Would Rainfed Agriculture Be the Right Option Under Climate Change Scenarios? A Case Study from Centro Region of Portugal

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Abstract Agriculture has changed significantly during the last 30 years in Portugal. One of the main changes is related to agricultural abandonment, mainly driven by demographic dynamics on areas that are marginal in terms of productivity. Such trend affects mainly rainfed agriculture, and was significant in the inland Norte and Centro regions of Portugal between 1990 and 2010. By contrast, irrigated areas dedicated to agriculture are increasing. Considering a predicted reduction on water availability under future climatic scenarios, determined by the decrease in the amount of annual precipitation, it is necessary to set strategies to adapt agriculture to a new climatic context, considering both production and consumption/dietary trends. To do so, and using as case study the Centro Region of Portugal, this work aims to evaluate how the suitable area for agriculture might change under future climatic scenarios (RCP 4.5 and 8.5 scenarios for the two time-windows of 2041–2070 and 2071–2100), and identify measures that contribute to adapt agriculture to a new context. Such assessment is based on a

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modelling approach that aims to evaluate suitability to agriculture, which is set from soil properties (soil type and texture), topographic parameters (such as slope and land morphology), and climatic conditions (water deficit). The expected reduction on water availability under future climatic scenarios, combined with recent trends on agriculture, namely the reduction of rainfed agriculture and the increase of irrigated agriculture areas, points to an unsustainable situation. This is of great concern, once there is a match between areas where water deficit is predicted to increase more and areas where irrigated area is expanding today. Thus, specific adaptation strategies/policies are needed to revert/cope with such trends, which must be spatially explicit and locally meaningful. The implementation of such approaches might be oriented by results from assessment of predicted changes in terms of suitable area for agriculture, but also consider economic and dietary aspects, an exercise that we try to validate based on the conditions of the Centro Region of Portugal.

Keywords Rainfed agriculture · Edaphoclimatic suitability model
Water deficit · Adaptation strategies · Climate change

Introduction

Adaptation or Mitigation?

Climate change is now considered to be a major threat to natural ecosystems and human activities, with great environmental and economic costs (Pimentel et al. 2005). Considering the predicted impacts, it is necessary to set priorities and dedicated measures in order to adapt to such a new context, a decision that should be based on the attributes of the territories. That condition demands that susceptibility, vulnerability or exposure should be considered on a first stage, in order to support the identification of adaptation measures that encompass the main vulnerabilities for a specific territory.

Considering the magnitude of foreseen climatic changes, validated by recent trends and observed facts (IPCC 2014), the focus seems to change from *mitigation*, where action is focused on reducing impacts, suggesting at some extent a capacity to *control*, to *adaptation*, indicating that action are oriented by measures focused on adapting to a new context. Despite the prevailing idea that adaptation measures could be also accepted as strategies to reduce impacts from climate change, in the sense of *mitigation,* evidences suggest that such actions must be focused on preparing for climate change impacts (Noble et al. 2014). Nevertheless, when considering farming systems and food systems at large, there is confirmation that a considerable amount of categories of adaptation have positive impacts respecting mitigation (Smith and Olesen 2010; Niles et al. 2017).

Climate Change Is Not in Question

It is not new to science that climate changed in the past, being the magnitude of change dependent on the time-scale considered. Considering large time-windows, several proxies point to different cycles of glaciation during the last 650,000, with climatic changes being attributed to very small variations in the Earth's orbit (Hays et al. 1976; Maslin 2016). But changes can also be detected for smaller time-windows and for recent past periods, such as the century scale (e.g. Little Ice Age) (Oerlemans 2005; Mann et al. 2008), or even at the decade scale (Beniston et al. 1994; Miranda et al. 2006). As expected, changes for small time-window periods are less evident, but can be detected by trends on databases for climatic records (Beniston et al. 2003) or from different proxies (Walther et al. 2002; Lloyd and Fastie 2003; Menzel et al. 2006; Torriani et al. 2007; Schleip et al. 2008; Sorg et al. 2012).

The evidence for climate change is convincing since the late 19th century, and has become an important topic of the 21st century. Current warming cycle is of particular importance since it is extremely likely (greater than 95% probability) that most of it results from human activity since the mid-20th century. Also, the current warming trend is evolving at a rate that is unprecedented over decades to millennia (Santer et al. 1996; Ramaswamy et al. 2006; Santer et al. 2003).

Climate is changing across the globe, modifying weather patterns, and increasing the vulnerability of many countries, regions, economic sectors and populations (IPCC 2014; EEA 2013). According to the records, temperatures warmed almost 0.75 °C from 1906 to 2005, becoming successively warmer than any preceding decade since 1850 (IPCC 2007, 2014). In Europe, from 2006 to 2015, the global average annual temperature was 0.83–0.89 °C higher than the pre-industrial period, with recent years becoming more and more known as the warmest years (EEA 2017a, b).

Climatic changes, including extreme events, have been sufficient to disturb, in different degrees, many of the planet's ecosystems, likely causing the loss of human lives, population displacement, and economic activities, including farming and agroforestry systems (WEF 2016; IPCC 2014).

Climate Change Impacts on Agriculture

Climatic conditions are the primary determinant of agricultural productivity. The water availability in the soil, conditioned by seasonal variation and spatial distribution of rainfall, together with the thermic conditions in each vegetative growing stage, govern, not only the spatial distribution of each type of crop, but also its productive capability, the carbon balance and ecosystem services (Pinto et al. 2006; Chang et al. 2016; Liang et al. 2017).

Therefore, it is highly expectable that climate change will affect the agriculture sector by causing impacts on the suitability and productivity of crops, conditioning the agricultural production (Olesen 2016). In particular, a higher variability in crop production is expected, with loss of productivity in certain crops and increase in others, accompanied by changes in the spatial distribution (Fellmann 2012), raising also concerns on food security and nutritional goals (FAO 2016).

Based on this evidence, agriculture is seriously threatened, forcing agricultural production strategies and design to be reassessed aiming its effective sustainability and resilience under foreseen climatic scenarios. This could entail the recovery of traditional management systems combined with the use of agroecological methods (Altieri and Nicholls 2017).

In Europe, climate change scenarios point to an increase in soil productivity in Northern Europe, favoured by increases in the period of crop's vegetative growth, and reversely by decreases in Southern Europe (Ciscar 2009). Some of the studies developed in Europe, point the Mediterranean Region as one of the most affected areas by climate change, especially in the warmer season, due to decreases in rainfall (ranging from 25 to 30%) and increases in temperature (ranging from 4 to 5 °C) (Skuras and Psaltopoulos 2012). Mediterranean agriculture is particularly vulnerable to the impact of climate change. Chiefly, changes in rainfall patterns deeply impact rainfed agriculture, limiting soil moisture and crop productivity, and new economic models of water use must be taken into account (Calzadilla et al. 2013; La Jeunesse et al. 2016).

