

Mapping of sustainable potential for advanced biofuel production on marginal lands in the Mediterranean Region

Consortium:

Acronym	Legal entity	Role
RE-CORD	CONSORZIO PER LA RICERCA E LA DIMOSTRAZIONE SULLE ENERGIE RINNOVABILI	CO
ENI	ENI S.p.A.	BEN
SKYNRG	SKYENERGY BV	BEN
CENER	FUNDACION CENER-CIEMAT	BEN
ETA	ETA – Energia, Trasporti, Agricoltura Srl	BEN
CCE	CAMELINA COMPANY ESPANA S.L.	BEN
JRC	JOINT RESEARCH CENTRE – EUROPEAN COMMISSION	BEN

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PRO	Technical/economic progress report (internal work package reports indicating work status)	**X**
DEL	Technical reports identified as deliverables in the Description of Work	
MoM	Minutes of Meeting	
MAN	Procedures and user manuals	
WOR	Working document, issued as preparatory documents to a Technical report	
INF	Information and Notes	

Dissemination Level

PU	Public	**X**

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0 Abbreviations

ARMOSA - Dynamic crop model that simulates the cropping systems at a daily time-step at field scale.
BBCH - Biologische Bundesanstalt, Bundessortenamt and CHemical industry, phenological classification scale
Bio4A – EC funded project: Advanced Sustainable Biofuels for Aviation
CAM- Camelina model
CAMBAR – Camelina in rotation with Barley model
CAP- Common Agricultural Policy
DIRECTIVE (EU) 2018/2001 – RED II- Renewable Energy Directive
FAO – Food and Agriculture Organization
EC – European Commission
EU – European Union
EU28 – Member States of the European Union
GHG – Greenhouse gases
GDD - Growing Degrees Day
LAI - Leaf Area Index
iLUC – Indirect Land use changes
LUC – Land use changes
LUCAS - Land Use and Coverage Area frame Survey
MARS - Monitoring Agricultural ResourceS
MCDA - Multi-Criteria Decision Analysis
NUTS - Nomenclature of territorial units for statistics
RCP- Representative Concentration Pathway
SOC – Soil organic carbon
UNEP- UN Environment Programme

1 Summary

This task builds upon information and results collected under Task 2.1, which aimed to assess the marginal land resources and feedstock production potential for drought resistant oil crops in Southern Europe by using a range of spatial data and subsequent editing and processing of the information via computer-based Geographic Information Systems (GIS) and mechanistic crop model. Under this task, the project assessed with a comprehensive and multifactor GIS-based analysis, the potential marginal and underutilised land that can be dedicated to growing energy crops in a sustainable manner in the Mediterranean region and neighboring countries. The crop growth ARMOSA Model developed by University of Milan was calibrated for the Camelina yields in Mediterranean using published data obtained by a literature analysis, the JRC’s LUCAS soil data and maps, the Monitoring Agricultural ResourceS (MARS) gridded agro-meteorological data in Europe for the study area being investigated. The analysis was targeted at regions with a predominantly Mediterranean climate with marginal agricultural conditions, Köppen classes BSh, BSk. BWk, Csa, Csb, Cfa.

The mechanistic crop growth model ARMOSA can estimate quantitatively a number of soil and water parameters, including impacts of bioenergy production on soil organic carbon (SOC) content and fluxes of related soil nutrient cycles (e.g. N and P) to air and water, resulting eutrophication risk or increased greenhouse gas emissions, and can be coupled to assess soil erosion risk. The results of this analysis were used to constitute two scenarios (Camelina in continuous cultivation conditions, namely CAM, and Camelina in rotation with Barley, namely CAMBAR), to derive the most effective sustainability recommendations for developing dedicated energy crops value chains on the marginal lands identified. From an agricultural perspective, a scenario of continuous camelina cultivation (CAM) is not advisable, similarly to continuous monoculture of any other crop. The CAM scenario was therefore provided to indicate a theoretical market capacity.

Both scenarios consider an area of investigation of around 500.000 km^2. The CAM scenario (continuous Camelina cultivation) obtained an average yield of 1870±717 kg ha^{-1} yr^{-1}, with an average SOC change of +31 kg ha^{-1} yr^{-1}. The high standard deviation reflects fluctuations in yields as a result of extreme weather patterns. The CAMBAR scenario (Camelina in rotation with Barley) obtained an average yield of 2468±641 kg ha^{-1} yr^{-1}, with a higher average SOC change of +43 kg ha^{-1} yr^{-1}. The modelling results of both scenarios showed a slight increase of SOC stock on average, even if in fertile regions with a good amount of precipitation throughout the crop cycle, the increase of SOC is lower than the study area average. Although in some cases the SOC stock change decreases, the Camelina cultivation area where SOC stock changes are positive -over 310.000 km2, accounting for more than 60% of study area- is more than four times larger than the cases where it declines. A SOC increase of +43 kg C ha^{-1} yr^{-1} is in line with other results of many studies carried out either in the Mediterranean or continental climates within a crop rotation by adopting minimum tillage and straw retention. SOC increase can however greatly increase when Camelina is introduced in rotation with cereal in areas with high desertification risk. In the case of Spain, Camelina Company España introduces camelina in the regions of Castilla La Mancha, Castilla y León and Comunidad de Madrid – these three regions account for 40% of the total area of investigation in Spain, equivalent to 88.233 km^2. SOC increase for the CAMBAR scenario for each of these three regions is as high +188, +255 and +236 kg ha^{-1} yr^{-1}, respectively. In case the SOC increase for these regions is calculated considering the weighted area, the average

SOC increase is as high as +222 kg ha^{-1} yr^{-1}. For reference, BIO4A field trials are located in two of these regions: Castilla La Mancha and Comunidad de Madrid. Considering the SOC stock average increase, organic fertilization is therefore advisable to maintain soil fertility in both scenarios. The average yield throughout the study area when Camelina is continuously cultivated is 24,3% less than for the scenario Camelina with Barley in rotation, whereas the production is obtained every second year. As expected, the Barley/Camelina scenario represents the most advisable insertion of the crop into Southern European countries cropping systems considered in this analysis. Statistics and maps per Country and NUTS 2 level are provided in the results section. To ensure sustainability in both scenarios, the 20% of the NUTS 2 needs a very accurate management plan to avoid SOC losses which included residue retention and organic fertilizations. Land considered for the modelling exercise represents the current extent of the study area agricultural systems which can include fallow and temporary abandoned land. No competition with food crops or impacts on other ecosystem services is foreseen by the cultivation of Camelina with low input chemical fertilizers, organic fertilization from manure or carbon enrichment using compost and biochar to minimize GHG emissions to avoid negative impacts.

The corresponding potential sustainable biofuel production of lands characterized by water scarcity, climatic variability, as well as other biophysical and socio-economic constraints that define them as marginal, are also based on the result of a crop growth and yield model. Establishing energy crops in potentially productive marginal lands could be an instrument to enhance rural development, whereas targeting at land with lower potential and apply biochar, compost or a mixture of them can help in reaching environmental targets.

The methodology, assumptions, data and results of this work include lessons learned and recommendations for the effective planning and management of natural resources in situations of marginality, due to biophysical and/or socio-economic constraints. The results of this work constitute a key contribution to policy development at the sub-national, national and EU level, through the investigation of low LUC/ILUC biofuel from marginal areas before these are lost due to land degradation processes and other anthropogenic impacts. Land use, terrain, climate and soil data are the main inputs to the assessment of features such as water availability, soil quality including SOC content, erosion and salinization risk that in the context of this task will be fundamental to the mapping of the marginal areas that show potential for the production of advanced biofuel crops.

The assessment has been performed according to the following structure:

- Identification of suitable lands to define the potential cultivation area. Implementation of a set of biophysical constraints to define the marginal and underutilized land suitable for growing dedicated no-food oilseed crops (Task 2.1) and other energy crops (total amount and spatial distribution of marginal land). The latter were defined as the result of a review of scientific literature, GIS analysis, together with previous EC-funded and international projects on the subject (i.e. harmonization of definitions).

- Planting zonation/crop suitability maps of Camelina on agricultural lands. The most suitable cultivation areas will be determined according to their meteorological time series, edaphic characteristics, environmental requirements, type of farming system and natural geographic conditions using a mechanistic crop growth model ARMOSA.

- The estimation of the amount of the potential feedstock production on the identified areas according to the availability of land, the level of exploitation and use of the selected areas, and the characteristics of the selected dedicated energy crop(s).

The JRC was the lead actor for this task, carrying out the action described above, reporting the results of the potential estimation on a GIS base in EU, and providing indication on the potential of the proposed approach at the international level, which can contribute to provide suggestions to policymakers and farmers for reducing GHG emissions and promote more sustainable energy crop production practices. RE-CORD and Camelina Company España supported the analysis of JRC, providing detailed information on the previous experimental phase and contributing to the definition of the criteria and the estimations for this task.

2 Introduction

Camelina (*C. sativa* L. Crantz), is one of the representatives of biofuel crops reported to be suitable for cultivation on marginal soils (Cappelli *et al.*, 2019; Cossel *et al.*, 2019; Von Cossel *et al.*, 2019; Zanetti *et al.*, 2021a) either as a main biofuel crop or usable in different crop rotation and intercropping schemes (Berti *et al.*, 2017; Richard *et al.*, 2020). There is an increasing interest in Camelina cultivation for biofuel production in Mediterranean (Chiaramonti & Panoutsou, 2019). There is limited knowledge on potential yields of oil crops grown on different marginal soils with different growth limiting factors. Many aspects need to be considered before embarking on cultivation. These include water use efficiency, high-temperature resilience, and many other factors, which are driven by differences in the plant morphology, physiology, and biochemistry.

Bioenergy is an important component of the renewable energy mix in the EU, helping to ensure a stable energy supply (Popp *et al.*, 2014). Energy crops can be divided into the four groups of sugar crops, starch crops, lignocellulosic crops and oil crops. All classes are subject to restriction to prioritise the growth of primary food crops. The theoretical potential for energy crops in many regions of the EU is large, but since food security is the first pillar of the Common Agricultural Policy (CAP), their cultivation is in competition for other uses for food consumption, and for fodder. Therefore, the extent of their cultivation can be limited by land constraints and water availability, to limit the decrease of a sufficient production of food commodities (EEA, 2013). The potential environmental and social impacts from the production of dedicated energy crops differ depending on the choice of crop and management system (Sallustio *et al.*, 2018). It has been estimated that about 40% of the terrestrial ecosystems could be classified as marginal land, suitable for growing bioenergy production (Kang et al., 2013), also according to the European Commission Directive on (Directive 2009/28/EC, 2009[11]) the promotion of the use of energy from renewable sources of biomass and biofuel crops cultivation is restricted to land that is unsuitable for food production or takes place in arable land when the latter are cultivated as cover crops or intercrops (Berti *et al.*, 2017). The possible competition of biomass and biofuel crops with food crops in high-quality soils may compete with cereal and other food crops (EEA, 2013).

The concepts of marginality involved biophysical as well as socio-economic factors (Lewis & Kelly, 2014; Panoutsou & Alexopoulou, 2020; Sallustio *et al.*, 2018). According to FAO & UNEP (2010), land supporting a yield of up to 40 % of its crop potential defined as the average yield of a region, is considered marginal. Considering both biophysical and socio-economic criteria, the identification of marginal lands in a given area is a dynamic process that depends on the target crop, the equipment adequacy, the specific background conditions such as market accessibility, management practices, product prices (Sallustio *et al.*, 2018). As a result, the degree of marginality in

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[1] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA relevance) https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32018L2001

a specific place can be considered as non-marginal in different spatio-temporal conditions (Lewis & Kelly, 2014; Link *et al.*, 2006; Soldatos, 2015). So the concept of marginality can be rather un-intuitive as it is referred to a change in state of the land, where the metric is the production of goods or an ecosystem service (Shortall, 2013). Among the definitions of marginal land, the fact that changing climates are pivotal to assess the degree of marginality is well known, as well as socio-economic properties (MAGIC project).

Rural areas can have a central role in production of energy if the market will allow favourable economic conditions for the cultivation of non-food crops. Costs and profitability of the main energy crops cultivation have been investigated at European scale from (Panoutsou & Alexopoulou, 2020) and can be used to define yield profitability for each member state for the majority of the energy crops. Biofuel crops have the ability to grow and develop in low quality soils, tolerate water stress and high temperatures (Amaducci *et al.*, 2017; Righini *et al.*, 2019; Zanetti *et al.*, 2020), and in turn, produce a large amount of root biomass that increases soil organic carbon content (Sarker *et al.*, 2017; Szczepanek & Siwik-Ziomek, 2019). Furthermore, rapeseed oil crops acts as a break crop from the Take-all fungus (*Gaeumannomyces tritici*), which adversely affects winter wheat in Western Europe (Sieling & Christen, 2015).

In this task, we developed a multi-criteria GIS for the definition of the suitable areas using topography, land cover and topsoil spatial data (Soil organic carbon and Bulk density) for the entire southern Mediterranean (only EU). The second step was to undertake a yield modelling exercise (using a mechanistic modelling approach ARMOSA) to assess suitable areas based on experimental field trials yield retrieved by literature and BIO4A field experiments, weather patterns from the Monitoring Agricultural ResourceS (MARS) gridded agro-meteorological data in Europe, soil properties, slope and aspect. Camelina yield potential and Camelina-barley rotation and the soil organic carbon pools were modelled for the past 20 years and for the future using (RPC 4.5 and 8.5 scenarios).

The term margin land is used in the literature to indicate unused land for agriculture such as abandoned, under used, degraded, fallow (Shortall, 2013). In this report, the meaning embedded in the term marginal is assumed as Economical marginal land, aimed at identify the land where cost effective agricultural production is not possible under a set of conditions. After the definition of the Mediterranean area according to Köppen bioclimatic regime, Marginal land were identified when the Camelina seed yield obtained from the 20 years modelling average was lower than Camelina average yields obtained in European countries based on a comprehensive literature assessment.

3 Material and methods

3.1 Camelina, history, agronomic traits, national statistics

Camelina (*Camelina sativa* L. Crantz) belongs to the Brassicaceae Family and is usually known in English as Camelina, Gold-of-pleasure, or False flax. Its potential as an emerging oil and feedstock crop due to the unique fatty acid profile (Gugel & Falk, 2011) has re-emerged in European agricultural systems since the early 1990s (Zanetti *et al.*, 2021a). In the past decade, a considerable number of studies have been carried out on this species in Europe and North America (Solis et al., 2013) to study its performances and integration in well-established rotations (Berti et al., 2017). Among the main reasons for the interest in Camelina, we highlight the broad environmental adaptability, low-input requirements, resistance to multiple pests and diseases, and the possibility to use it in for food, feed, and biomass-based applications. Due to the increasing interest in this crop, the promotion of scientific research on its genetics and breeding, management and inclusion in different cropping systems, has to be fostered. In the present conditions, rapeseed is the major oil crop cultivated in the EU countries [2]. Camelina and rapeseed needs same agronomic management, farmers and end-users can have a real potential by introducing Camelina in their farming systems to reduce the EU’s dependence on fossil fuel aviation fuels.

3.2 Biophysical constraints identification and land suitability

The land potential for oil crops production can be determined by an evaluation of the main biophysical factors such as topography, climate, soils and management as well as economic factors (farm distance to transportation networks and Refineries and Processing plants, agricultural mechanization, crop rotation, irrigation, ecosystem services). Consistently with the scale of investigation, logistic aspects of the post-harvest are not taken into account. To this end, a Multi-Criteria Decision Analysis (MCDA) in a GIS framework that provides soil, land cover, terrain and climate traits was adopted to define the suitability of each single landscape unit (500m pixel scale) for the cultivation of Camelina in Southern European regions. MCDA methods support decision-makers in analysing a set of alternative spatial solutions, furthermore, it uses decision rules to aggregate the criteria, which allows the alternative solutions to be ranked or prioritised. The MCDA provided a general framework to operate a suitability mapping by relating previously unrelated agro-ecological parameters. It consisted in the definition of an area based on climate pattern, previously cultivated agricultural land cover (CORINE), soil texture, fertility (SOC % based on LUCAS soil survey) and soil bulk density. Topographic features (slope and aspect) were also taken into account to define the main local condition for the crop modelling scenarios (Figure 1).