For Skuras and Psaltopoulos (2012) the major threats to agriculture in Mediterranean countries, including those derived from climatic constraints, are related with:

- water availability and irrigation demand;
- fertility, salinity and soil erosion;
- conditions of growth, productivity and distribution of crops;
- soil use;
- conditions for livestock production;
- pests and diseases;
- adaptation/recovery in the face of extreme weather events.

As an European Southern country, Portugal is particularly sensitive to current and future climatic conditions shifting patterns. The National Climate Change Adaptation Strategy for Agriculture and Forests (APA 2013) highlighted some problems that will greatly affect the agricultural sector adaptive capacity and building resilience:

- increased impacts on the areas occupied by pasture land, permanent crops and temporary rainfed crops (cereals, in particular);
- water availability, significantly affecting temporary rainfed systems and pastures associated with extensive livestock farming;
- extreme weather events with aggravated impacts on horticulture and agricultural infrastructures;

- pests and diseases with changes in its dynamics and patterns, and new ones will emerge;
- increased susceptibility to desertification, with consequences on soil fertility and erosion.

Adding to these problems, the ageing of the active population in the agricultural and productive sectors, associated with low levels of education, is considered an important barrier to resilience, as a consequence of a greater resistance to innovation (introduction of new technologies and production systems) and weaker investment capacity.

Climate Change, Changing Food Systems and Diets

In a recent study on the vulnerability of the food system in Europe, conducted through consultation with actors and experts, the multidimensional nature of vulnerability was often linked to food system activities such as agriculture, post-production and food consumption (Paloviita et al. 2016).

According to the IPCC, vulnerability is "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes"; and it is commonly agreed to be function of its exposure, sensitivity, and capacity to adapt (Engle et al. 2014).

The concept of vulnerability is frequently addressed in the field of food planning studies, since the negative results of vulnerability affect food security (Paloviita et al. 2016). The Food and Agriculture Organization (FAO) of the United Nations (UN) defined food security in 1996, as: "when all people, at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO 1996).

Food and agriculture are significant contributors to and heavily impacted by climate change. Concerning food system vulnerability, the impact of climate change on the sustainability of the food supply is a priority area, frequently addressed with agricultural suitability and crop yield assessments.

Even if sustainability considerations have largely been absent for years from food security assessments (Gustafson et al. 2016), there is a growing awareness that the food system's contribution to total anthropogenic environmental pressures and CC is considerable (Tukker et al. 2006; Garnett 2011).

Changes in Food Systems are essential to mitigate and adapt to climate change and meet food security demands. While it is estimated that agriculture contributes to 14–24% of global greenhouse gas emissions (GHG), estimates of emissions from agriculture and all the other food system activities are up to nearly 19–29% of all global GHG emissions (Vermeulen et al. 2012). Although agriculture makes the greatest contribution to total food system emissions, a food system approach enables a greater opportunity for adaptation and mitigation to CC, while sustaining food security (Campbell et al. 2016).

In particular, food consumption is a major area for climate change mitigation and adaptation, and there is a growing widespread support for a “demand restraint perspective”. This perspective on sustainable food security proposes a dietary shift as a means of tackling the environmental impacts of the food system, as well as any food-related disease burden (Garnett 2014). Animal protein-intensive diets are at the forefront in terms of GHG emissions (Garnett 2011) and water consumption, as evidenced by recent studies on water consumption related to different diets (Vanham et al. 2017).

In Portugal, there are significant apparent food consumption deviations from the recommended dietary requirements, and food-related disease incidence is the main factor responsible for the years of life prematurely lost (Graça et al. 2016; Pinho et al. 2016). In a recent study for the Mediterranean, Galli et al. (2017) showed that Portugal had the highest *per capita* ecological footprint for apparent food consumption, mostly because of an animal protein-intensive diet (Galli et al. 2017).

The resolution for these problematic trends requires policies and actions to shift eating patterns, which need to target health, and sustainability-relevant consumption practices (Garnett et al. 2015). However, the National Climate Change Adaptation Strategy (APA 2013), does not consider the food system, either from the perspective of food supply or from a demand restraint perspective. Only recently, the food system was included as a key sector in a climate change adaptation plan developed for a group of municipalities, and strategies for joint action on adaptation, mitigation and food security were identified (Saavedra Cardoso et al. 2017a).

The linkages between the critical domains of water and food security require integrated approaches in the context of climate change. Therefore, sustainable food security should be pursued by balancing agricultural specialization, with protecting or promoting diversification of production from city region food systems (CRFS) (FAO 2012). The potential of CRFS to build regional food self-reliance has also been considered as a strategy to enhance resilience and promote sustainable land use and food and nutrition security (Ruhf 2015; Paci-Green and Berardi 2015).

Given the fundamental role of agriculture in human and animal welfare, there is a worldwide growing concern with the need to adapt agriculture and agroforestry (and forest systems) in order to better handle changing climate conditions and to preserve their multifunctional services. Rapid changes and transitions to climate change-resilient farming systems increasingly call for effective national and regional governance systems, financial support and investment in the sector as to promote innovation for sustainable agriculture, rural prosperity and food security (FAO 2017).

Measures to adapt agriculture, or other sectors, to a new climatic context demand the existence of studies that evaluate exposure, vulnerability and susceptibility to climate change. Considering all this, the main objective of this study was to produce spatial outputs that might help on the definition of adaptation measures focused on improving the capacity of agriculture to adapt to a new climatic context at a regional level, i.e., in the Centro Region of Portugal. Last, but not the least, this work also aimed to develop an algorithm that might be applied in other territories and for different resolutions.

Study Area

The Centro Region of Portugal, located at the central part of the Portuguese mainland, is a territory that encompasses very different environmental conditions, namely a significant difference between inland and coastal areas. While on low altitude coastal areas it is clear the dominance of gentle slopes, inland significant areas are associated to steep slopes, namely on "Cordilheira Central" (Fig. 1), one of the most important mountain massifs of the country.

In particular, only 34% of the region presents very gentle slopes (<5% of slope), and only 4% presents soils associated with high productivity (e.g., fluvisols), which are associated to alluvial plains mainly located at the end sections of the main rivers, mostly on western areas, used by intensive and irrigated agriculture. Only 9% of the area used by agriculture in the region is associated to such conditions, namely very gentle slopes and soils with high productivity. In the inland, despite the existence of areas with gentle slopes, those are very often associated to poor soils, namely on granitic substrates.

In terms of climate, the region is associated to a Mediterranean pattern, with significant differences in terms of rainfall and temperature regimes, determined by the distance to the Atlantic Ocean and altitude. The higher values of precipitation are associated with the mountains, whose summits are among the wettest in Portugal, while lower values are registered on easternmost inland areas, especially those located southeast and leeward to "Cordilheira Central". Such dryer areas are also those with higher variation in temperature along the year. Winter frosts are common, and hot and dry summers are particularly long. On the opposite, coastal areas have higher values of precipitation and lower temperature range, a fact associated to the higher influence of the Atlantic Ocean. In fact, frosts are very unusual on these areas. According to projected climatic scenarios, average annual precipitation will decrease in the region, mainly on southern and inland areas (Fig. 2), and average temperatures will increase; a spatial pattern that is clearly detected on results for water deficit (Fig. 11). In terms of extreme weather events, projections predict an increase in frequency, intensity and duration. It is expected an increase in the number of days with average maximum temperatures higher than 30 °C/35 °C, and in the number of days with precipitation higher than 20 mm. Such changes are also more pronounced on the southern and inland areas. The only change that benefits agriculture is related with the decrease in the number of frost days, associated to a projected rise on average minimum temperatures[1].

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[1] Projected scenarios produced by IPMA—Portuguese Institute for Sea and Atmosphere, 2017. An online version can be accessed on http://portaldoclima.pt/.

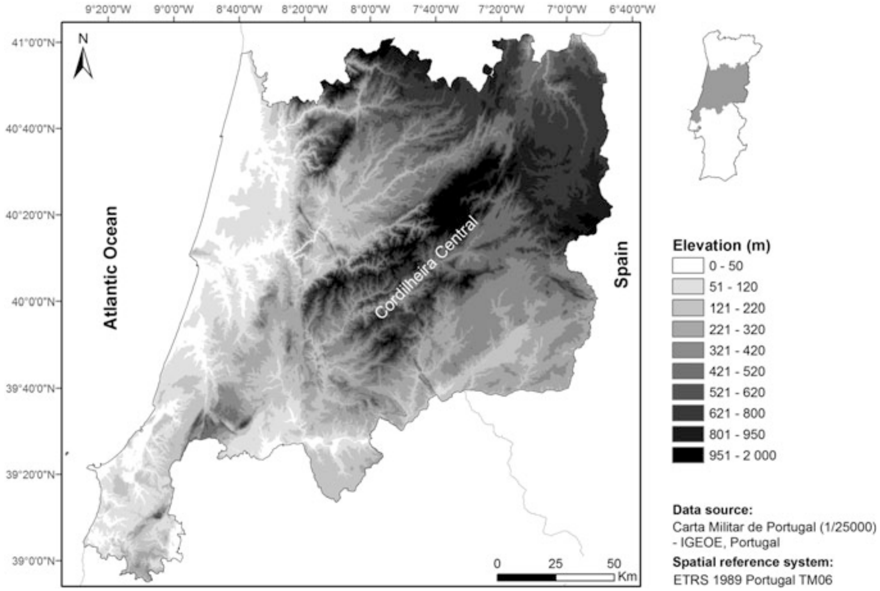

Fig. 1 Topography for the Centro Region of Portugal

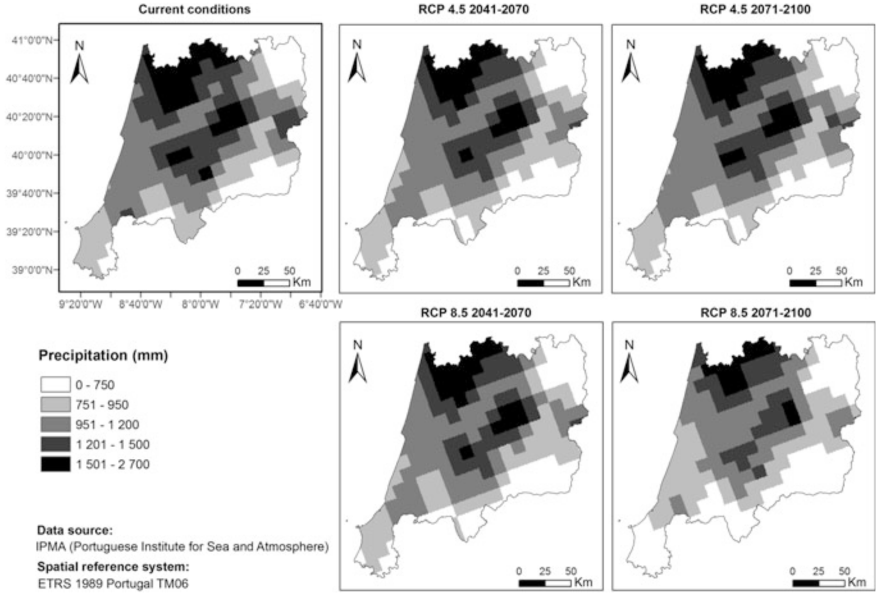

Fig. 2 Spatial distribution for precipitation for current climatic conditions and projected scenarios

Land Use

Topography and soil conditions are important to understand current land use patterns in the region. For the period under study (1990–2010), *forest and semi-natural areas* are the land use class with higher representation in the Centro Region, and registered an increase on importance of about 6% along this period (60–66%) (Fig. 3). Such evolution is mainly supported by the abandonment of agriculture, allowing the conversion of such areas to forest. In fact, from 1990 to 2010, the area dedicated to agriculture decreased about 7%.

As expected, the geographic pattern exhibited by agriculture is deeply associated to topographic and soil conditions. The areas where agriculture assumes higher importance at the landscape level are associated to gentle slopes, namely on the south-eastern sector and on the western areas (Fig. 4).

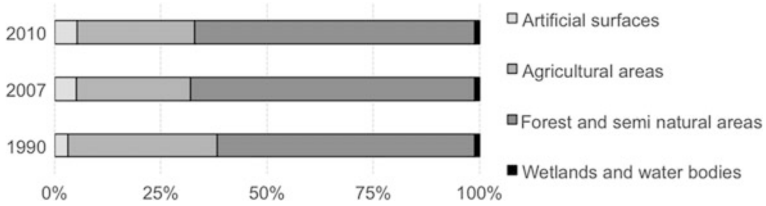

Fig. 3 Land use changes in Centro Region of Portugal between 1990 and 2010 (level 1). *Source* Carta de Ocupação do Solo, DGT (1990, 2007, 2010) (Land use and cover)