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[2] [2] https://agridata.ec.europa.eu/extensions/DashboardCereals/OilseedProduction.html

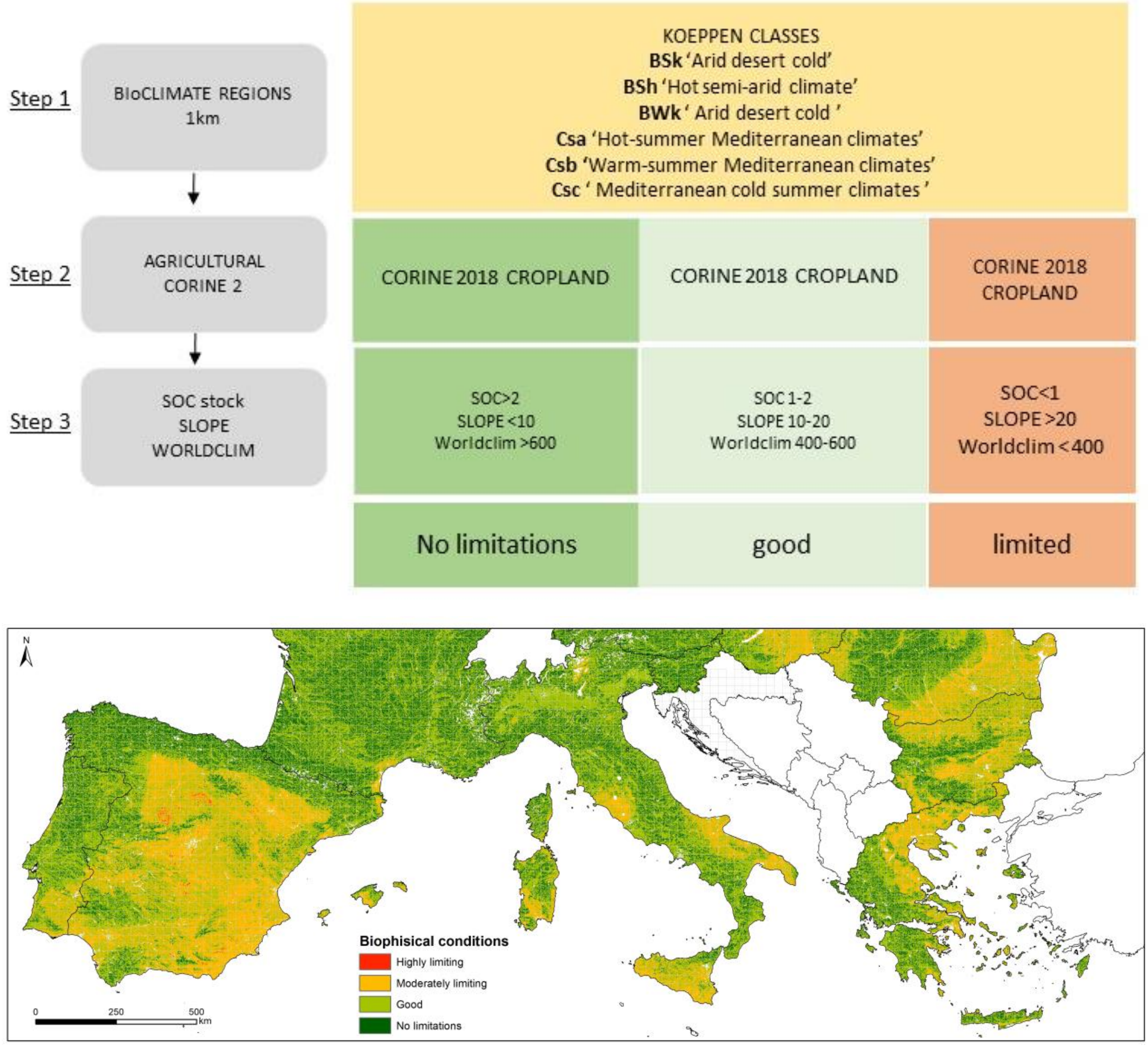

Figure. 1, climate, land cover and biophysical parameters taken into account to define the study area.

3.2.1 Climate classification - Köppen climate zones

The Köppen-Geiger climate classification (Chen & Chen, 2013; Rubel & Kottek, 2010) was developed based on the empirical relationship between climate and vegetation. This climate classification scheme provides an efficient way to describe climatic conditions defined by multiple variables and their seasonality with a single metric. This classification is generally accepted in ecology and agronomy to define homogeneous zones for both conservation and management. Many examples of its use can be found in literature for mapping geographic distribution of long-term mean climate and associated ecosystem conditions. Recently, there was an increasing interest in using the classification to identify changes in climate and potential changes in vegetation over time.

This work used a Köppen dataset developed by (Beck *et al.*, 2018) to reveal potential semi-arid areas for Camelina production in the Mediterranean Region of the EU and other European countries.

The most widespread class is the dry climate (B) in which the controlling factor on vegetation is dryness, which is defined by the relationship between the precipitation input to the soil in which the plants grow and the evaporative losses. Since evaporation is difficult to evaluate and is not a conventional measurement, aridity is defined in terms

of a temperature-precipitation index. To meet these conditions the total annual precipitation is less than 10 times the dryness threshold accompanied by a significant areal of Mild temperate, with a coldest month temperature greater than -3 °C and less than +18 °C climate (E) since the 1980s, which have practical and theoretical implication.
In particular three classes of dry climates were identified as suitable:

- **Bwk** Total annual precipitation is less than or equal to 5 times the dryness threshold. Annual mean temperature less than +18 °C (i.e. generally cold, dry winters),
- **Bsh** (semi-arid) which has a total annual precipitation is greater than 5 times the dryness threshold annual mean temperature is greater than or equal to +18 °C (i.e. hot, dry summers and cool, humid winters)
- **Bsk** (semi-arid) which has a total annual precipitation greater than 5 times the dryness threshold. Annual mean temperature is less than +18 ° (often found bordering Bsh, with warm, dry summers and cold, humid winters)

In addition, we also find occurrences of dry temperate climates (C), with two classes of interest:

- **Csa**, Mild temperate with dry summer, driest month precipitation in summer is less than driest month in winter, wettest month precipitation in winter is more than 3 times the driest month precipitation in summer, and driest month precipitation in summer is less than 40 mm, Warmest month temperature is greater than or equal to +22 °C.
- **Csb**, Mild temperate with dry summer, coldest month averaging above 0 °C (32 °F) (or −3 °C (27 °F)), all months with average temperatures below 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). At least three times as much precipitation in the wettest month of winter as in the driest month of summer, and driest month of summer receives less than 40 mm (1.6 in).
- **Cfa**, Different from Cs and Cw, can be defined as mild temperate, fully humid. Warmest monthly temperature is greater than or equal to +22 °C

3.2.2 Land cover

Traditionally, human activity has shaped our landscape, with an impact on the environment. Natural capital entail, land resource used for multiple purposes: agriculture, mining, manufacturing and construction, transport and residential use. The effects of overexploitation have changed natural vegetation to cropland and pastures, and sometimes the signs of desertification are visible in certain EU regions [3]. Global warming has contributed towards increasing awareness and recognition that land provides many ecosystem services, and it is a limited resource. The Corine land cover (CLC) is a pan-European inventory of land cover coordinated by the European Environment Agency. It provides a biophysical classification of artificial areas, agricultural areas, forests and semi-natural areas, wetland and water bodies. In this work, the dataset for 2018 is used to select all the agricultural areas that could be suitable for the production of Camelina. This layer is made up of several classes, including rainfed cropland (Corine code 211), fruit and trees (Corine code 223) and complex agricultural patterns (Corine code 241), where the interpretation of the spectral information denoted a mixture of agriculture and natural vegetation. A high proportion of the EU’s territory, 40%, is defined as agriculture (EUROSTAT, 2021).

3.2.3 LUCAS Soil data, texture, Soil organic Carbon and Bulk Density

The Land Use and Coverage Area frame Survey (LUCAS) has collected statistical information on land use and land cover over the territory of the EU from 2006. In 2009, a Soil Component (LUCAS Soil) was added. The soil sampling follows a complicated sample design, based on the random stratified sample of the field verification points of the main survey. Soil samples and supporting data were collected by direct observations of about 22,000 points (a similar number were also collected by the 2015 LUCAS survey) by surveyors on the ground (in situ). The initial objective for the LUCAS Soil survey was to collect data on soil organic carbon (SOC), with emphasis on agricultural soils. Over time the scope of the LUCAS Soil survey was broadened and additional parameters were collected and analysed. For the chemical and physical laboratory analysis, composite sample of approximately 500 g are taken from five subsamples collected with a spade at each LUCAS point. The first subsample is used to report the location coordinates, the other four subsamples were collected at a distance of 2 m following the cardinal directions (North, East, South and West). In the exact place of sampling, stones (>6 cm) (FAO, 2006), plant residues, grass and litter were removed from soil surface by raking with the spade. The five subsamples in the bucket were mixed with a trowel. Aliquots (about 500 g) of the mixed soil are taken with a trowel from the bucket, placed in a plastic bag, and labelled to derive the composite sample. Soil samples were allowed to air dry before the bags were sealed. Based on the 2009 data, topsoil texture has been mapped for the EU, (EU 26) with a nominal pixel resolution of 500x500 m (Ballabio et al., 2019). These data are available for the yield model simulation. Furthermore, soil organic carbon data are available from both the 2009 and the 2015 sampling campaign and spatially available at the same resolution of the fine earth fraction (Ballabio et al., 2016). Relatively high values of BD indicate soil compaction which may lead to reduced water infiltration especially in agricultural land, where it can hamper the growth of crop root systems (Schillaci et al., 2021). Soil Bulk Density (BD) is calculated as the dry weight of soil divided by its volume. Volumes include soil particle volume and pore space between soil particles. Soil BD is typically expressed in g cm^{-3} or Mg m^{-3} (SI). BD is necessary to calculate SOC stocks and is directly linked to soil functionality including mechanical support of crop plants, circulation of soil solution, and soil aeration. In LUCAS soil BD values are derived from packing density data using the equation proposed by (Jones et al., 2003) conditioned by clay content and quantify the meaning of qualitative categories of packing density for mineral soils.

3.2.4 Topography

Due to the scale of the analysis, the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) with an original resolution of 30 m (Farr et al., 2007), was resampled to 500 meters. This information was used to calculate the additional geomorphometric derivatives of slope and aspect, (using SAGA GIS, Conrad et al., 2015). The derived slope map was reclassified in two classes: slope from 0-15% and >15%. Aspect was reclassified into North (315-45 degrees), East (45-135 degrees), South (135-225), West (225-315).

3.3 Crop modelling

The ARMOSA model simulates the agricultural production of selected crops at a daily time-scale. It consists of four main modules: (1) crop growth and development, (2) soil water dynamics, (3) C and N cycles and (4) management operations (5) Crop residues.

(1) **Crop growth and development**

The crop growth and development module represents the following processes: evapotranspiration, biomass growth, partitioning between products of the photosynthesis, phenological development. The reference evapotranspiration (ET0) has been estimated using the Penman-Monteith equation. Crop evapotranspiration (ETc) is estimated using the FAO 56 approach (Allen *et al.*, 1998); actual evapotranspiration (ETa) is calculated using a water stress factor (Sinclair *et al.*, 1987), which influences the crop-related processes such as carbohydrate production and photosynthates partitioning. The crop growth is based on the gross C absorption following the WOFOST approach (de Wit *et al.*, 2019) with a substantial improvement: the canopy is divided into 5 layers with different light interception.

The model calculates the growing degree days (GDD) and the development rate (used in the assimilate partition and LAI estimation) using the BBCH scale to indicate the crop stages (Martinelli & Galasso, 2011; Meier *et al.*, 2009) which is an international benchmark for a precise and detailed description of the different phenological growth stages.

(2) **Soil water dynamics**

Water dynamics are simulated for each soil layer using a bucket approach, according where each soil layer is filled to field capacity before water flows into the underneath layer (Campbell & Diaz, 1988). Soil temperature is simulated according to the method of Parton (Parton *et al.*, 1998) and (Neitsch *et al.*, 2011).

(3) **C and N cycles**

Carbon and Nitrogen related processes are simulated for each soil layer and implemented following the approach of the SOILN model (Johnsson *et al.*, 1987) with the difference that each input of C and N is considered independently, with each one having its own decomposition rate and fate. The input could be of three types, which correspond three types of organic C and N pools: stable, litter, and manure. Mineral pools are CO_2-C, NH_4-N, NO_3-N, N_2O-N. Mineral and organic pools are calculated daily for each layer as the results of soil processes, which are immobilization, mineralization of the organic pools C and N, nitrification (NH_4-N to NO_3-N), crop uptake of NH_4-N and NO_3-N, NO_3-N leaching, denitrification (N_2O-N to NO_3-N), atmospheric deposition of NH_4-N and NO_3-N, and NH_4-N volatilization.

(4) **Management operations**

The agronomical management operations have been designed as events which occur at a specific date during the simulation and affect soil and crop processes. The model setting requires information related to the cropping system (i.e. crop sequences, sowing and harvesting dates, residues management, dates of grass cutting), irrigation (water amount, timing, option of automatic irrigation as a function of water depletion threshold), N fertilization (mineral or organic, amount, timing, application depth, C/N ratio, NH_4-N over total N), and tillage.

(5) **Crop residues**

The ARMOSA model simulates the crop residues decomposition according to the type of crop, the tillage depth, the specific potential decomposition rate for each organ of the crop, C and N content in crop residues. The decomposition process is represented according to mineral nitrogen availability (both nitrate and ammonium), soil moisture and temperature to implicitly represent the microbial activity.

3.3.1 Model calibration and validation

Using the data taken from the experimental sites described below, the model has been calibrated using the crop yield as a reference variable. Soil data (Texture, SOC) are taken from the LUCAS soil maps.

The first task performed was the characterization of the phenological development stages specifying the Growing Degrees Day (GDD) necessary to reach each one of the BBCH stages. After this operation, the calibration process focused on the amount of biomass, Leaf Area Index and yield simulated.

The main parameters modified during the process are:

- crop development partitioning coefficients
- nitrogen dilution curve specific parameters
- CO_2 potential assimilation rate at light saturation
- water stress sensibility
- specific leaf area / biomass ratio
- maintenance respiration of leaves
- initial and final BBCH stage for ear photosynthetic activity

The final stage of the calibration process was the test of the calibrated crop using meteorological and soil data of all the other cells beside the ones of the experimental (calibration) sites. Eight sites where Camelina was cultivated in field trials were used to calibrate the model. The validation was performed on six sites, of which five were found in the literature and one was the first year of the Camelina company field trials results.

3.3.2 Experimental sites

To collect the observations needed for the calibration, a Scopus research has been conducted. The research was based on the following query:

"(TITLE-ABS-KEY ("camelina sativa" OR "Camelina" OR "camelina") AND TITLE-ABS-KEY ("field" OR "grassland")) AND LIMIT-TO (AFFILCOUNTRY , "Italy") OR LIMIT-TO (AFFILCOUNTRY , "Spain") OR LIMIT-TO (AFFILCOUNTRY , "France") OR LIMIT-TO (AFFILCOUNTRY , "Greece") OR LIMIT-TO (AFFILCOUNTRY , "Croatia") OR LIMIT-TO (AFFILCOUNTRY , "Slovenia")) AND (LIMIT-TO (SUBJAREA , "AGRI"))"

The query contained the names of six different countries in the Mediterranean basin that potentially included the Bwk, Bsh, Bsk, Csa, Csb, Cfa Köppen climate zones.

The Scopus research found 35 scientific papers. All the publications were checked to found agronomic variables that describe the *Camelina sativa* traits. Different agronomic variables were found such as above ground biomass productivity, seed yield, growing degree days at various vegetative stages, and others related to the agronomic management. Eight suitable experimental field trials were used to derive the yield data. Yield data used for the modelling exercise came from at least two years experiments. Only one experiment reported irrigation (Figure 2).

All the data was useful to calibrate the ARMOSA model in this specific geographic area.

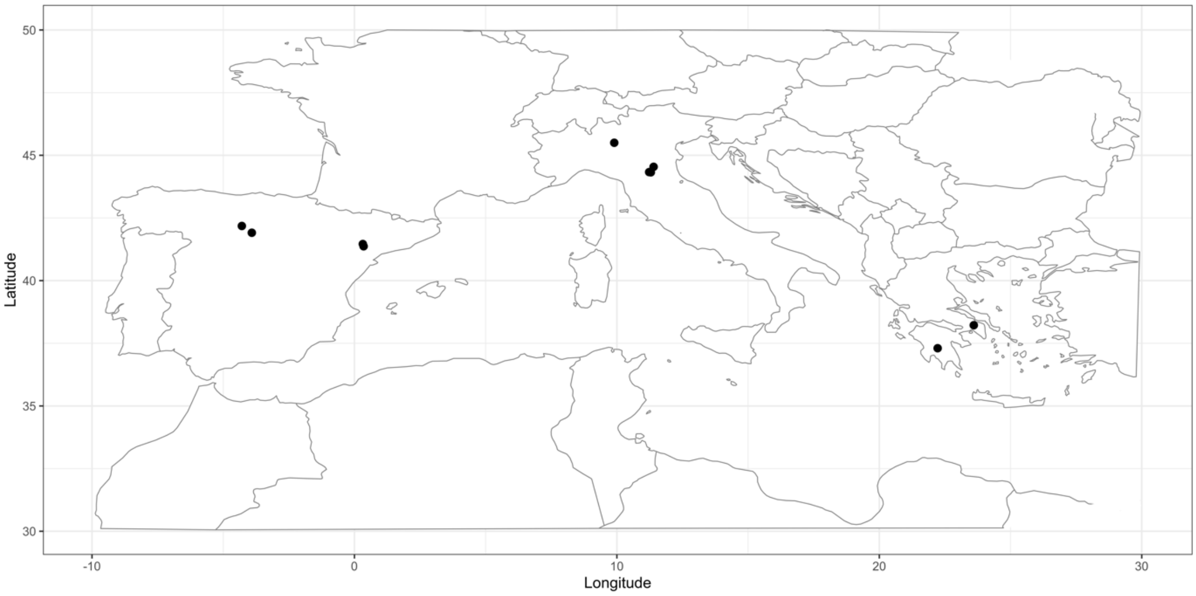

Figure 2. Sites used for the calibration of ARMOSA model calibration and validation sites

3.3.3 Weather data MARS-RCP

The JRC MARS Meteorological Database contains meteorological observations from weather stations interpolated on a 25x25 km grid, on a daily basis from 1979 to the last calendar year completed, for the European Union and neighbouring countries. The data version used is the 3.1, published in 15/01/2021. The service is accessible via the link: https://agri4cast.jrc.ec.europa.eu/DataPortal. The maximum dimension for each query is (60.000.000 records), Grid Spatial Projection, Lambert Azimuthal Equal Area 3035 (EPSG code). The data used for this experiment are from 01/01/1999to 31/12/2019.

Table 1. Weather variables available in the AGRI4Cast database

Variables
maximum air temperature (°C),
minimum air temperature (°C),
mean air temperature (°C),
mean daily wind speed at 10m (m/s),
vapour pressure (hPa),
sum of precipitation (mm/day),
potential evapotranspiration from a crop canopy (mm/day),
total global radiation (KJ/m2/day)

The weather monitoring pipeline for the generation of MARS gridded data entails four steps: acquisition, interpolation, aggregation and climatology analysis. The output of the weather monitoring module is used in two ways: firstly, to derive agro-meteorological indicators for a direct evaluation of alarming situations such as drought, extreme rainfall during sowing, flowering or harvest etc. Secondly, as input to the crop simulation module to simulate crops behaviour and to evaluate the effect of weather on crops. Each day encoded reports from more than 5100 synoptic weather stations, that regularly collect and supply one or more meteorological variables, are acquired over Europe and its neighborhood and are added as quality checked data to the station weather database. The data collected are: air temperature, precipitation, radiation, air humidity, wind speed and direction, cloud cover, snow depth, atmospheric pressure, visibility, and duration of sunshine, evapotranspiration is derived from the measured data and also added to the database.

In addition to observed weather data, we used the future climate scenario RCP 4.5 and 8.5, also called forced scenarios, accessed at: http://open-research-data-zalf.ext.zalf.de/ResearchData/DK_59.html. These scenarios are derived from the JRC AGRI4Cast baseline whether data. The data set contains daily time-step observed and scenario climate data on a European grid with 25 km x 25 km spatial resolution and is intended to be used for crop modelling applications. The dataset covers the period 1980-2010 for observations (for a baseline period of 1981-2010 and the year 1980 for crop model simulations with sowing dates in the autumn) and the periods 2040-2069 and 2070-2099 for 5 GCMs x 2 forcing scenarios (RCP4.5 and RCP8.5) The JRC Agri4Cast gridded dataset was used for the baseline. The scenarios have been calculated using an enhanced delta change method that applies changes in aspects of temperature and precipitation variability in addition to changes in mean climate.

3.3.4 Soils

Soil data were derived from the publications chosen for the calibration of the model. All publication reported the fine earth fraction of topsoil, SOC and BD. Other physical and chemical properties were not taken into account for the modelling.

3.3.5 Management

The management used for the simulation of Camelina and Barley is the following:
- sowing date: 15th October
- harvest date: 10th June
- one tillage operation before sowing
- one inorganic fertilization at stem elongation of 50 kg/ha of nitrogen [3].
- crop residues incorporated into the first 20 cm of soil profile at harvest
- no irrigation

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[3] Due to the restricted number of evidences we considered 50 kg ha-1 of N fertilization according with several field trials. We found very few 0 kg ha-1 N field trials that showed contrasting level of productivity mainly due to the crop rotation.

3.4 Biochar and Compost applications

According with the Deliverable (D2.2 Task 2.1) results and product characterization, woody and agro-residue biochars were characterized (Table 1). The two chars obtained showed different characteristics, mainly in terms of carbon and ash content in weight. Chestnut biochar has been used both directly and in COMBI production (a mixture of compost and biochar with various percentages) for the agricultural field tests in Spain performed in collaboration with CCE. Such field tests are currently ongoing, so we are not able to consider the direct effect of these amendments on SOC stock in a long term view. On top of the modelling exercise which modelled the rotation of Camelina and Barley in a conventional tillage scenario with stubble retention, three scenarios or SOC stock recovery are provided: i) Compost 20t/ha, ii)Wood-biochar and iii) Wheatstraw-biochar application, their application was derived by the field trials (Table 2). However, in BIO4A field trials, only chestnut biochar was applied. The calculation of the effective SOC stock take into account quantity applied, moisture of the products, C contents, and coefficient of stabilization found in literature.

In particular for the Biochars, a coefficient of 0.95 was used (Wang et al., 2016). The biochar high stability is generally related to its chemical structure, (aromatic and heterocyclic C), (Fischer et al., 2018). For this reason, biochar mineralization is expected to be much lower than the compost.

Compost effect in the literature has been resulted in significant change soil characteristics and nutrient status. However, its stabilization dynamics are complex, it is important to achieve some standards for the production of a stable, pathogen-free and non-phytotoxic material that can be used as soil conditioner, (COM/2019/1009). For the Compost stabilization rate was difficult to assess, especially for the long term, according with literature findings, (García-Gómez et al., 2003; Hartz et al., 2000; Hénin, S.; Dupuis, 194AD; Novara et al., 2020; Priori et al., 2018; Szmidt, 2001) an average and conservative value was used 0.8 (Table 2).

Table 1. Biochar Characterization

Parameter	U.M.	Value	Value	Method
Typology	-	Chestnut	Wheat straws	
HHV	MJ kg-1	-	26.13	UNI EN ISO 18125
LHV	MJ kg-1	30.8	25.74	EN 14918 for WC UNI EN ISO 18125 WS
Water content	% w/w a.d.	5	1.2	UNI EN ISO 18134-2
Volatile matter	% w/w d.b.	14.5	11.9	UNI EN ISO 18123
Fixed carbon	% w/w d.b.	80.8	64.3	calculated
Ash	% w/w d.b.	4.7	23.8	UNI EN ISO 18122
Total C	% w/w d.b.	86.2	69.1	UNI EN ISO 16948
Total H	% w/w d.b.	2.1	1.9	UNI EN ISO 16948
Total N	% w/w d.b.	0.6	1	UNI EN ISO 16948
Total S	% w/w d.b.	0.04	0.4	ASTM D4239
Specific surface area (BET)	m2 g-1	216	118	ASTM D6556

Table 2. Compost and biochars application rates

		Compost	Woodchip Biochar	Wheatstraw biochar
Application rate	t/ha	20	4.8	4.8
Umidity	%	50	5	5
Carbon in d.b.	%	51.8	86.2	69.1
Stabilization rate		0.80	0.95	0.95
SOC gain	t/ha	4.3	3.7	3

3.5 Marginality definition

Biophysical parameters were used to obtain an assessment of land suitability for the camelina cultivation according with five open source layers such as the Köppen bioclimatic variables, agricultural land cover (CORINE), soil organic carbon content, texture, slope (LUCAS soil module).

In order to identify areas Camelina will be economically sustainable, two thresholds taken form the literature were applied:

i) 1 Mg ha^{-1} considered a reliable yield threshold for the profitable cultivation of camelina in marginal or semi-marginal soils (Stolarski *et al.*, 2019; Zanetti *et al.*, 2021b),

ii) ii) an average yield of 1.34 Mg ha^{-1} (~0.13–3.9 Mg ha^{-1}, variation coefficient of ~62%) (Masella *et al.*, 2014) regardless of the year, sowing time and genotype was obtained in various environmental conditions.

Therefore, we can consider as marginal such land that cannot achieve on a 20 year basis this average yield at regional scale NUTS2, which is in turn a proxy of its economical sustainability (Ciria *et al.*, 2019).

Furthermore, additional uncertainty at regional scale can be derived by the definition of areas with limitations shows low soil organic carbon (lower than 1% in the topsoil), and high soil erosion by water (Panagos *et al.*, 2015) (>10 Mg ha^{-1}) considering this land highly susceptible to degradation.

4 Results

To run the modelling exercise, yield and soil data from literature and BIO4A field trials, soil type, SOC and BD from LUCAS, topography such as slope (0-15% and >15%) and aspect (N,S,E,W). The land that falls under semi-arid climatic conditions (Köppen climate Bwk, Bsh, Bsk, Csa, Cfa,Csb) under an agricultural land cover type according with CORINE 2000-2018, considered suitable for the cultivation of Camelina in southern Europe is around 501.524 km^2 (around 5% of the whole EU-28 territory), the 69 NUTS2 identified covers in total 1.353.356 km^2 and the 23% of their surface is potentially suitable for the Camelina cultivation, based on the crop modelling exercise and the yield threshold found in the literature (1.45 Mg ha^{-1}).

The modelling framework soil texture which represented less than 5% in the MARS cell 25x25 km^2 were not modelled. Due to their uncertainty these areas are not displayed in the map of the Yield Average per Country, standard deviation, and SOC stock change. From a sustainability point of view Avola et al., (2021) showed negligible effects when high input are applied to Camelina production in a semi-arid environment. Low input regime such as conservation agriculture practices resulted in satisfactory yields in terms of both quantity (yield t ha^{-1}) and quality (oil).

4.1 Biophysical constraints identification and land suitability

A crucial component contributing to the energy resilience of the European Union is land-use and the cultivation of feedstock for the provision of bioenergy. The spatial distribution of suitable land can affect both quantity and quality of the cropping systems as well as the ecosystems and their services. In addition, energy crop can help in recovering degraded lands if inserted in rotation, to cover the soil throughout the year, and mitigate climate change by storing more carbon and reducing GHG emissions. Land planning will require a special effort in order to improve cropping system resilience and avoid further degradation.

The result presented the quantitative analysis of the use of land for the production of Camelina. This modelling exercise is based on the MARS 25 km daily meteorological data and it is upscale at 500 m pixel scale, taking as a reference LUCAS soil properties maps, the results for the suitability, yield and soil carbon are presented at pixel scale and at regional (NUTS2) scale. Previously published reports have described biophysical limitation, morphological and climatic suitability, as key elements to consider when evaluating productivity level (yield) for the production of food, feed and energy. The highest overall suitability will reduce the fertilizers input which is extremely important for the production of biomass for energy purposes, Biochar and Compost amendments can offset C losses in sites where the model showed losses due to the cultivation. It is therefore of particular interest to evaluate, at local scale NUTS 2 level, the land resources necessary to support the production of land-based energy sources and the provision of other services, as demanded by the upstream economic and energy models.

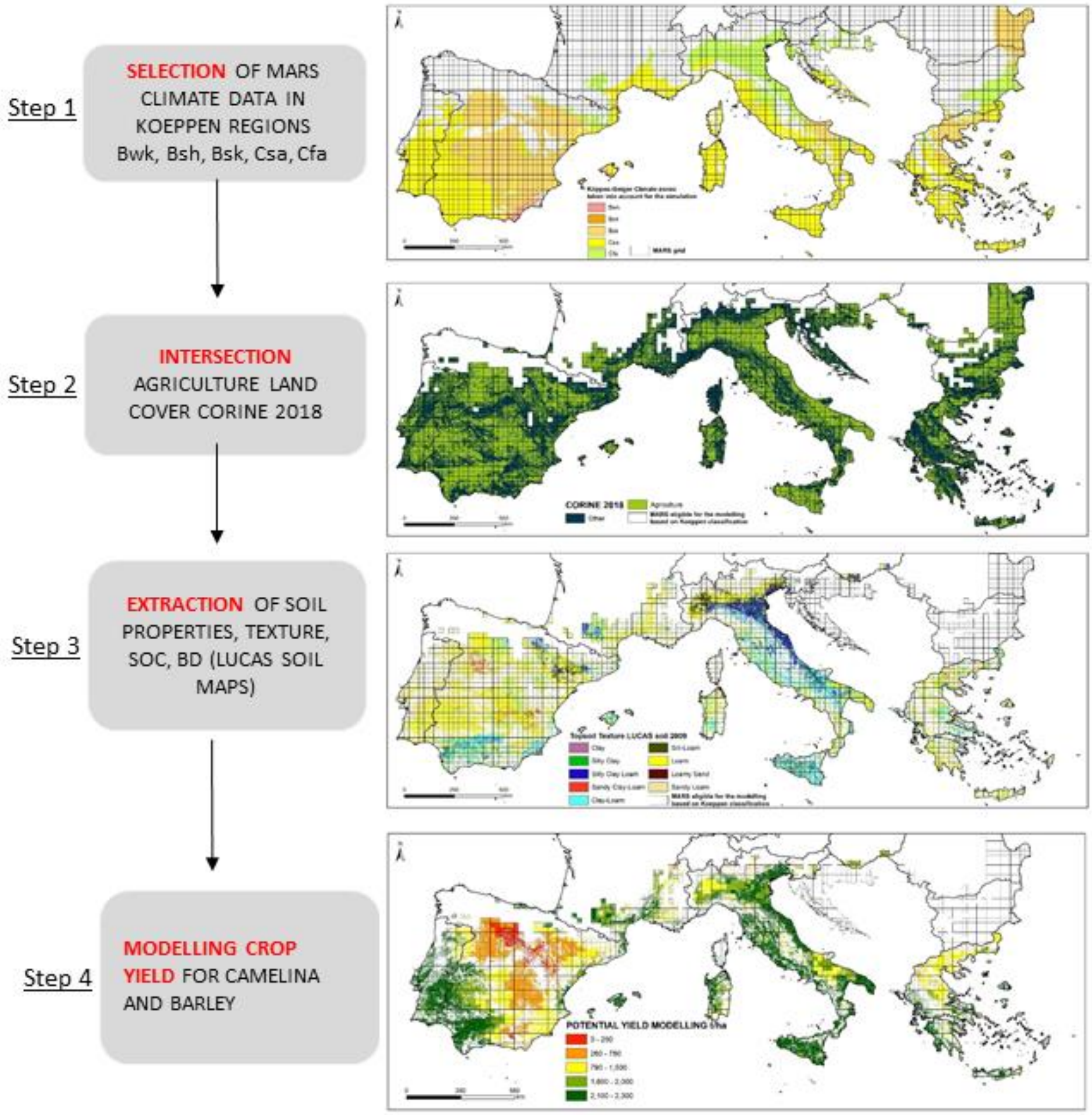


Figure 3. Conceptual diagram showing the four steps performed prior to the simulation using ARMOSA crop model. The Köppen climatic regions offer a long term condition of biophysical conditions throughout the seasons. In the step 2, land cover defined the study area inside the climatic region, LUCAS soil properties provided the physical properties and the initial fertility conditions upon which the model calculated the dynamics due to the cultivation.

4.2 Crop modelling

The ARMOSA model was calibrated using published field trials results having in their framework a set of parameters such as, date of sowing, tillage, fertilization, irrigation. The average yield results are reflecting the interplay among the weather, biophysical characteristics of the land especially SOC and BD. This implies that trade-offs between the use of Camelina as energy crop in the optimal locations and as cover crop in the less favourable.

The references for Camelina cultivation in Europe and in semi-arid climate under open field condition in the study area are few. The average for all the data found in the literature for all sowing time and genotype was 1.5 Mg ha^{-1} ±0.7 Mg ha. With regard to the potential Camelina yield, our results were similar to those obtained in the field experiments in Southern European countries. Results of the calibration, showed good accordance between observed and simulated value.