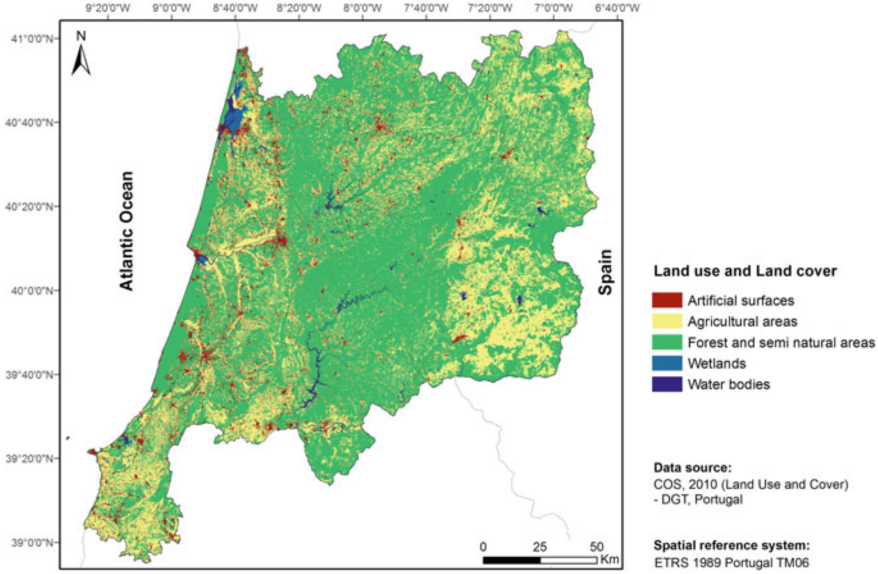

Fig. 4 Land use in Centro Region Portugal in 2010

While in the eastern sector rainfed agriculture is dominant, in western areas practices related to irrigation are significant, being very often associated with alluvial plains, where hydro-agricultural plans were installed. In fact, the potential area for irrigation is higher on the western part (Fig. 5—left), where irrigated area registered a higher increase between 1989 and 2009 (Fig. 5—right).

Such trend is clearly associated with investments on agriculture to ensure higher productivity, but increases water dependency. Moreover, it is opposite to the dominant pattern on inland areas, where it is clear an increasing conversion to extensive practices, namely to pastures or agroforestry systems on areas with poor soils, low availability of water, slopes unsuitable for the introduction of technology, and the prevalence of aged people, configuring very often a pre-stage to abandonment.

The loss in terms of area dedicated to agriculture is a common trend to inland Norte and Centro regions of Portugal, and is associated to important socio-demographic changes, namely associated to emigration to Europe (Almeida et al. 2009), promoting important changes on landscape (Almeida et al. 2012). Until the 1960s, agriculture was the most important activity on rural areas, a fact clearly identified by the dominance of area dedicated to such activity in the rural landscape. In fact, such activity played a major economic and cultural role, very often in combination with other activities, namely forestry and livestock production (Nunes 2008). Socio-demographic changes, in association with environmental constraints (steep slopes, nutrient-poor soils) and land holdings attributes (size, access), deeply contributed to abandonment, a trend that was reinforced after the implementation of new agricultural policies by the European Union (EU), namely the "set-aside" program, which promoted a breakdown in the productive system and the massive abandonment of agriculture in areas of low productivity. Such result is also determined by the lack of capacity to adapt to more competitive markets, contributing to the marginalization of such areas (Alves et al. 2016). In fact, 60 of the 100 municipalities of Centro Region are fully or partially classified as disadvantaged areas for agricultural activities (Portaria n.º 22/2015, de 5 de fevereiro).[2]

Non-irrigated land, which is associated to rainfed agriculture, registered a loss of about 20% between 1990 and 2010 (Fig. 6). In a more detailed analysis, it is possible to identify annual crops and olive groves as two types of rainfed agriculture that registered the highest decrease in terms of occupancy area (Fig. 7).

With an opposite trend, the area dedicated to irrigation increased, corresponding to 20% of the total area occupied by agriculture in 2010 (Fig. 8). Such increase in area is mostly promoted by an important expansion of irrigated annual crops, which increased 32% between 1990 and 2010. Because of their cultivation particularities, rice fields were the less important crop, concentrating essentially on the Lower Mondego valley.

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[2] Portaria n.º 22/2015, 5th of february. Diário da República, Série I, n.º 25. Ministério da Agricultura e do Mar, 694–698.

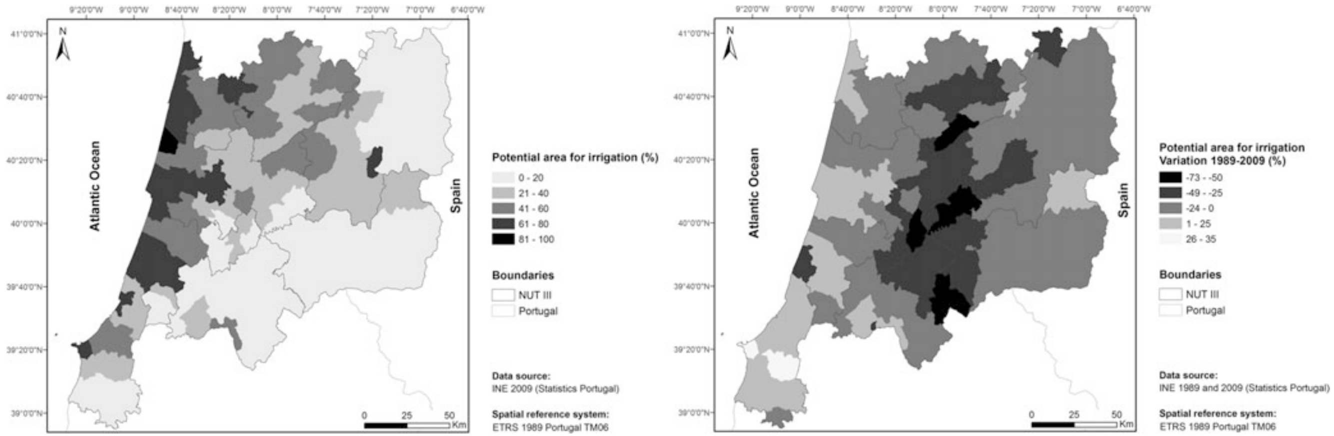


Fig. 5 Potential area for irrigation (2009) (left) and variation of irrigated area between 1989–2009 (right)

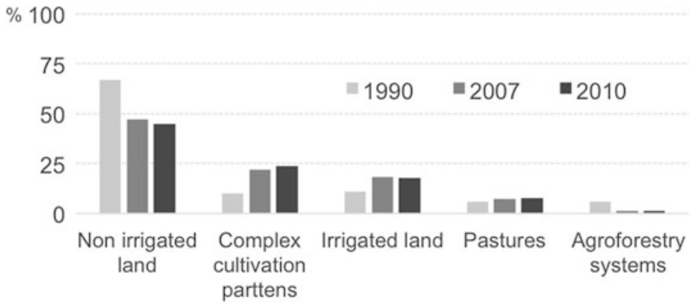


Fig. 6 Changes on area for different types of agriculture in the Centro Region (1990–2010)

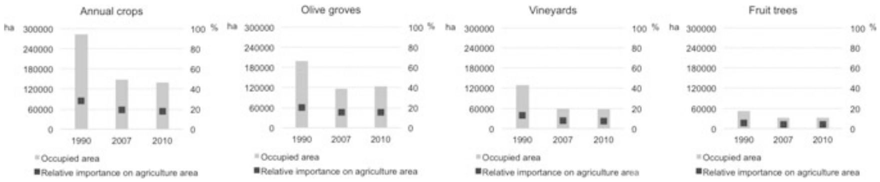


Fig. 7 Changes in area for different types of rainfed agriculture in the Centro Region (1990–2010)