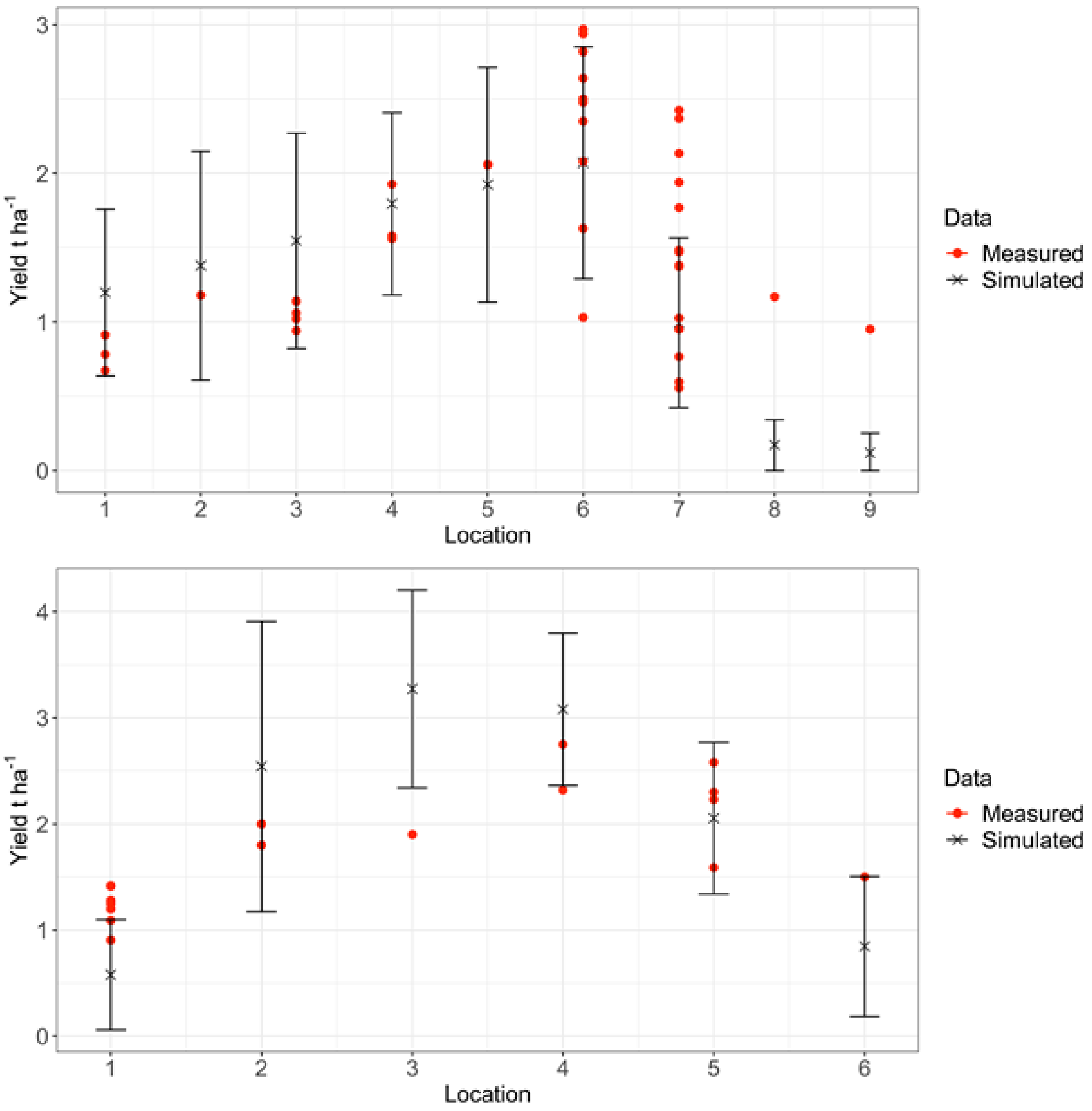


Figure 4. Yields data, calibration and validation sites.

Table 3 data used for the calibration and validation of the ARMOSA model

ID	Paper	Anno	Country	Utilization
1	Angelopoulou et al.	2020	Greece	calibration
2	Zanetti et al.	2017	Greece	calibration
3	Matteo et al.	2020	Italy	calibration
4	Masella et al.	2014	Italy	calibration
5	Cappelli et al.	2019	Italy	calibration
6	Royo-Esnal et al.	2018	Spain	calibration
7	Royo-Esnal et al.	2017	Spain	calibration
8	Stefanoni et al.	2020	Spain	calibration
9	Stefanoni et al.	2020	Spain	calibration
1	Martinez et al.	2021	Spain	validation
2	Avola et al.	2021	Italy	validation
3	Angelini et al.	2020	Italy	validation
4	Tedone et al.	2020	Italy	validation
5	Righini et al.	2019	Italy	validation
6	Camelina Company España	2019	Spain	validation

Based on the potential yield obtained from ARMOSA model at NUTS 2 level over the time period 2000-2020, we can define marginal lands using as a threshold at NUTS 2 level the average yield found in the literature (1458 kg ha^{-1}) the 21% (128.144 km^2) of the 69 NUTS 2 suitable for Camelina cultivation. The remaining 79% (372.230 km^2) performed above the average found in the literature.

Table 4. Low potential yield, marginal NUTS 2 land

NUTS ID	NAME	Yield kg ha-1 CAM	Yield kg ha-1 CAMBAR *taken as reference scenario*	Yield diff CAM-CAMBAR	YieldStd CAM	Yield Std CAMBAR	SOC change kg ha-1 yr-1 CAM	SOC change kg ha-1 yr-1 CAMBAR	SOC difference kg ha-1 yr-1 CAM-CAMBAR	AREA CAM km2	Yield tot per NUT CAM t	Yield tot per NUT CAMBAR t	Area NUT km2	area%
ITC2	Valle d’Aosta/Vallée d’Aoste	617	206	411	249	87	-1245	-960	-285	36	2236	7455	3261	1.1
ITH1	PA Bolzano/Bozen	466	381	85	211	170	-629	-460	-169	406	18906	154765	7398	5.5
ES41	Castilla y León	370	460	-91	324	319	237	255	-19	42125	1557025	19395609	94226	44.7
HU23	Dél-Dunántúl	390	515	-126	170	171	56	76	-20	2047	79800	1055253	14197	14.4
ES24	Aragón	606	586	20	466	468	-31	-61	30	21215	1285262	12435646	47718	44.5
ITH2	Provincia Autonoma di Trento	663	613	50	273	256	-588	-470	-118	662	43938	406210	6207	10.7
ES23	La Rioja	741	663	77	538	437	108	41	67	1188	87981	788188	5047	23.5
ES42	Castilla-La Mancha	777	935	-158	642	639	195	188	7	43140	3352375	40352217	79457	54.3
ES62	Región de Murcia	1012	1028	-17	909	936	-147	-191	44	6293	636718	6471773	11315	55.6
ES30	Comunidad de Madrid	751	1050	-299	581	639	197	236	-39	2968	222882	3115029	8030	37.0
ES22	Comunidad Foral de Navarra	1159	1116	43	697	554	-107	-194	87	3621	419533	4039611	10392	34.8
SI03	Vzhodna Slovenija	1376	1217	158	637	503	-888	-957	69	1129	155350	1374708	12432	9.1
EL53	Dytiki Makedonia	787	1382	-595	324	567	312	563	-251	3306	260241	4568901	9460	34.9
HR06	Sjeverna Hrvatska	1330	1422	-92	563	526	-433	-443	10	8	997	10661	8028	0.1

In the remaining regions, it is possible to identify two different patterns, depending whether the Camelina Yield is high but with a very high standard deviation (Emilia-Romagna, Kriti, Veneto, Peloponnisos, Centro (PT), Umbria, Algarve, Alentejo, Illes Balears, Toscana, Jadranska Hrvatska, Área Metropolitana de Lisboa, Voreio Aigaio, Sicilia, Marche, Abruzzo, País Vasco, Liguria Corse), mostly middle latitudes, and places with high Camelina yield and middle-high standard deviation, Campania, Friuli-Venezia Giulia, Calabria, Lazio, Ipeiros, Dytiki Elláda, Aquitaine, Ionia Nisia, Cantabria, Principado de Asturias).

Table 5. Average and high potential yield NUTS 2

NUTS ID	NAME	Yield kg ha-1 CAM	Yield kg ha-1 CAMBAR *taken as reference scenario*	Yield diff CAM-CAMBAR	YieldStd CAM	Yield Std CAMBAR	SOC change kg ha-1 yr-1 CAM	SOC change kg ha-1 yr-1 CAMBAR	SOC difference kg ha-1 yr-1 CAM-CAMBAR	AREA CAM km2	Yield tot per NUT CAM t	Yield tot per NUT CAMBAR t	Area NUT km2	area%
HR02	Panonska Hrvatska	1599	1488	111	697	630	-671	-755	84	40	6436	59905	23201	0.2
SI04	Zahodna Slovenija	1613	1490	123	570	454	-1109	-1206	97	1114	179658	1659746	7840	14.2
ES52	Comunitat Valenciana	1488	1575	-87	918	947	-3	-61	58	8616	1282444	13571259	23261	37.0
ES51	Cataluña	1289	1596	-306	657	728	-53	-82	29	10866	1401109	17336539	32113	33.8
BG41	Yugozapaden	1048	1603	-555	366	647	269	367	-99	14	1467	22439	20300	0.1
EL52	Kentriki Makedonia	1161	1692	-531	556	849	265	305	-40	9534	1107273	16132490	18847	50.6
ITF2	Molise	1744	1811	-67	835	696	49	-44	93	2722	474843	4930861	4442	61.3
BG42	Yuzhen tsentralen	1045	1852	-808	441	478	233	340	-107	21	2194	38902	22367	0.1
FRK2	Rhône-Alpes	1496	1993	-497	601	535	-278	-299	21	7154	1069861	14255691	44964	15.9
HR03	Jadranska Hrvatska	2189	2041	148	660	457	-949	-1102	153	19	4104	38260	24645	0.1
EL61	Thessalia	1344	2053	-708	509	593	261	345	-85	5995	805885	12306418	14055	42.7
ITG2	Sardegna	1961	2140	-180	885	837	-79	-150	71	11064	2169182	23681179	24114	45.9
ITF5	Basilicata	1862	2188	-326	746	677	78	20	58	5684	1058597	12436865	9989	56.9
ITH5	Emilia-Romagna	2011	2205	-193	724	662	37	-73	110	14985	3014196	33041520	22453	66.7
EL42	Notio Aigaio	1795	2313	-518	851	819	19	1	18	1100	197452	2543906	5307	20.7
FRJ2	Midi-Pyrénées	1912	2325	-413	862	783	28	-71	99	10264	1962374	23864219	45601	22.5
EL30	Attiki	1925	2330	-405	847	828	125	111	14	952	183185	2217313	3817	24.9
EL43	Kriti	2069	2371	-302	1019	1026	77	46	31	3511	726443	8325675	8354	42.0
EL51	Anatoliki Makedonia, Thraki	1360	2373	-1013	508	841	305	378	-73	5253	714180	12464111	14191	37.0
FRL0	Provence-Alpes-Côte d'Azur	1522	2375	-853	644	646	128	203	-76	6176	940062	14665779	31844	19.4
ITF4	Puglia	1904	2390	-487	816	774	80	60	20	15532	2956450	37120716	19365	80.2
EL64	Sterea Elláda	1811	2396	-585	729	703	149	156	-8	4810	871006	11525759	15564	30.9
ITF1	Abruzzo	2334	2405	-71	782	634	-73	-206	133	4837	1128958	11633616	10800	44.8
ES61	Andalucía	1847	2563	-716	885	809	35	81	-45	49183	9085350	126075638	87610	56.1
ITC4	Lombardia	1731	2597	-866	564	433	-115	-102	-13	11164	1932202	28991263	23880	46.8
ITH3	Veneto	2163	2605	-442	653	499	-106	-189	82	10223	2210722	26628549	17756	57.6
ITI2	Umbria	2174	2636	-462	869	795	159	63	97	4306	936194	11352453	8455	50.9
ITC1	Piemonte	1581	2667	-1086	623	590	54	125	-70	10873	1718949	28998430	25399	42.8
ITG1	Sicilia	2376	2668	-292	1076	1198	-51	-112	61	17347	4121559	46273440	25726	67.4
ITI3	Marche	2364	2706	-343	779	871	122	-4	126	5981	1413533	16185799	9383	63.7
FRJ1	Languedoc-Roussillon	1970	2815	-846	856	852	141	125	16	8510	1676280	23960038	27766	30.6
ES21	País Vasco	2350	2820	-470	638	557	-89	-168	79	535	125789	1509228	7230	7.4
ITH4	Friuli-Venezia Giulia	2536	2856	-321	661	417	-494	-651	157	2849	722325	8136263	7708	37.0
ES53	Illes Balears	2211	2867	-656	909	797	-65	-54	-11	2553	564454	7320181	4993	51.1
ITF3	Campania	2481	2967	-486	873	859	-37	-112	75	7419	1840498	22007786	13605	54.5
ITI1	Toscana	2355	3035	-681	943	841	136	57	79	10368	2441157	31469884	22992	45.1
ES43	Extremadura	1960	3059	-1099	1124	897	142	252	-109	25493	4997183	77978030	41631	61.2
PT11	Norte	1514	3130	-1616	675	640	99	311	-212	6652	1007351	20822206	21286	31.3
EL65	Peloponnisos	2141	3213	-1072	798	596	111	206	-95	5904	1263712	18965913	15516	38.0
PT15	Algarve	2200	3214	-1014	1128	869	45	142	-97	1857	408456	5967282	4972	37.3
ITI4	Lazio	2809	3519	-710	898	696	45	-47	91	9663	2714325	34004969	17209	56.1
PT18	Alentejo	2229	3579	-1350	1008	629	114	293	-179	20046	4468906	71745254	31525	63.6
ITF6	Calabria	2747	3823	-1075	797	888	-32	-9	-23	7196	1976917	27507145	15088	47.7
ITC3	Liguria	2458	3827	-1369	821	665	-125	-127	2	883	217063	3379974	5421	16.3
EL41	Voreio Aigaio	2355	3888	-1533	715	473	88	195	-107	1224	288178	4757044	3854	31.7
FRM0	Corse	2503	3929	-1426	791	903	-30	34	-64	950	237680	3731011	8729	10.9
ES11	Galicia	1962	4026	-2064	944	516	-121	50	-171	496	97378	1997961	29571	1.7
PT17	Área Metropolitana de Lisboa	2375	4046	-1671	1054	728	157	361	-204	1215	288675	4917048	2853	42.6
EL54	Ipeiros	2875	4154	-1278	703	573	-387	-390	4	2096	602766	8707558	9164	22.9
PT16	Centro (PT)	2170	4496	-2326	688	646	24	302	-278	9387	2036793	42200983	28150	33.3
FRI1	Aquitaine	3461	4532	-1071	925	481	-350	-500	150	911	315315	4128878	41725	2.2
EL63	Dytiki Elláda	2994	4606	-1612	781	421	-80	19	-99	4629	1385605	21319033	11326	40.9
ES13	Cantabria	4185	4818	-633	817	535	-685	-858	173	714	298581	3437404	5326	13.4
EL62	Ionia Nisia	3892	4908	-1016	682	324	-374	-481	107	1062	413271	5211256	2305	46.1
ES12	Principado de Asturias	4550	5192	-641	994	761	-854	-1146	292	285	129573	1478337	10602	2.7

4.2.1 Scenario Camelina continuous (CAM)

The scenario that consider the continuous cultivation of Camelina over an area of investigation of 500.373.3 km^2, obtained an average yield of 1870±717 kg ha^{-1} yr^{-1}, with an average SOC change of +31 kg ha^{-1} yr^{-1}, and a hypothetical total yield of 82,317,347 t. The high standard deviation reflects fluctuations in yields as a result of extreme weather patterns.

The NUTS 2 that reported an increasing SOC stock after continuous cultivation of Camelina, had a slightly lower potential than CAMBAR but it can be considered beneficial for the soil fertility. Moderate to high losses were observed in fertile regions with a good amount of precipitation throughout the crop cycle. In this context, residue retention is crucial to guarantee soil organic carbon (SOC) and total nitrogen (TN) sequestration to compensate losses (Dlamini *et al.*, 2016; Iocola *et al.*, 2017; Muñoz-Rojas *et al.*, 2015).

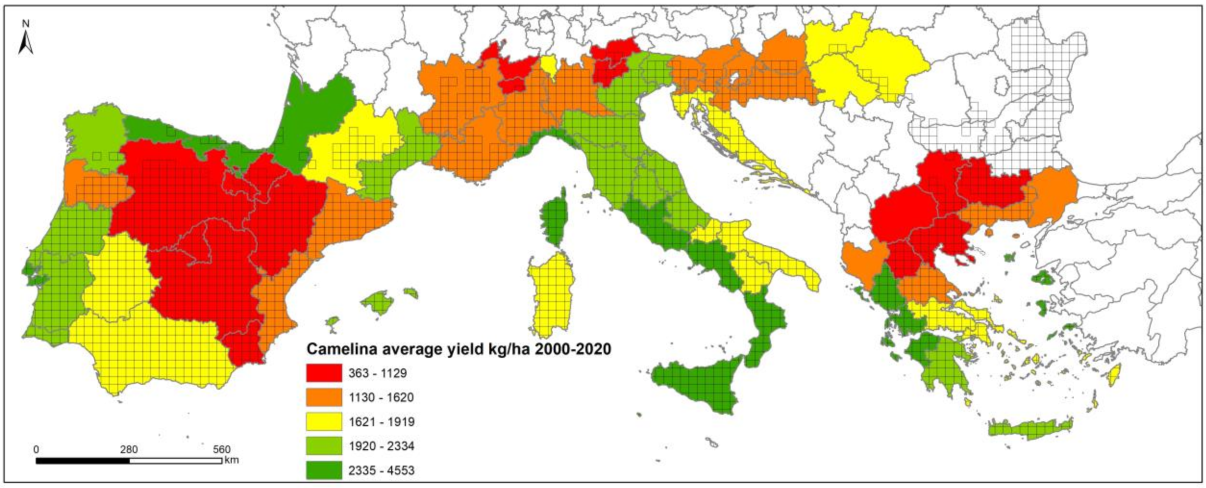


Figure 5. ARMOSA CAM model average yield (kg ha^{-1}) for the period 2000-2020

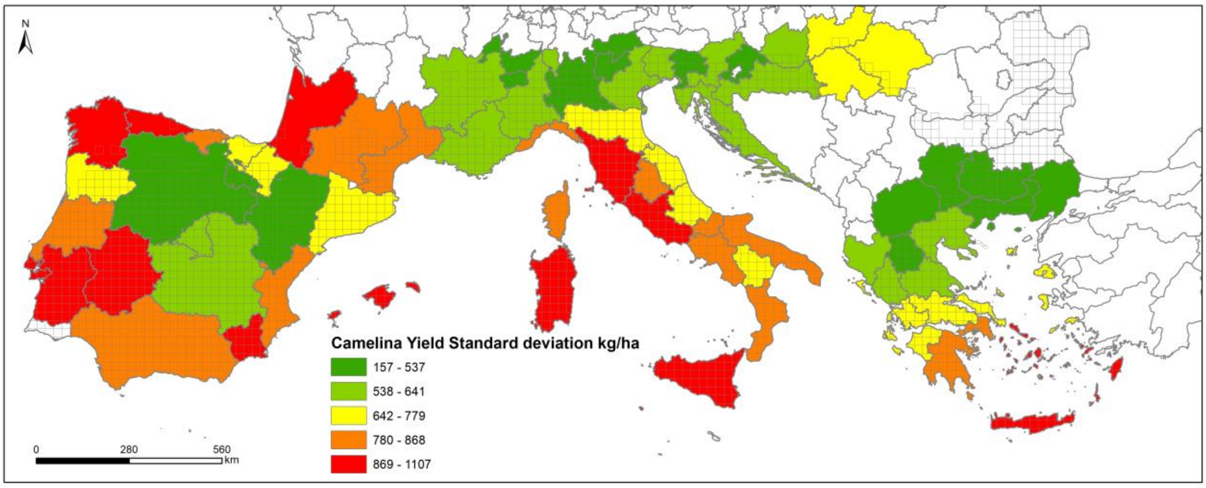


Figure.6. ARMOSA CAM model yield standard deviation (kg ha^{-1})

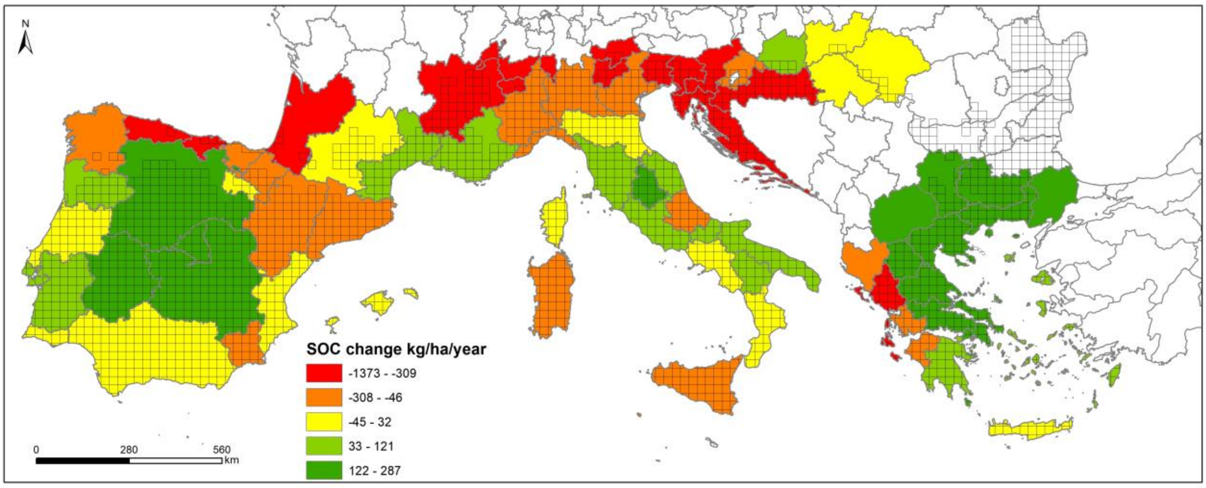


Figure.7 ARMOSA CAM model SOC change in kg ha^{-1} yr^{-1}

Overall, 20 of the 69 NUTS2 regions (30%) presented Average Yield lower than the average Camelina yield found in the literature, whereas in 25 of the 69 NUTS2 (35%) the Average Yield was lower than the calibration average. This can be observed for the Northern Spain, Northern Italy, and Northern Greece, where this trend is probably due to the very different soil characteristics and weather pattern.

All the NUTS2 regions bordering the Mediterranean Sea and some of the inner ones before the Alps were the regions with the majority of the potential crop allocation.

This trend can be used for the allocation of energy crops that can act as winter cover crop and therefore limit the soil loss by erosion, often in combination with the relatively scarce availability of SOC. Examples of this latter case are found in central and southern Italy, western Greece and northern Spain. In addition, the pressure generated by the expansion of tourism and greenhouses can contribute to moving the cultivation of energy crops to less suitable areas.

On the opposite side, regions where the cultivation of cereals and other commodities is decreasing can be suitable candidates for the expansion of Camelina cultivation on degraded land (low SOC and high erosion rates), to lower the pressure derived by inappropriate management or overgrazing.

Few regions across Europe are located in NUTS2 with less than 1 % of the land where the Camelina forecasted.

Finally, in few NUTS2 regions Camelina is well performing crop, Dytiki Elláda, Aquitaine, Ionia Nisia Cantabria, Principado de Asturias, despite some of them are small in area.

Generally, this pattern is also due to the relatively abundant availability of nutrient as well as a favourable weather (e.g, no frost in the germination phenological stage, and dry spells during the flowering phenological stage). This is the case of the region of Central Italy, where the presence of animal farming and rotations mainly cultivated with cereals, that in turn implies high level of organic N distributions.

When analysing the allocation patterns, it is useful to highlight that in some regions, the suitability of the land is high due to the gentle topography and high share of agricultural land versus artificial or natural land covers.

This might further be the cause for some crops to be allocated on highly suitable land.

This information is reported in Figure 5, in terms of share of available land that is suitable (Camelina yield is above the average or higher level).