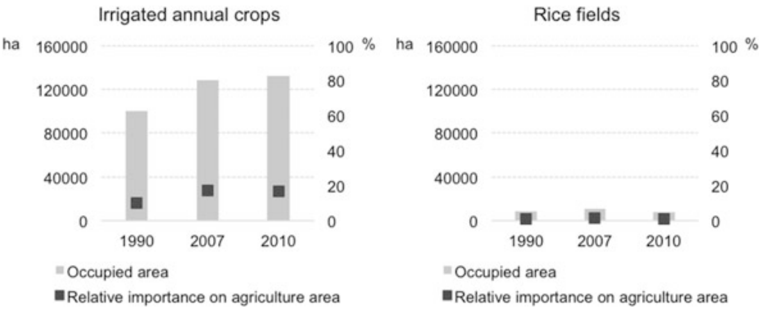


Fig. 8 Changes on area for different types of irrigated agriculture in the Centro Region (1990–2010)

Food Self-reliance Assessment

Food availability depends on production and food trade. To describe the current regional foodshed for the Centro Region, through the current production potential, we analyzed food consumption and regional production, i.e., a food self-reliance assessment. We used national data on food availability, the 2016 Portuguese Food Balance (INE 2017a), as a proxy for estimates of *per capita* food consumption. We considered these data to account for food consumption at a regional level, with

Table 1 Main crop and animal production (t), consumption and self-reliance: production in Portugal (1) and Centro Region (2); consumption (3) and self-reliance (4) in Centro Region

Plant crops and animal products	Production Portugal (t)	Production Centro Region (t)	Consumption Centro Region (t)	Self-reliance (%)
Cereal grains	1,138,086.00	308,234.00	242,994.34	126.85
Rice	169,289.00	33,307.00	45,370.27	73.41
Dried pulses	3603.00	1040.00	9515.86	10.93
Tubers	451,041.00	128,167.00	190,827.03	67.16
Vegetables	935,287.00	–	251 405.69	–
Fresh fruit	464,408.00	287,798.00	141,293.56	203.69
Citrus fruit	354,295.00	13,083.00	49,533.46	26.41
Nuts	40,130.00	4371.00	5607.56	77.95
Olive oil	69,526.84	7195.47	17,458.16	41.22
Wine	596,174.83	158,755.01	102,318.80	155.16
Beef meat	90,702,000.00	10,386,000.00	40,697.30	25,520.12
Pork meat	399,674,000.00	162,922,000.00	55,650.80	292,757.68
Poultry meat	369,119,000.00	278,045,000.00	72,388.52	384,100.93
Sheep and goat meat	18,242,000.00	3,506,000.00	3738.37	93,734.08
Eggs	134,576,000.00	116,713,000.00	19,796.39	589,567.02
Milk	1,849,375.00	219,757.00	165,508.04	132.78

Source Adapted from National Statistics of Food Availability (INE 2017a), Agricultural Statistics (INE 2017b) and Population Census (INE 2013)

reference to the total resident population (INE 2013), and compared the results with the regional production data to estimate the regional food self-reliance (RFSR). Our goal was to estimate the RFSR potential status by food agricultural products, i.e., the mass balance between the current production capacity and food consumption, for the resident population (number of inhabitants). The results of the food self-reliance assessment are shown in Table 1.

In 2016, the agricultural production of Centro Region met 127% of the annual required cereal grains, 204% of fresh fruits, 155% of wine, and 133% of milk consumption requirements. All the other food groups have self-reliances below 100% (Table 1), even though high for rice and nuts, respectively with 73 and 78% of group requirements attained. However, in what regards the animal production the RFSR exceeds the order of magnitude of consumption requirements by 200–6000 times, what evinces the regional profile of production specialization.

Consequently, some of these productions for which the region is self-reliant contribute heavily to domestic and international trade. These results enable us to identify areas of current food demand where increased regional production is necessary to meet food consumption requirements.

Approximately 50% of the virtual land import or “grabbed” by the EU is connected to soybean oil and feed products (Von Witzke and Noleppa 2010). This value increases if we consider the amounts of cereal grains used as feed. Intensive animal production, especially of granivores (pig and poultry farming), is largely independent on the utilized agricultural area (UAA) in the territories where this production takes place, although dependent on water for the production itself and other activities. However, the external dependence of cereals, soybeans and other raw materials used in feed, as well as fodder, can be considered as a vulnerability factor (Paloviita and Järvelä 2016). This is especially true in a context of uncertainty about maintaining global production potential, and the possible consequences of the fall in this potential on the price stability of these inputs.

Methodology

An edaphoclimatic suitability model focused on agriculture was created, based on a methodology structured by an ecological-landscape system planning perspective (Magalhães 2007; Saavedra Cardoso et al. 2017b). This spatial model relates edaphic (soil ecological value) (Cortez 2007; Cortez et al. 2013) and topographic components (slope, land morphology) (Cunha et al. 2013) with climatic variables. The variables for soil conditions and land morphology were used to produce edapho-morphological suitability, a procedure based on Multicriteria Decision Analysis (MCDA) (Munier 2011) that considers different forms of transforming variables to a common scale and assigns weights for the criteria used, according to the nature of the attributes and their relation with the MCDA goal (Satty 1988; Malczewski and Rinner 2015) (Fig. 9).

The estimation of the weight assigned to each factor was carried out considering the greater importance of the soil ecological value as a synthesis factor related to several qualities of FAO land evaluation methodology, namely: nutrient availability, nutrient retention capacity and rooting conditions (FAO 1976, 1988); according to Eliasson (2007), among the most commonly used qualities in assessing suitability for rainfed agriculture. According to Cortez (2007), the soil ecological value considers the intrinsic properties of the soil determining the biomass production capacity, namely: profile depth, nature of the originary material, clay and organic matter contents, structure, pH, cation exchange capacity and base saturation percentage. According to Eliasson (2007), slope is also among the qualities most used in assessments of agricultural suitability. Therefore, it was considered the second factor with the greatest weight due to its relationship with FAO qualities—potential for mechanization and erosion hazard (FAO 1988).