Country scale focus

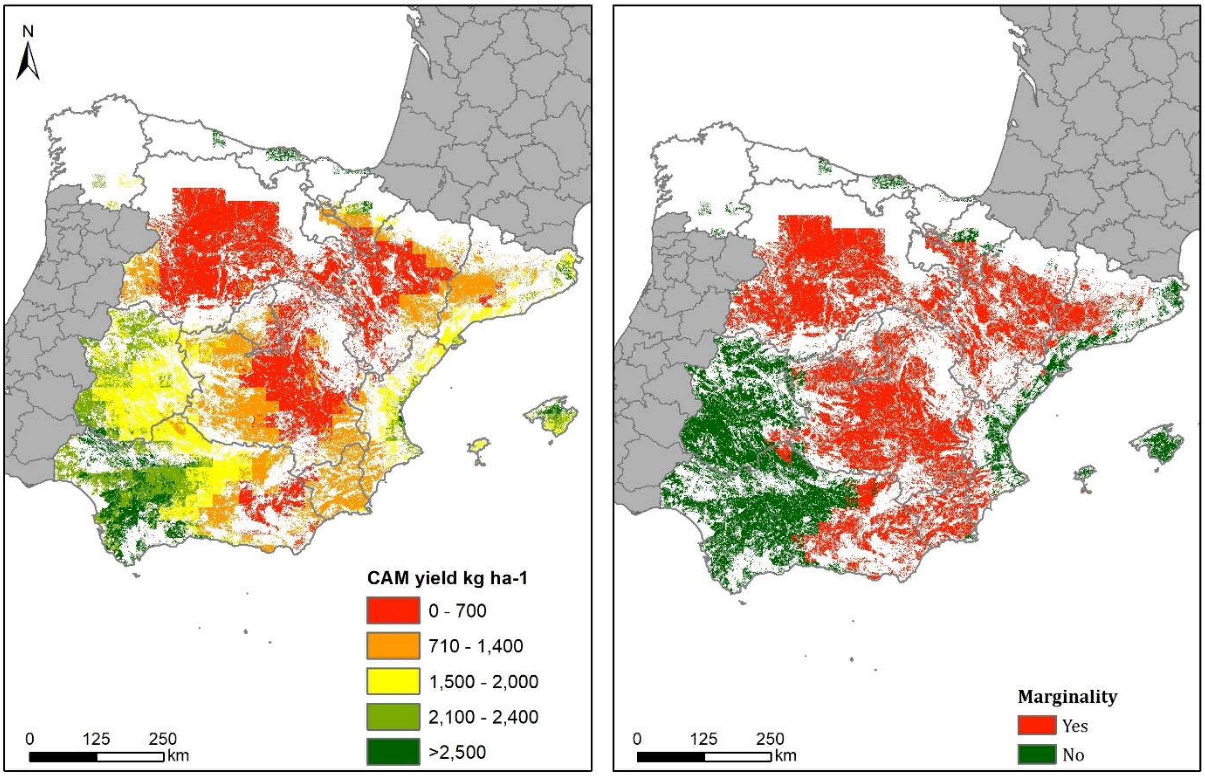


Figure.8 ARMOSA CAM model average yield 2000-2020 kg ha^{-1} Spain

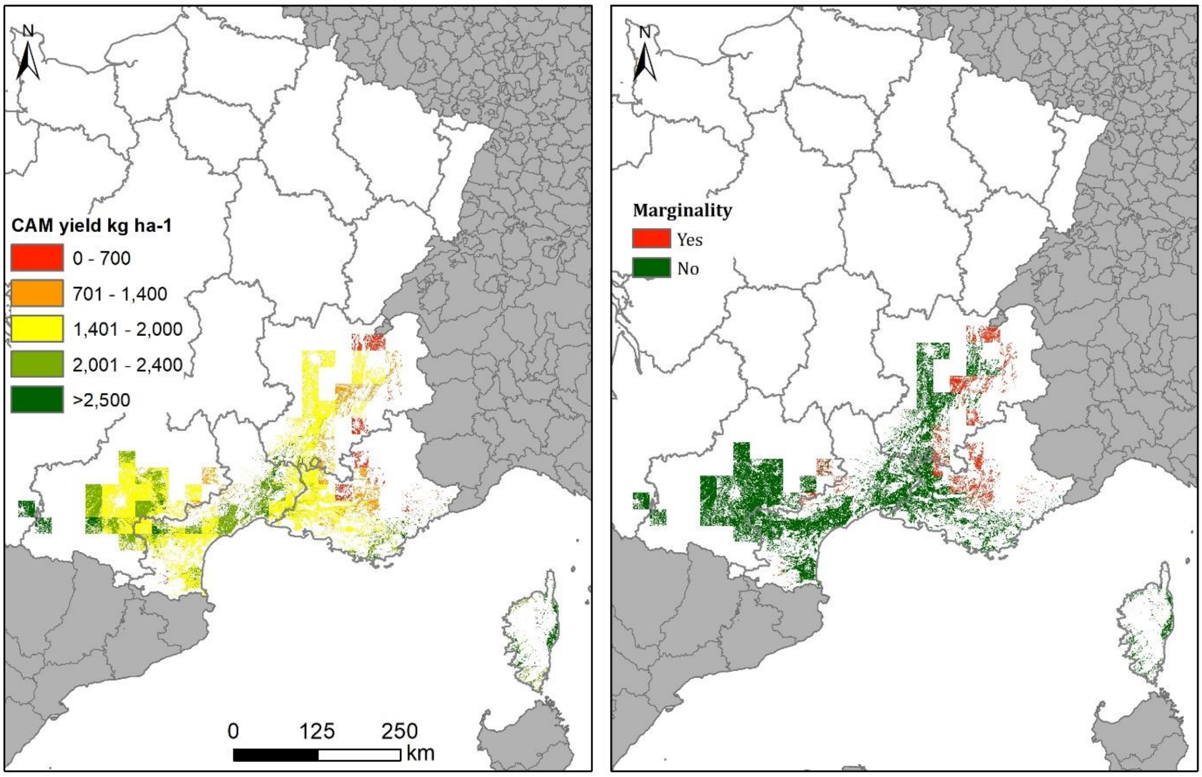


Figure.9 ARMOSA CAM model average yield 2000-2020 kg ha^{-1} Southern France

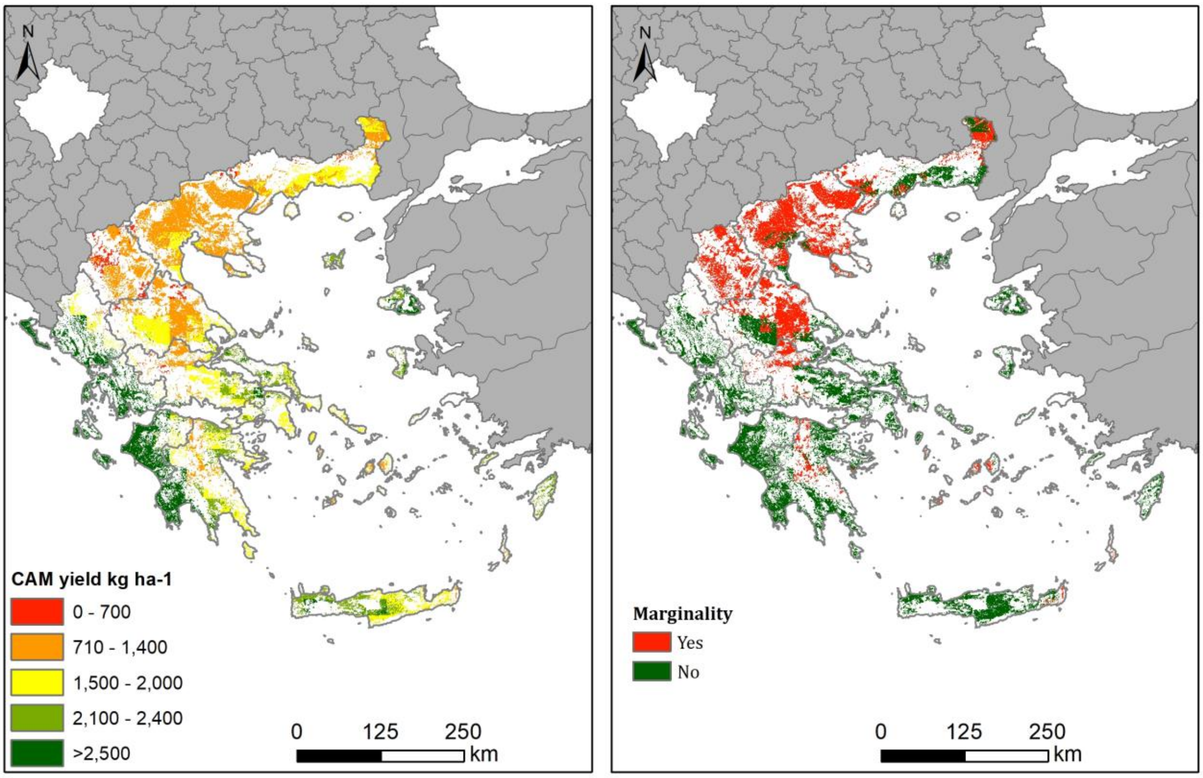


Figure.10 ARMOSA CAM model average yield 2000-2020 kg ha^{-1} Greece

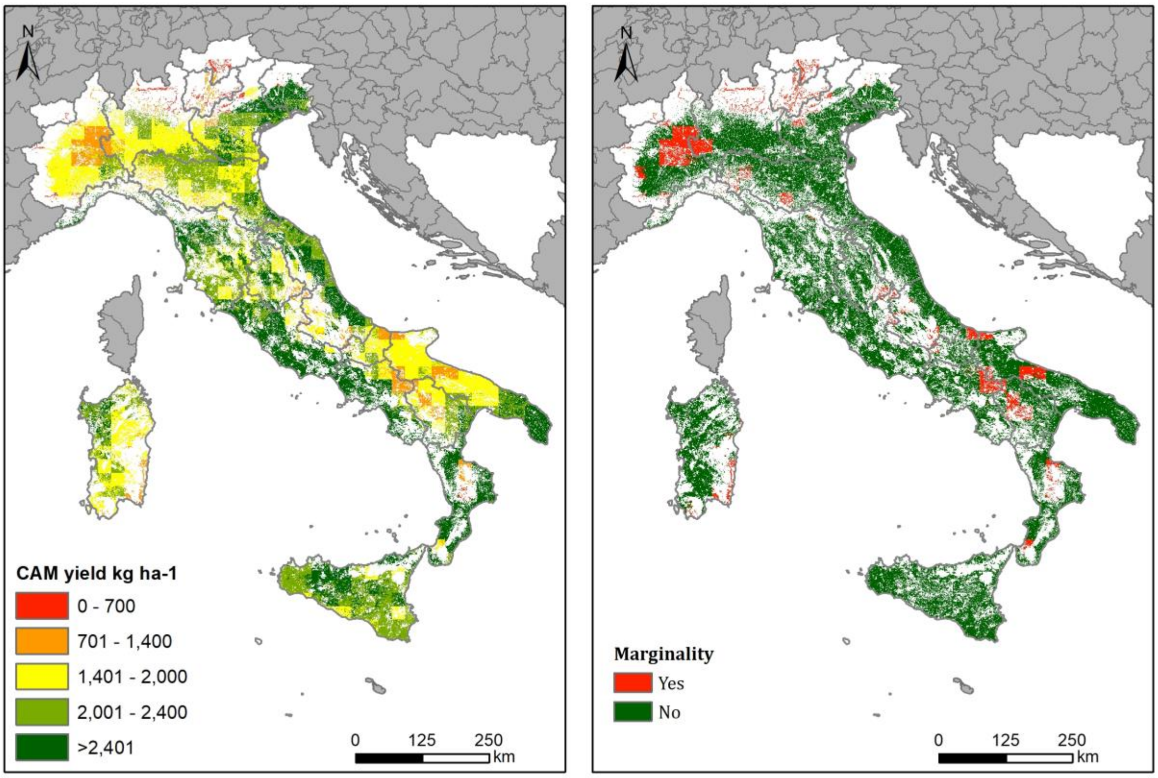


Figure.11 ARMOSA CAM model average yield 2000-2020 kg ha^{-1} Italy

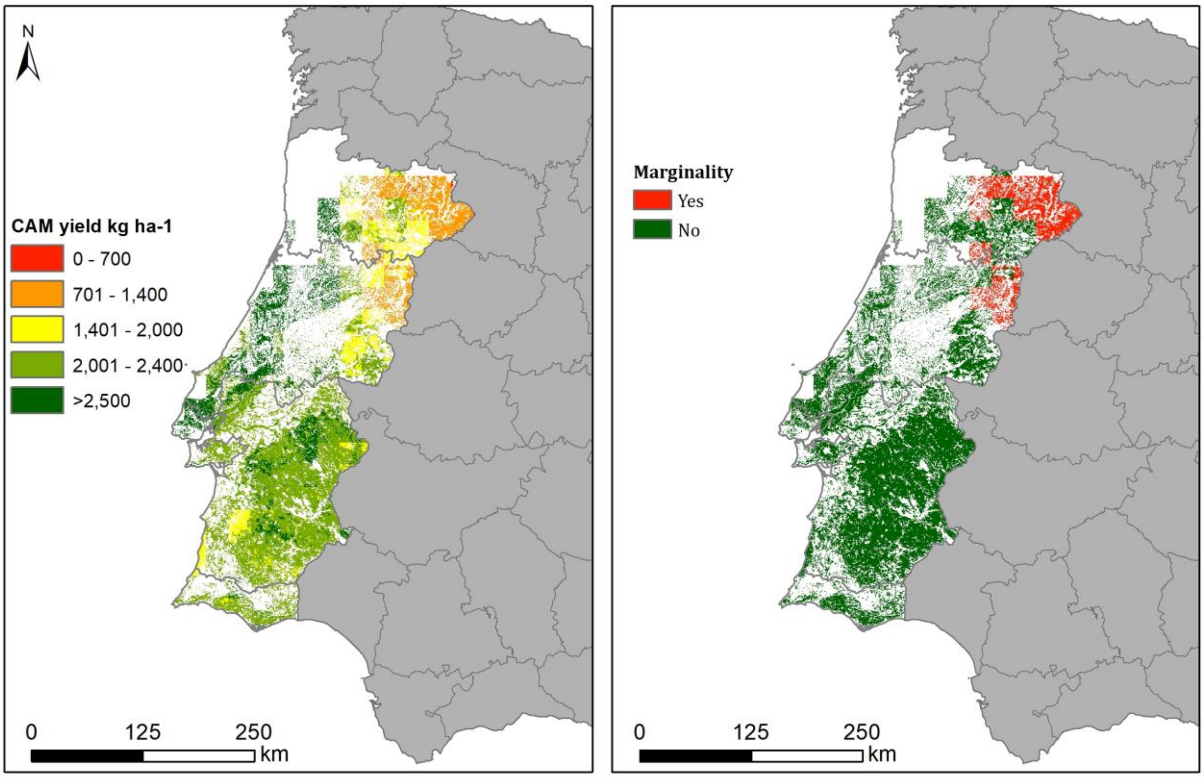


Figure.12 ARMOSA CAM model average yield 2000-2020 kg ha^{-1} Portugal

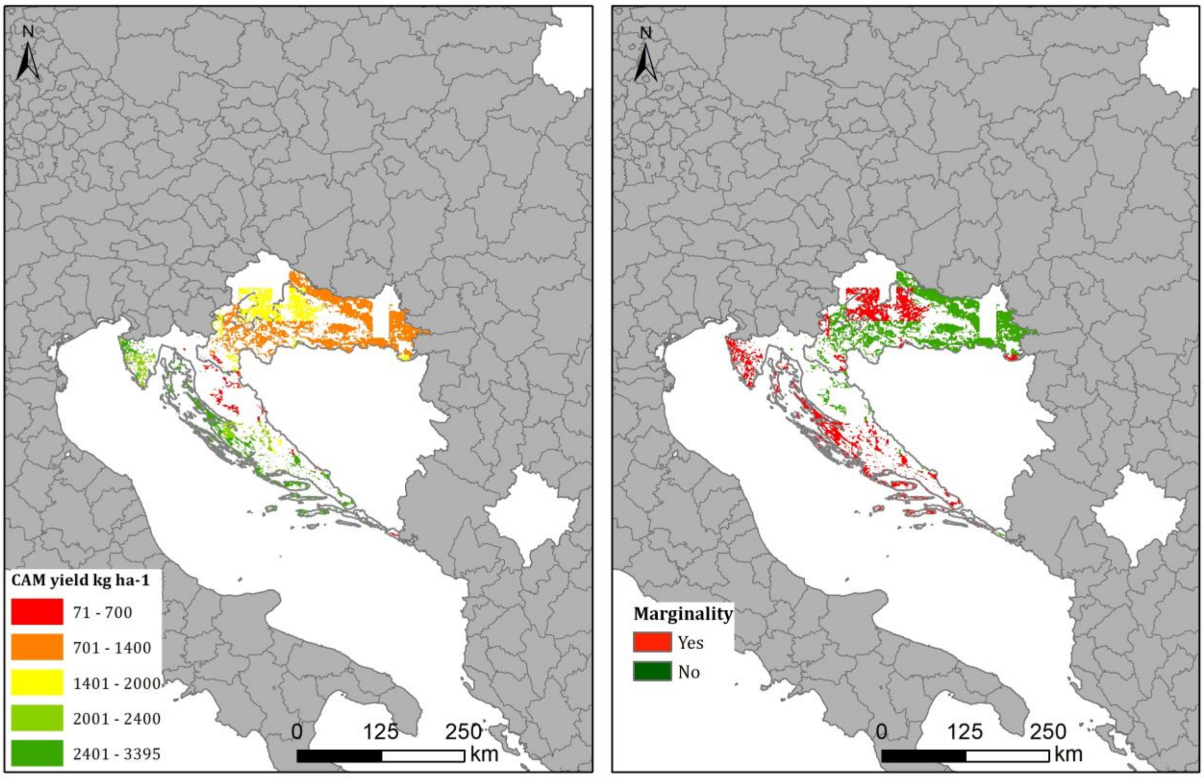


Figure.13 ARMOSA CAM model average yield 2000-2020 kg ha^{-1} Croatia

4.2.2 Scenario Camelina-Barley rotation (CAMBAR)

Despite higher yields, the production of both crops will be available every second year, due to the nature of the rotation, and only half of the production can be insured. The scenario that considers the Camelina in rotation with Barley for the same area obtained an average yield of 2468±641 kg ha^{-1} yr^{-1}, with an average SOC change of +43 kg ha^{-1} yr^{-1}. The SOC is decreasing in 49% NUT 2, at tolerable rates in low fertility land, moderate losses of SOC in soils with high SOC stock prior to the cultivation.

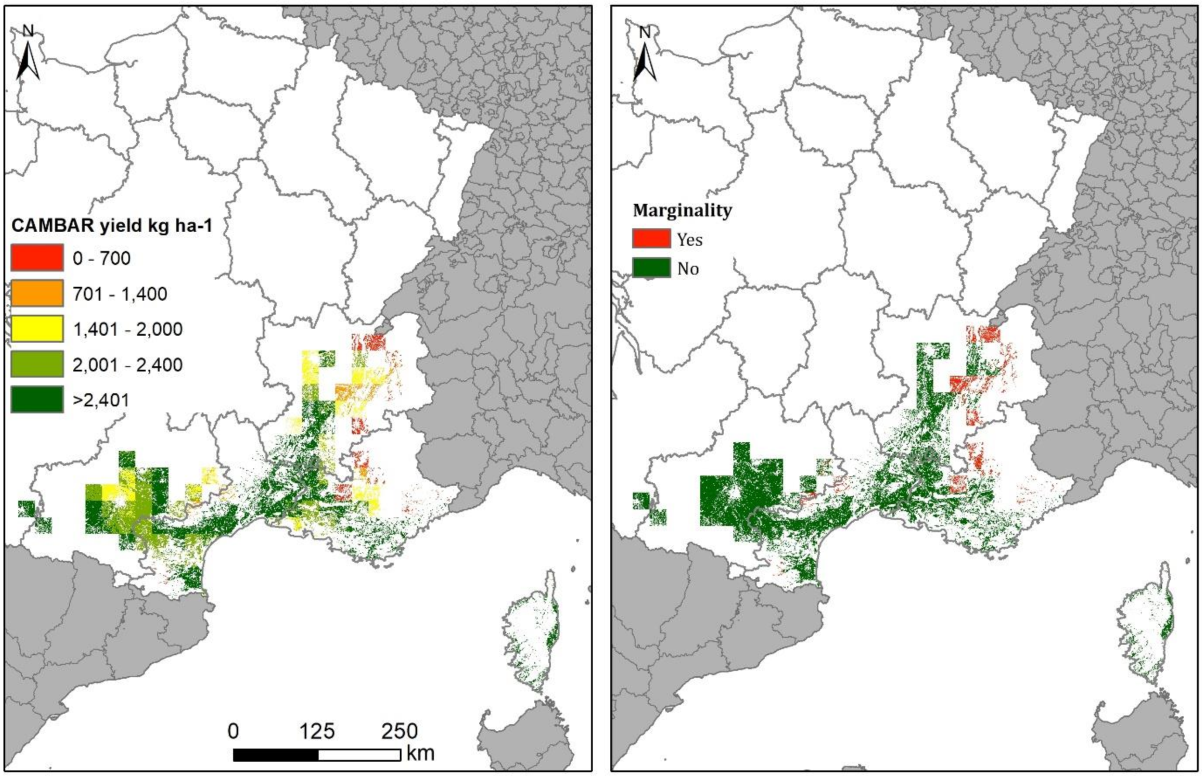


Figure.14 ARMOSA CAM-BAR model average yield 2000-2020 kg ha^{-1} Southern France

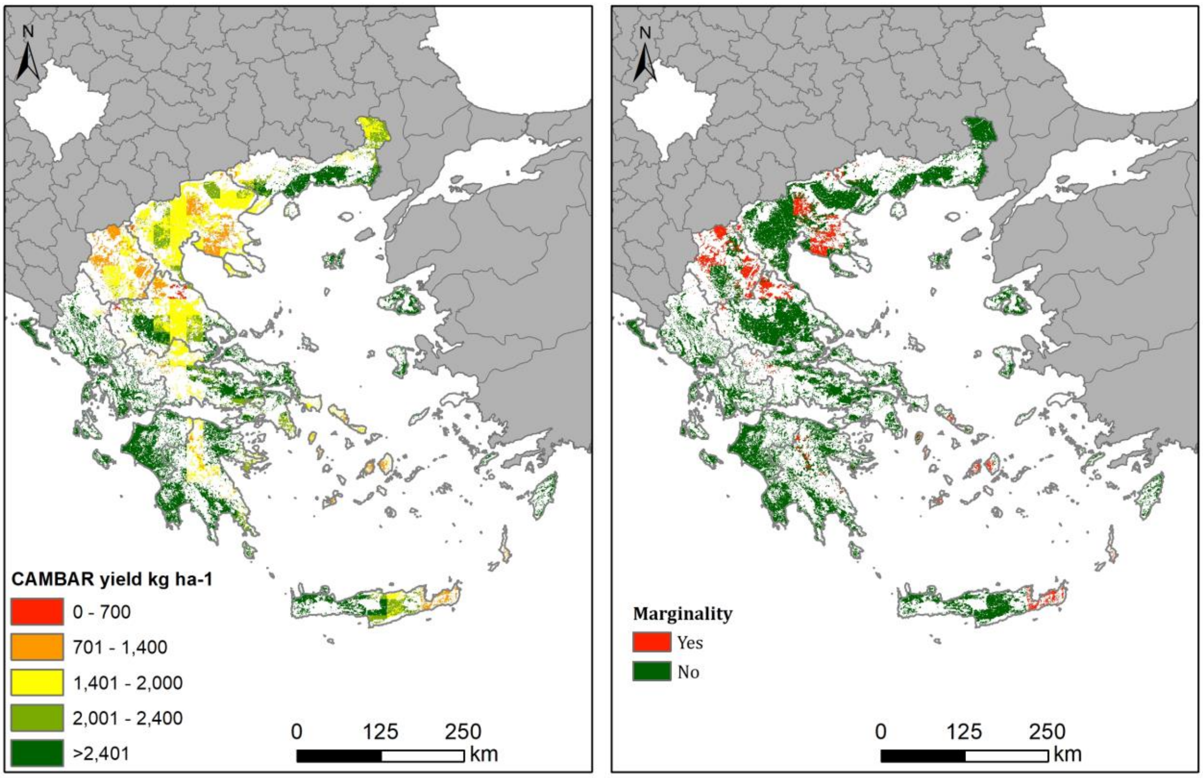


Figure.15 ARMOSA CAM-BAR model average yield 2000-2020 kg ha^{-1} Greece

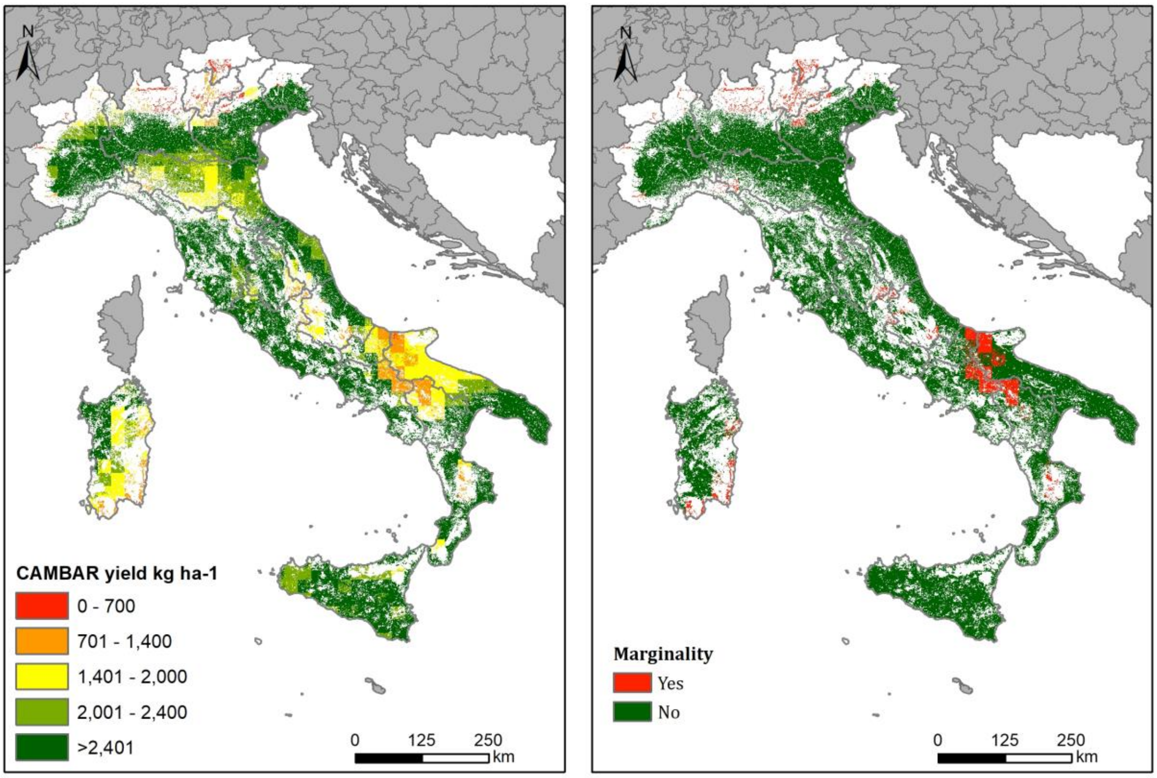


Figure.16 ARMOSA CAM-BAR model average yield 2000-2020 kg ha^{-1} Italy

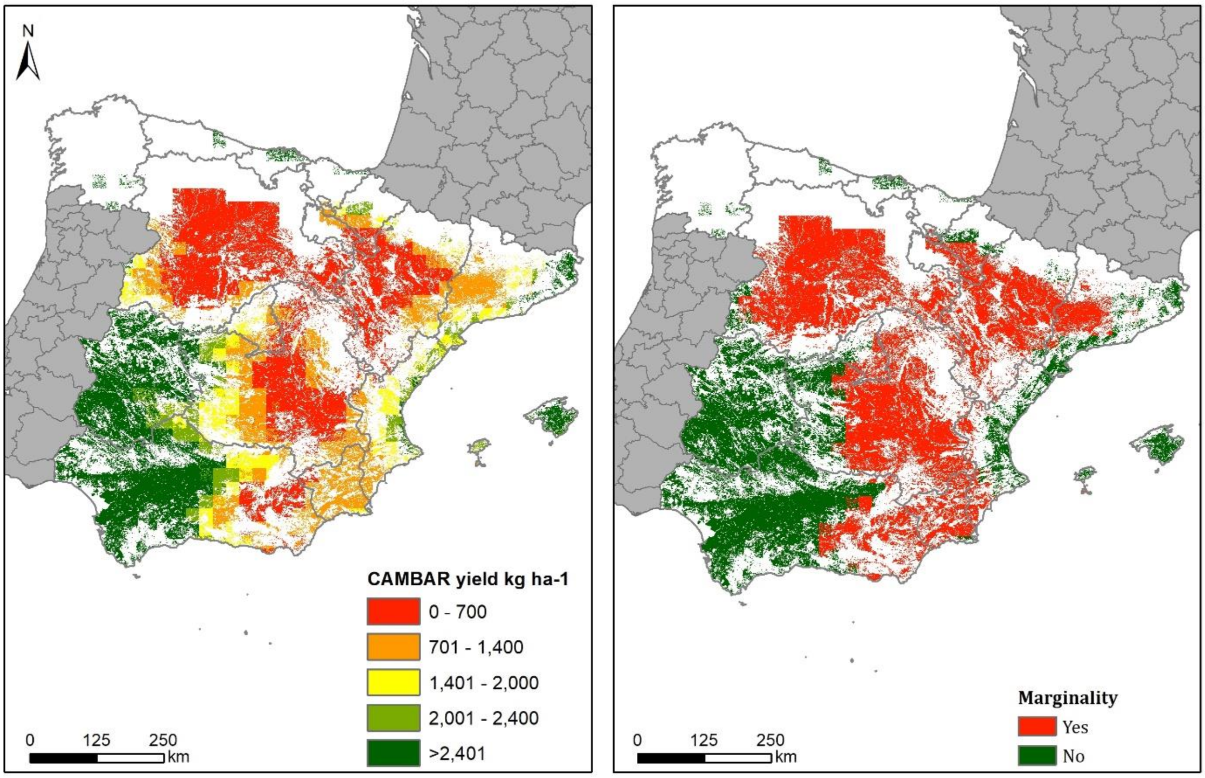


Figure.17 ARMOSA CAM-BAR model average yield 2000-2020 kg ha^{-1} Spain

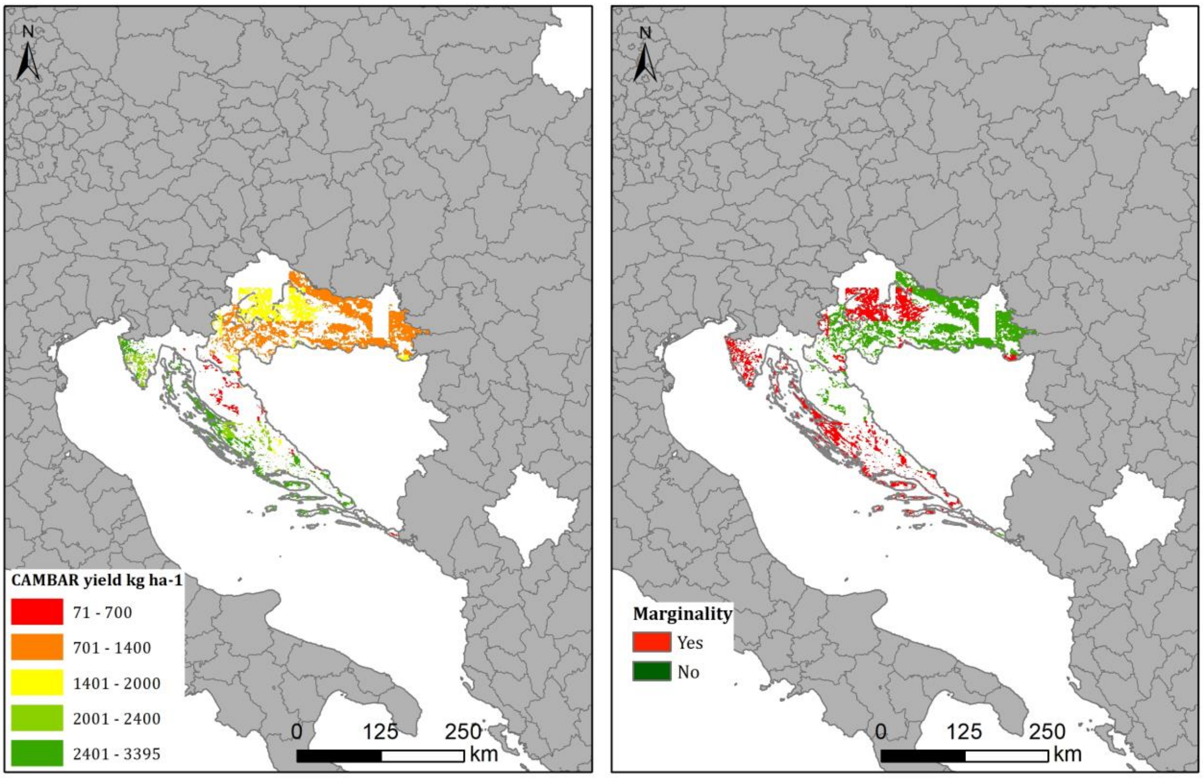


Figure.18 ARMOSA CAM-BAR model average yield 2000-2020 kg ha^{-1} Croatia

4.3 Soil Organic Carbon dynamics modelling results

Meta-analytic findings can help in identify the potential effect of biochar/compost applications as used in the field trials. According with many literature findings, we can consider stable the C content of the specific Biochar (Bio4a has produced biochar from Chestnut) and part of the new SOC pool, but according with the quantity distributed in the field trials (4800kg ha^{-1}) the increase in C of the 0-30cm strata (in average +5% increase in SOC stock). The ARMOSA Model provided the potential SOC stock change due to cultivation of the Camelina in rotation with barley in conventional agriculture. To include biochar in biogeochemical modelling is still not advisable because few evidences are available in the literature on the effect on long term SOC dynamics. As the calibration parameter, we used the mineralization rate of stable carbon (Valkama *et al.*, 2020). Initialization of the model organic matter pools was done by attributing 90% of organic matter at the start of the experiment to stable C pool and 10% to the litter pool and simulating the conventional system for 20 years. At the end of this period, there is a new ratio of stable/litter pools that was applied to the initial total organic C content to run the calibration of the model.

According with the CAMBAR scenario, which is the scenario that makes full agronomical sense, we are delivering NUTS2 averages. This provides a weighted average of +32 kg ha^{-1} SOC change in CAM scenario and +43 kg ha^{-1} SOC change in CAMBAR, which is considered not impacting on soil health. However, if we go into specific NUTS, the situation changes drastically. The average SOC stock decrease in both scenarios in several regions for instance the Spanish País Vasco, Principado de Asturias, Italian NUTS Sicily and Abruzzo. In case we narrow this to the main production areas for Camelina in Spain -semiarid areas with high desertification risk-, namely Castilla y León, Castilla La Mancha and Comunidad de Madrid, the results are far better. These are the regions where it makes sense to produce Camelina from a farmer rotation and a sustainability perspective (to sequester carbon and reduce soil erosion). These are also very large cultivation areas - three regions account for 40% of the total area of investigation in Spain, equivalent to 88.233 km^2. SOC increase for the CAMBAR scenario for each of these three regions is as high +188, +255 and +236 kg ha^{-1} yr^{-1}, respectively. In case the SOC increase for these regions is calculated considering the weighted area, the average SOC increase is as high as +222 kg ha^{-1} yr^{-1}. The results confirm that the SOC stock change obtained by the model parametrization with residues retention ~~attributable to biochar~~ is better in these regions, and can be further enhanced by the application of biochar. These are also the regions where the Camelina field trials in BIO4A were implemented, namely Castilla La Mancha and Comunidad de Madrid.

Table 6. SOC stock, baseline, CAMBAR scenario with Compost and Biochars applications (where SOC stock recovery is possible)

NUT2	Baseline SOC before cultivation started	Area Camelina in Km2	AREA NUT2 in km2	Baseline SOC before cultivation started	SOC change after 20 years rotation	SOC stock baseline + 20 years rotation CAMBAR	SOC stock baseline +CAMBAR+CMP	SOC stock baseline +CAMBAR+WSB	SOC stock baseline + CAMBAR+wob
ES62	47.64	5937	11315	47.64	▲ -2.44	45.2	46.86	45.8	46.463
ITC3	83.00	859	5421	83.00	▲ -2.38	80.6	82.34	81.2	81.937
ES11	109.30	496	29571	109.30	▲ -2.24	107.1	108.92	107.8	108.524
ES22	58.05	2894	10392	58.05	▲ -2.22	55.8	57.71	56.6	57.312
ITC4	62.58	10054	23880	62.58	▲ -2.17	60.4	62.34	61.2	61.938
ITH3	61.99	8661	17756	61.99	▲ -1.85	60.1	62.39	61.3	61.988
ES21	82.05	528	7230	82.05	▲ -1.50	80.5	83.14	82.0	82.739
EL63	68.54	4613	11326	68.54	▲ -1.29	67.2	70.05	69.0	69.651
ITG2	60.24	10835	24114	60.24	▲ -1.27	59.0	61.79	60.7	61.391
ITF1	63.50	4509	10800	63.50	▲ -1.10	62.4	65.39	64.3	64.987
ES53	47.60	2517	4993	47.60	▲ -1.02	46.6	49.66	48.6	49.256
ES51	60.67	9984	32113	60.67	▲ -0.42	60.3	63.94	62.8	63.539
ITF3	61.48	6977	13605	61.48	▲ -0.42	61.1	64.75	63.6	64.349
FRM0	64.60	898	8729	64.60	▲ -0.36	64.2	67.98	66.9	67.582
ITF6	61.04	6958	15088	61.04	▲ -0.32	60.7	64.49	63.4	64.092
ITG1	49.47	14632	25726	49.47	▲ -0.29	49.2	52.99	51.9	52.590
ES24	49.32	19249	47718	49.32	▲ 0.19	49.5	53.80	52.7	53.403
ES52	51.97	8432	23261	51.97	▲ 0.28	52.2	56.63	55.5	56.233
PT16	58.90	9366	28150	58.90	▲ 0.48	59.4	63.96	62.9	63.561
EL42	56.40	1097	5307	56.40	▲ 0.59	57.0	61.69	60.6	61.286
FRJ2	65.27	9170	45601	65.27	▲ 0.66	65.9	70.68	69.6	70.283
ITH5	57.56	12669	22453	57.56	▲ 0.90	58.5	63.47	62.4	63.066
ITC1	58.69	10356	25399	58.69	▲ 1.07	59.8	64.93	63.8	64.532
ES61	46.00	45058	87610	46.00	▲ 1.08	47.1	52.26	51.2	51.859
ITI4	57.59	9499	17209	57.59	▲ 1.18	58.8	64.06	63.0	63.660
PT15	56.59	1773	4972	56.59	▲ 1.22	57.8	63.13	62.0	62.731
ITF2	60.77	2195	4442	60.77	▲ 1.44	62.2	67.74	66.6	67.339
EL43	60.84	3474	8354	60.84	▲ 1.85	62.7	68.63	67.5	68.235
EL41	61.66	1206	3854	61.66	▲ 1.90	63.6	69.55	68.5	69.154
ITF5	54.21	5324	9989	54.21	▲ 1.91	56.1	62.13	61.0	61.730
PT11	71.89	6651	21286	71.89	▲ 2.05	73.9	80.10	79.0	79.702
ES23	41.81	1145	5047	41.81	▲ 2.07	43.9	50.06	49.0	49.662
ITF4	48.51	13703	19365	48.51	▲ 2.17	50.7	56.94	55.8	56.537
EL65	62.17	5873	15516	62.17	▲ 2.45	64.6	71.17	70.1	70.767
PT18	49.58	19658	31525	49.58	▲ 2.50	52.1	58.68	57.6	58.280
FRL0	74.51	5884	31844	74.51	▲ 2.63	77.1	83.87	82.8	83.466
EL30	49.47	944	3817	49.47	▲ 2.74	52.2	59.06	58.0	58.661
ITI3	50.68	5687	9383	50.68	▲ 2.77	53.5	60.33	59.2	59.927
FRJ1	62.90	8232	27766	62.90	▲ 3.00	65.9	73.00	71.9	72.601
ITI1	53.94	9591	22992	53.94	▲ 3.08	57.0	64.20	63.1	63.802
ES43	51.44	25096	41631	51.44	▲ 3.11	54.5	61.76	60.7	61.364
EL64	52.49	4749	15564	52.49	▲ 3.18	55.7	62.94	61.8	62.544
HU23	48.97	662	14197	48.97	▲ 3.25	52.2	59.57	58.5	59.168
PT17	47.41	1202	2853	47.41	▲ 3.36	50.8	58.23	57.1	57.834
ITI2	58.67	4065	8455	58.67	▲ 3.51	62.2	69.79	68.7	69.387
ES42	40.65	40877	79457	40.65	▲ 3.86	44.5	52.47	51.4	52.072
ES30	42.31	2906	8030	42.31	▲ 3.90	46.2	54.22	53.1	53.817
ES41	41.32	40331	94226	41.32	▲ 4.50	45.8	54.42	53.3	54.018
BG42	51.54	19	22367	51.54	▲ 5.14	56.7	65.92	64.8	65.525
BG41	60.56	12	20300	60.56	▲ 5.19	65.8	75.05	73.9	74.646
EL52	40.78	8796	18847	40.78	▲ 5.37	46.1	55.62	54.5	55.222
EL61	43.85	5926	14055	43.85	▲ 5.38	49.2	58.70	57.6	58.303
EL51	39.90	4873	14191	39.90	▲ 6.12	46.0	56.24	55.1	55.836
EL53	46.40	3251	9460	46.40	▲ 6.27	52.7	63.04	61.9	62.636

Table 7. SOC stock, baseline, CAMBAR scenario with Compost and Biochar applications (where SOC stock recovery is not possible)

NUT2	Baseline SOC before cultivation started	Area Camelin a in Km2	AREA NUT2 in km2	Baseline SOC before cultivation started	SOC change after 20 years rotation	SOC stock baseline + 20 years rotation CAMBAR	SOC stock baseline +CAMBAR+C MP	SOC stock baseline +CAMBAR+W SB	SOC stock baseline + CAMBAR+wo b
ITC2	151.88	35	3261	151.88	▼ -24.45	127.4	107.08	106.0	106.685
SI04	127.66	768	7840	127.66	▼ -23.18	104.5	85.39	84.3	84.993
HR03	104.66	15	24645	104.66	▼ -19.94	84.7	68.87	67.8	68.475
SI03	98.16	875	12432	98.16	▼ -17.46	80.7	67.34	66.2	66.936
ES12	137.67	284	10602	137.67	▼ -16.42	121.2	108.92	107.8	108.524
HR02	79.43	24	23201	79.43	▼ -14.76	64.7	54.02	52.9	53.618
ES13	118.16	711	5326	118.16	▬ -12.63	105.5	96.99	95.9	96.590
ITH1	114.44	400	7398	114.44	▬ -11.87	102.6	94.80	93.7	94.400
ITH2	109.07	650	6207	109.07	▬ -11.20	97.9	90.77	89.7	90.371
ITH4	87.30	2481	7708	87.30	▬ -9.60	77.7	72.20	71.1	71.802
EL54	92.62	2094	9164	92.62	▬ -7.47	85.1	81.78	80.7	81.381
EL62	86.11	1055	2305	86.11	▬ -6.99	79.1	76.24	75.1	75.840
FRI1	64.13	905	41725	64.13	▬ -6.66	57.5	54.91	53.8	54.514
HR06	70.13	5	8028	70.13	▬ -5.57	64.6	63.08	62.0	62.682
FRK2	85.15	6945	44964	85.15	▬ -5.09	80.1	79.08	78.0	78.678

Without any addition of Biochar or other organic sources of carbon, under the current climate conditions the simulations of SOC changes showed that during 20 years of Camelina-Barley rotation under conventional tillage, the SOC declined in average in 26 NUTS2 between -24.5 to -1 Mg ha^{-1} on a 20 year modelling results. However, the Camelina cultivation area is limited in this case, amounting to less than 70.000 km^2. In particular, although 14 NUTS2 regions show an average SOC decline greater than -5 Mg ha^{-1} on a 20-year modelling results, the Camelina cultivation area is as small as 10.302 km^2, equivalent to roughly 2% of the study area. 11 NUTS showed very small SOC stock changes (-0.42, to + 0.66 Mg ha-1) whereas 33 NUTS2 showed positive annual SOC changes (+0.90, to + 6.27 Mg ha^{-1}) (Table 2). The Camelina cultivation area where SOC stock changes are positive (over 310.000 km^2) is more than four times larger than the cases where it declines.