Land Morphology is a concept and a mapping method that represents landforms, categorised according to their hydrological position in the watershed (Magalhães 2001). This classification outlines two different systems, the wet and dry (concave-convex surfaces) in the hillslope profile, including valley bottoms, hilltops

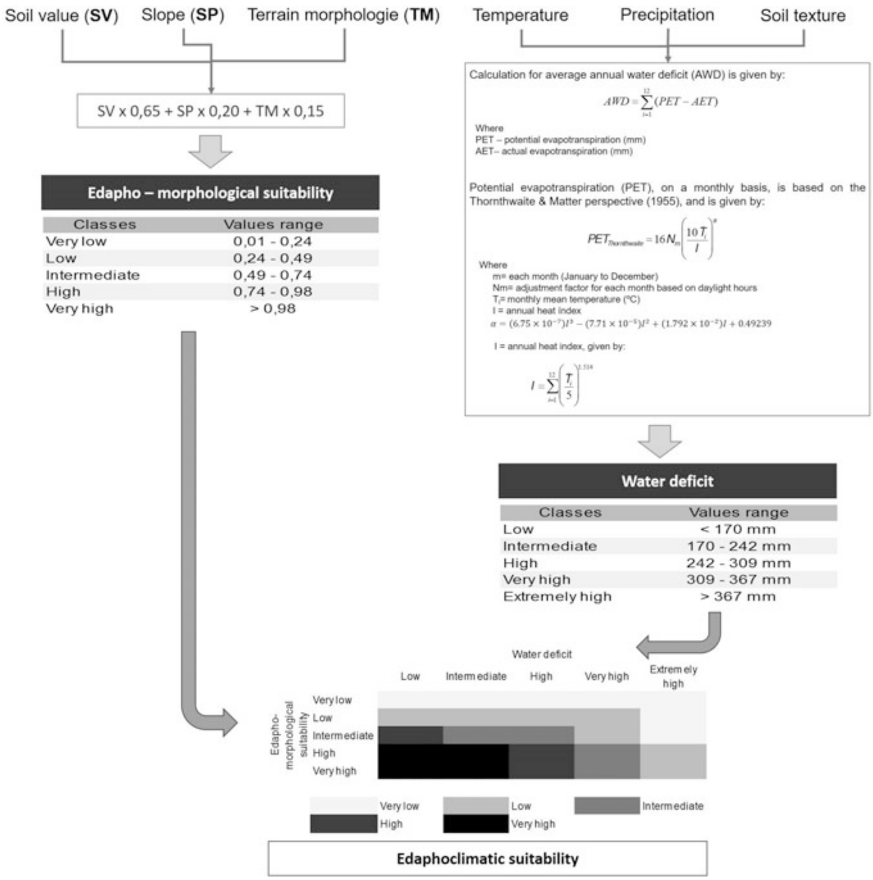


Fig. 9 Flow chart of the methodological approach for edapho-morphological suitability

and hillslope (Magalhães 2001, Cunha et al. 2017). As such, land morphology was considered as synthesis factor of water availability and nutrients availability, although as a factor it has no direct relation with the FAO qualities. For these reasons, and considering some redundancy with the other factors, its weight is lower.

The weight attributed to each class of the selected factors (from 1 to 5, increasing sense of class suitability) results from the literature review, from the definition of each class in the case of soil ecological value (Cortez 2007) and for slope the established bio-physical criteria to define natural constraints for agriculture (Orshoven et al. 2012).

The results, based on the weighted sum, were classified on different levels of edapho-morphological suitability, a classification procedure that relies on standard deviation (mean +/−1 standard deviation).

The integration of climatic variables, used to produce the edapho-climatic suitability model, was based on the use of water deficit, a calculation that follows the Thornthwaite method (Thornthwaite and Matter 1957; Fernández-García 1995). This method considers not only mean climatic conditions, based on mean temperature and precipitation for each month, but also different conditions in terms of soil water content that are available for plants/crops, considering data for soil texture (clayey: 100 mm; silty: 150 mm; sandy: 50 mm). Processes were generated automatically by an algorithm previously implemented in Python using the GDAL/OGR Python API (http://www.gdal.org/) and the package Numpy (http://www.numpy.org/). It calculates the water deficit for each pixel on the raster of the study area. Water deficit results were also classified into 5 classes based on quintiles.

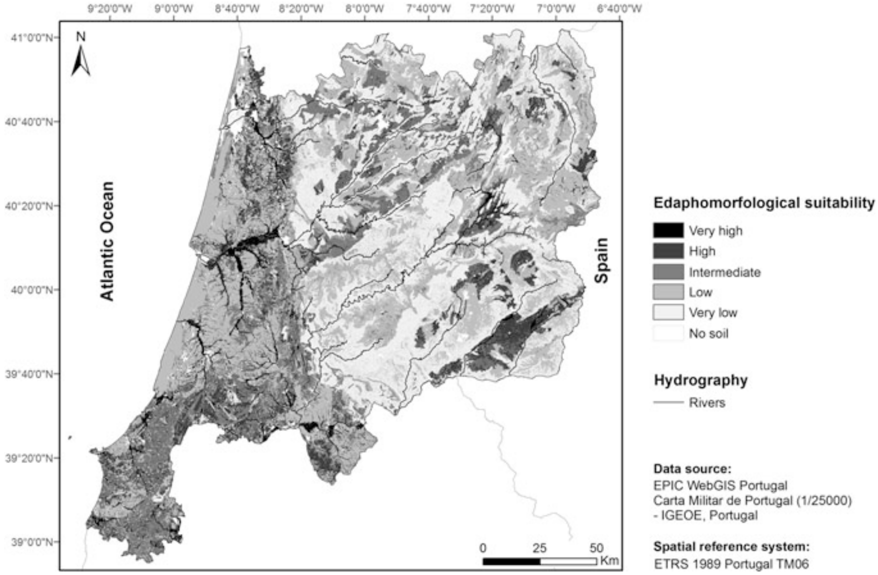
The combination of both results, edapho-morphological suitability and water deficit, allowed the identification of different levels of edaphoclimatic suitability. Considering that previous variables were classified into 5 categories, the classification for suitability followed that condition. Thus, suitability level for each pixel was determined by the spatial coincidence of categories for each variable, as presented on Fig. 9.

As the main objective of this study was to produce a spatial output that contributes to a better understanding of potential impacts from climate change on agriculture, and help on the identification of adaptation measures, the calculation of edapho-climatic suitability was also carried out for future climatic scenarios. Two climatic scenarios (RCP 4.5 and RCP 8.5) and two time-windows (2041–2070 and 2071–2100) were considered in this study. The assessment of impacts from climate change was evaluated based on changes on average annual water deficit (AWD), using projections for mean monthly temperature and precipitation produced for the climatic projections. This was the only component that changed when assessing changes on edapho-climatic suitability under future climatic conditions, once soil conditions and land morphology were considered to be stable.

Results

Edapho-Morphological Suitability

Considering soil conditions and land morphology, it is clear that in the study area *very high* suitability is limited to small areas. Those areas are associated to alluvial plains located at the low section of the rivers, being the Baixo Mondego plain (lower Mondego) the most significant (Fig. 10). Also, only about 70% of the study area has low to very low edapho-morphological suitability considering agriculture.



Data source:
EPIC WebGIS Portugal
Carta Militar de Portugal (1/25000)
- IGEOE, Portugal

Spatial reference system:
ETRS 1989 Portugal TM06

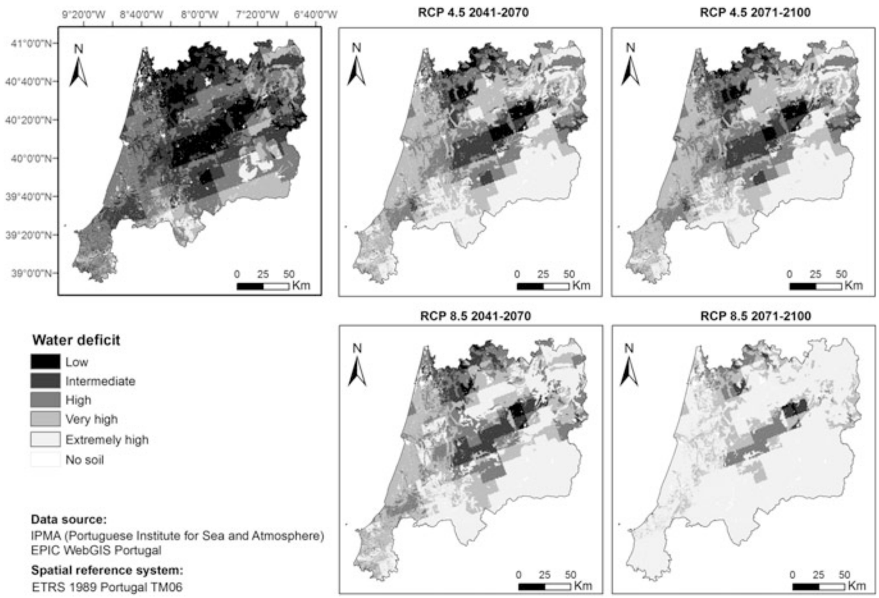
Fig. 10 Edapho-morphological suitability for the Centro Region of Portugal

It is also evident that western areas present higher suitability values, and only small patches have *intermediate* to *high* scores inland.

Water Deficit

In terms of water deficit, the lower values are identified on mountain areas, a fact determined by higher values of precipitation and lower mean temperatures, especially in the northwest and central areas (Fig. 11). The higher values of precipitation are greatly associated to the barrier effect associated with mountains considering prevalent western winds, responsible for the trajectory of low pressure systems (W-E) and associated fronts, which are responsible for a significant percentage of rain, reinforced by orography. Such context also explains the identification of higher values of water deficit in eastern areas, located on the leeward side of mountains. The higher values are also identified on southernmost areas, an expected pattern considering the increasing climatic dryness towards south (Fig. 11).

Considering climatic projections for both scenarios and the two time-windows considered, it is predicted an expansion of areas with *very high* and *extremely high* water deficit conditions, a result mostly dependent on the foreseen reduction of annual precipitation. Such increase on water deficit is expected to be higher for the RCP 8.5 scenario for the period 2071–2100, which is considered the “worst



Data source:
IPMA (Portuguese Institute for Sea and Atmosphere)
EPIC WebGIS Portugal
Spatial reference system:
ETRS 1989 Portugal TM06

Fig. 11 Water deficit for current and future climatic conditions in the Centro Region of Portugal

scenario". Still, other outputs for water deficit also predict important changes, exhibiting a similar spatial pattern.

The areas that are more susceptible are those that already experience higher values of water deficit, namely on south and eastern sectors of the study area.

Edapho-Climatic Suitability

The combination of edapho-morphological suitability and water deficit reveals that a significant percentage of the study area has *low* to *very low* edapho-climatic suitability to agriculture under current conditions (Fig. 12). As expected, *very high* suitability is mainly associated to alluvial plains, being mostly concentrated on western areas. Although, considering the expected increase of water deficit under future climatic scenarios, even those areas might register a decrease on suitability in the future, if conversion to irrigated farming systems is not possible, e.g., as water supply diminishes and irrigation demands can not be satisfied. According to the results of each model, only very small areas would conserve *high* and *very high* suitability to rainfed agriculture under future climatic scenarios.

In fact, significant areas will register a significant loss of suitability, changing from *high* and *very high* to *low*, especially in the scenario RCP 8.5 for the period 2071–2100, considering current conditions as reference (Fig. 13).

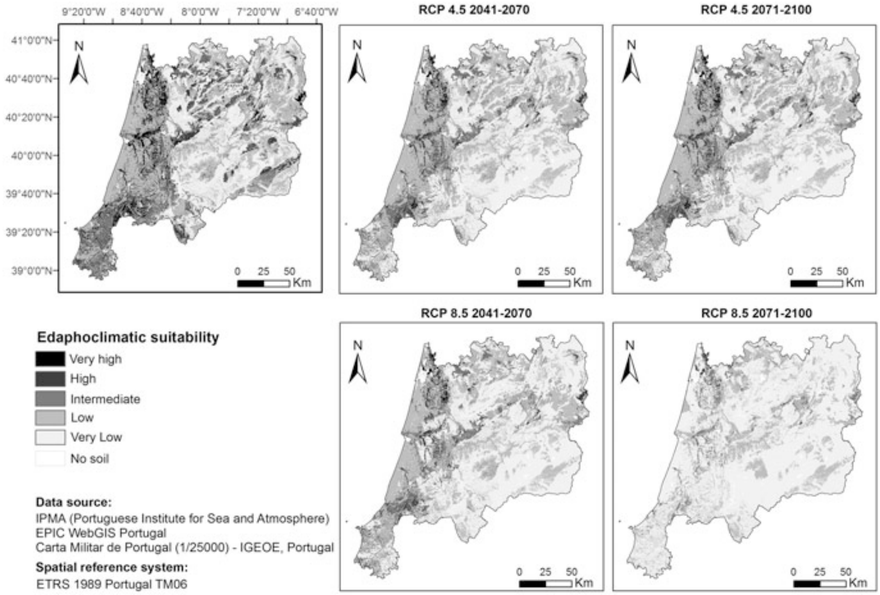


Fig. 12 Edaphoclimatic conditions for current and future climatic scenarios in the study area