Among the three scenarios of SOC recovery, the COMPOST showed a higher SOC stock increase effect in the short term (+4.1 Mg ha^{-1}), Woodchip Biochar allowing the highest rates of C sequestration (+3.9 Mg ha^{-1}) among biochars, followed by Wheat straw Biochar and Compost (+2.98 Mg ha^{-1}).

In contrast, in initially high SOC stock sites reduced their SOC stocks about 2–3 times more compared to middle and low SOC stock sites. One of the reasons is the large difference in residue biomass between the sites that can be derived by the lower yields, therefore lower biomass return to the soil (Figure 19-20).

4.3.1 Compost and Biochar amendments effect

Focused on understanding the effects of cultivation of Camelina and Barley rotation toward the sustainable soil management and climate change on soil biodiversity and cascading effects on soil-based ecosystem services and wellbeing we considered the amendment with compost and biochar. Soil restoring actions should take into account the physical or chemical indicators as well as the improvement of soil structure. SOC is key to maintain the provision of soil-based ecosystem services such as biomass production or water holding capacity, and, as a consequence, even if knowledge gaps still remain, we need to restore it if the objective of 100% healthy soils for 2050 must be achieved.

Biochar use for soil improvement and soil remediation is widely documented in literature (Calamai et al., 2020; Chiaramonti & Panoutsou, 2019). Biochar stores atmospheric CO2 in the soil, it reduces leaching of nutrients, improves soil's water holding capacity and porosity, acts as a space enhancing soil microbiome growth. Biochar can be used for soil remediation due to its capacity to adsorbed organic pollutants.

A recent meta-review demonstrates that biochar has a wide range of agronomic benefits such as higher yields, improved water retention, improve soil structure, and the amount of carbon added is very stable in the mid-term (0-8 years > 85%) (Wang et al., 2016).

According with review of meta-analytic findings, the application of biochar delivered mean positive effects for all soil and crop parameters regarding performance and environmental benefit (Schmidt et al., 2021).

No negative agronomic or environmental effects were consistently demonstrated for soil and crop parameters taken into account in the literature also shows that biochar pyrolysed at 600 °C or higher containing heavy metals do not leach the heavy metals (Roberts et al., 2017), so biochar regulation for soil use should take this into account and define limit values for use of biochar in soil based on risk of heavy metal release instead of concentrations of heavy metals in biochar.

Figure 19. SOC stock, Baseline, ARMOSA and after compost, biochars application Italy.

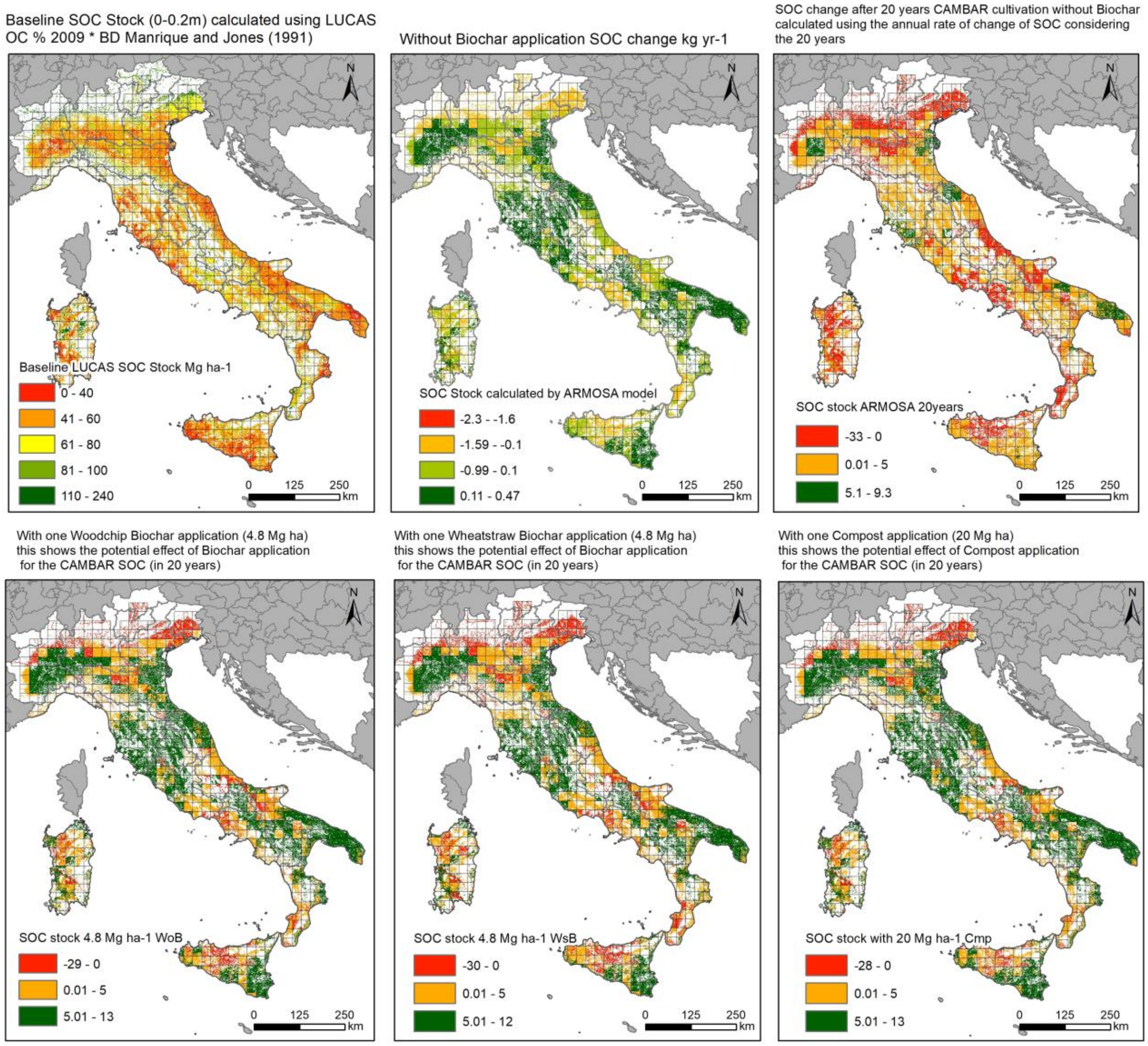
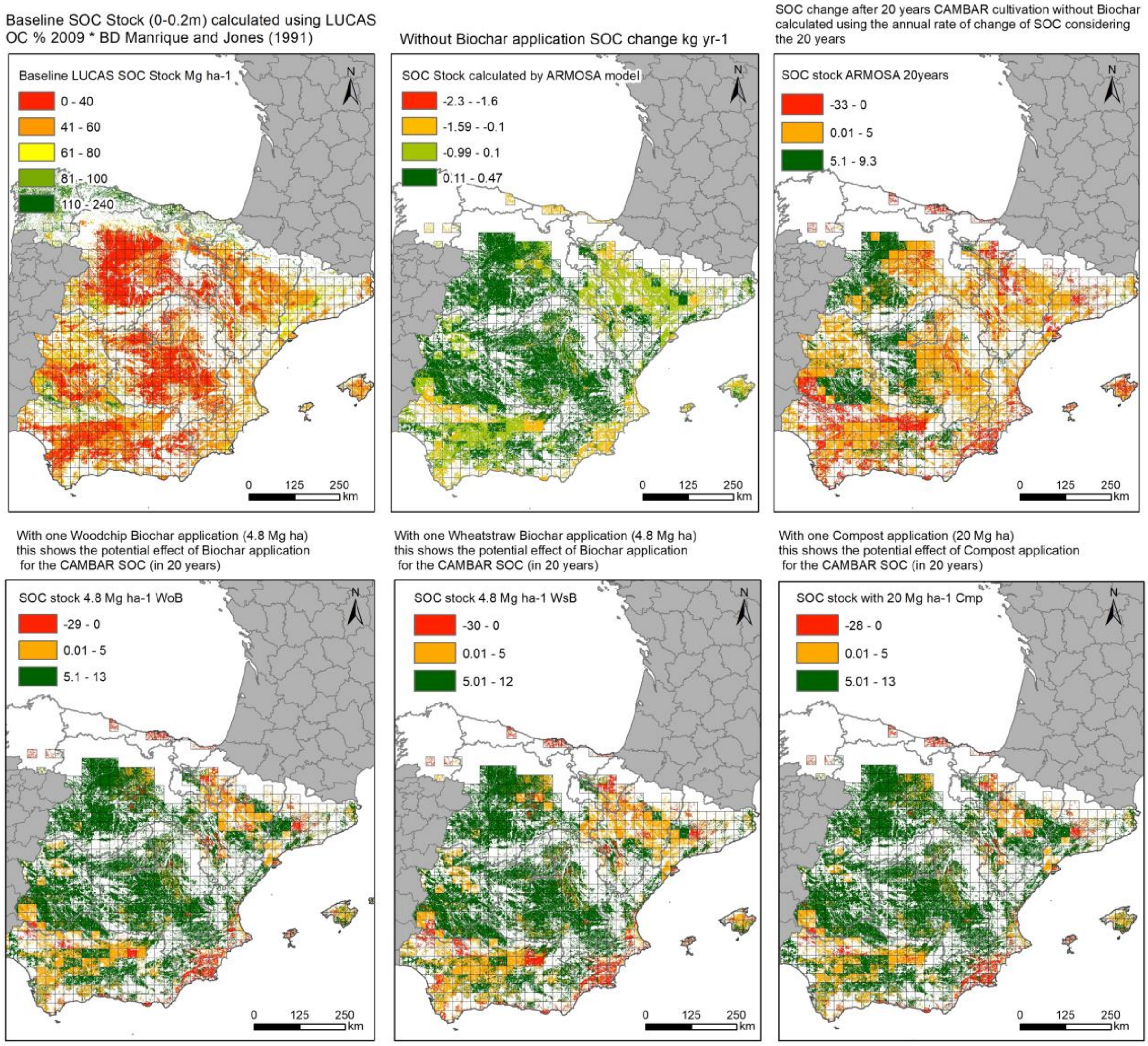


Figure 20 SOC stock, Baseline, ARMOSA and after compost, biochar application Spain.



5 Conclusions

The last report of the Intergovernmental Panel on Climate Change (IPCC) has confirmed the increasing temperature trends and warns of future heatwaves, droughts and flooding. This is a strong message for the scientific community which has to make an effort to deepen the understanding in drought resistant crops and agronomic strategy that can offset climate extremes. In addition, Southern Europe and especially Mediterranean countries are affected by anthropic pressure and cultivation since centuries (Lionello et al., 2006). Favourable land condition such as gentle slope, high soil organic carbon content and water availability were the main driver of agricultural development. Through time, nutrient depletion from the agroecosystems due unsustainable farming practices has led to decreasing productivity and quality of the crop yields, and due to actual production conditions and availability of highly technology machinery, less suitable soils can be improved with the adoption of ad-hoc management strategies.

The analysis at NUT2 highlighted that Camelina can be a valuable and profitable crop to use in cereal rotation across the study area, especially in marginal areas. While only a 2% of the study area shows a SOC stock loss greater than -5 Mg ha^{-1} over a 20-year modelling result, in those cases with SOC stock losses – limited to a maximum of -5 Mg ha^{-1}–, SOC loss can be offset by the application of Compost, or Biochar. Considering the Camelina with Barley rotation scenario (the realistic scenario), the production is obtained every second year and a 24% increase in the yield respect the continuous Camelina cultivation. The Camelina and Barley in rotation scenario represents the most advisable cultivation condition in Southern European countries considered in this analysis. In particular, 33 NUT2 showed positive annual SOC changes (+0.90, to + 6.27 Mg ha^{-1}). The Camelina cultivation area where SOC stock changes are positive (over 310.000 km^2), accounting for more than 310.000 km^2 and more than 60% of the study area, is more than four times larger than the cases where it declines. Maps per Country showed that the suitability pattern follow the fertility and favorable topographic conditions (e.g. southern slopes coupled with sufficient amount of precipitation, or northern slopes in dryer conditions).

Despite the scenarios were deployed over all agricultural land cover according with CORINE 2018, in some NUTS tree crops such as olive groves, vineyards and fruit trees are the main sources of incomes not comparable with the cultivation of Camelina, therefore we do not advise to replace Camelina with any other crop that is in place. However, in some other very large semiarid areas with high desertification risk, Camelina can be sustainably introduced as a rotation crop with barley, providing a large SOC increase. In the regions in Spain where BIO4A field trials are being deployed Castilla La Mancha and Comunidad de Madrid – the SOC increase is much higher than the average value (), reaching +188 and +236 kg ha^{-1} yr^{-1}, respectively. No competition with food crops or impacts on other ecosystem services is foreseen by the cultivation of Camelina with low input inorganic fertilizers and with organic fertilization from compost, or carbon enrichment using biochar to minimize negative impacts. According with the literature, there is limited evidence on the impacts of bioenergy cultivation on soil biodiversity.

In the result section, figures 8 to 13 provide an overview at country scale of the potential Camelina yield allocated per suitability class. The total amount of land that we investigated is reported for the current period in table 3. Spain (206.442,5 km^2 and 348.918 t) has the highest share of land that can be suited for energy crop production. Italy

(140.136,5 km^2 and 275.156 t) showed a higher share of non-marginal land. Most of the remaining countries contribute significantly, ranging from 47.949,5 km^2 and 97.942 t for Greece [4]. In particular, the modelling results showed an overlap between degraded lands especially referred to the very low SOC content. The analysis of the MARS rainfall trends revealed that for the largest suitable NUTS are allocated on the stable areas and they are not affected by drought during the Camelina growing season.

By looking at the near future, considerable expansion of energy crop can be beneficial and become part of the south European agricultural systems, with rotations and consideration as a cover crop that can be harvested optionally. The suitability levels of the land are spread with a pattern that follows mainly SOC baseline stocks and the weather conditions. Areas which experience drought periods during the growing seasons have been subject to failure in single years therefore the average yield obtained on the 20 year timeframe can be lower than the average European yield as it was found in the literature. When the competition for land is highly intense in a given territory, a specific land use/cover might cause the displacement of another one, leading to land-use conversion and, potential negative environmental, economic and social impacts. The competition for land between food and bio-fuel production has become a well-known example. In the long term, this competition might increase the pressure and impacts on the land capacity to support ecosystems and productive systems which deserve to be in-depth investigated.

The territorial assessment carried out by the mechanistic model ARMOSA highlights the current climatic trends and suggests the need of soil amendments in areas where the profitability of the cultivation might be uncertain. In the other hand high yield targets might pose a threat to our land resources in the mid to long term. This might improve less suitable lands at a regional or local scale and increase their fertility and capacity to deliver ecosystem services.

In general terms, growing Camelina on highly suitable land will result in higher yields and reasonable production costs (fertilizer use and tillage). However, as result of the increasing availability of biochar as by-product of energy power plans there is the possibility to sustain yields and offset SOC stock losses in several southern European areas. Cultivating Camelina in rotation with cereals will, in turn, shift towards the use of marginal land for growing energy crops with environmental and economic benefits. However due to the lack of long term specific studies at field-scale in Mediterranean conditions the impact of biochar addition to energy crops has to be carefully evaluated. The approached used in this report can be theoretically carried out in Northern African countries when soil data will be available.

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[4] Literature showed an oil production of 38 to 43% of the seed mass.

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