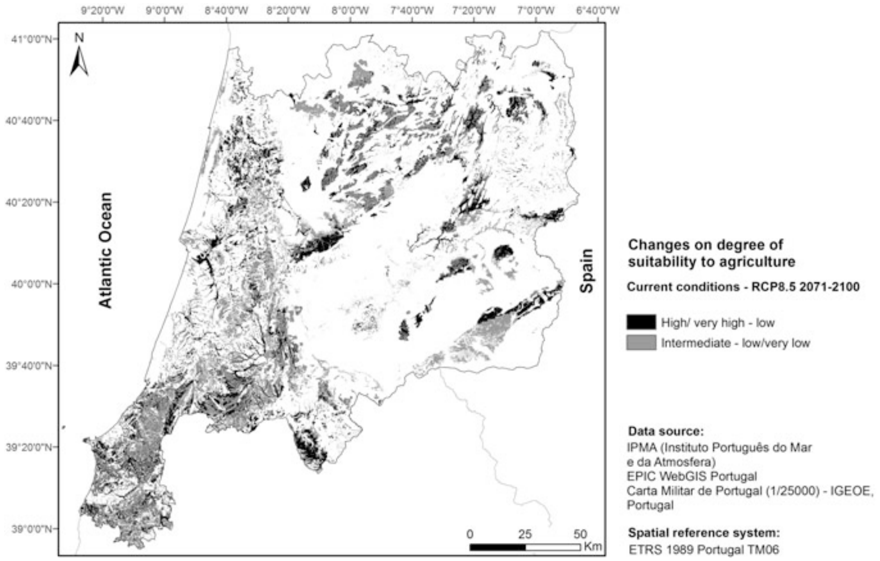


Fig. 13 Areas with higher loss on edaphoclimatic suitability in the study area for the scenario RCP8.5

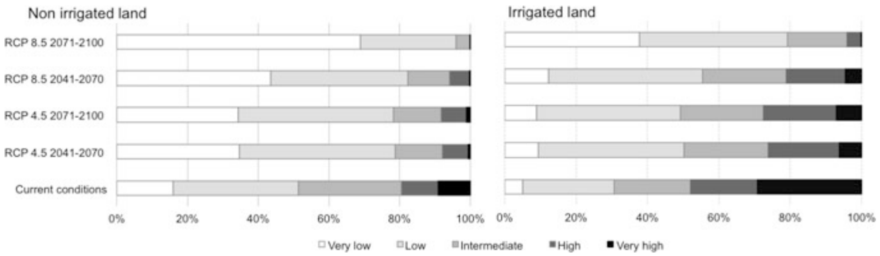


Fig. 14 Changes on edaphoclimatic suitability considering current area dedicated to agriculture

In fact, significant areas that are now occupied by agriculture (2010) will lose the capacity to support rainfed agriculture. Considering this type of land use, the loss of suitability is significant for both scenarios and time-windows, considering the important increase on water deficit. The model predicted that at least 40% of the area currently dedicated to rainfed agriculture will have *very low* suitability under future climatic scenarios, an important decrease considering that nowadays such value is around 15% of the study area. A prediction that is even higher under the scenario RCP8.5 for the period 2071–2100 (Fig. 14).

Discussion

Considering that is possible to produce outputs with higher resolution, the approach used in this study can be further applied to assess suitability at finer (local) scales, allowing the implementation of strategies for small territories or administrative areas. Such condition is of critical importance when considering the identification and application of adaptation measures at local scales. Although, validation based on current land use identified a very good match between land use and edaphoclimatic suitability for current conditions, the validation of the model should be improved through the use of new strategies dedicated to the evaluation of models' results and by its application in different territories and at different scales.

For this study, a very clear mismatch between recent trends on agriculture and foreseen climatic scenarios was detected in the Centro Region of Portugal. Recent trends on agriculture identified an increase in irrigated agriculture and an important reduction in terms of rainfed agriculture, which reflects an increasing pressure on water resources. Such trend seems to be incompatible to climatic projections for future scenarios, considering that projections predict an important increase on water deficit, determined by a reduction in terms of annual average precipitation and an increase in mean temperature, forecasting a reduction in terms of available water resources.

The areas that are more susceptible to increasing water deficit under future climatic scenarios are those where agriculture has higher importance today. Also, even more relevant, is the increase of the area for irrigation on the southwest sector, predicted as highly susceptible to increasing water deficit.

Due to the increases in water deficit, models for edaphoclimatic suitability predicted an expansion of areas that have *low* to *very low* suitability. In many cases the loss of suitability is very relevant, and might affect significant areas, especially when considering scenario RCP8.5 for the period 2071–2100.

Considering the reduction on water availability, a critical resource for irrigation, which may contribute to the loss of suitability for rainfed agriculture, it is important to identify measures that could be implemented in the short-medium term, helping to adapt agriculture to a decrease in available water resources, which must be based on the following concepts: *assess* and *repair, convert* and *cooperate*. *Assess* and *repair* is mostly dedicated to the type of agriculture that is associated to intensive use of water, and depends on infrastructures to store and transport water—irrigated agriculture. In this specific case, and considering the importance in the western area of the region, it seems advisable to invest on reducing water wasting, mainly by monitoring and improving the quality of the infrastructures associated with water storage and distribution. For example, in the "Baixo Mondego" region, an important area associated with irrigation, there are evidences that point to significant waste because of delays in the system associated to human decision (Alves et al. 2017).

Repair and cooperation measures should not be only focused on the hard repair of systems, but should also encompass integrated water resources management, at river basin level, i.e. land use planning and decision-making processes, models and technologies for assessing the capacity of water resources to meet current and future water demands (UNESCO 2009). This should include *cooperation* among stakeholders and water management entities in order to coordinate and balance the various water-using sectors. It must include the assessment of water resources availability and future water demands based on climatic and socio-economic scenarios (Milano 2012). A monitoring system that considers, among others, a sustainable water allocation index (SWAI), based on the ratio of water supply to water demand should be implemented for this purpose.

However, the bigger effort should be focused on conversion in different domains, namely irrigation techniques, crop varieties, type of agriculture and even changes at the land use level. Related to irrigation, conversion should be dedicated to water saving by motivating/supporting farmers in updating irrigation techniques when that option is possible, giving preference to water-saving technologies. In addition, and despite the fact that such option very often implies a decrease in profit, it is necessary to use crop varieties that are lower water demanding, or even convert irrigated areas of lower productivity to rainfed agriculture.

Despite the fact that engineered and technological adaptation strategies are still the most common as adaptive responses, results from ecosystem-based solutions indicate that measures should not rely only on technology (Noble et al. 2014). For those areas currently associated to rainfed agriculture that are expected to lose suitability, it could be considered the conversion to agroforestry, silvopastoral and polycultural systems, advocated for their resilience to climate change (Altieri et al.

2015; Altieri and Nicholls 2017). Farming systems and agroecological practices related to the maintenance of *landscape, crop and genetic diversity* (polyculture and agro-silvo-pastoral systems, rotations, use of drought tolerant local varieties); *soil managemen*t that, e.g., improves soil water holding capacity (cover cropping, green manures, no-till, organic farming) and *soil conservation* (contour farming, terracing, grass strips), have been considered relevant to enhance resilience to CC through various effects on soil quality and water conservation (Altieri et al. 2015). In particular, several studies on mitigation and adaptation in the agricultural sector have identified a range of practices that enhance soil carbon storage as relevant to reducing vulnerability to climate change (Smith and Olesen 2010). For instance, the adaptive capacity of soils can be enhanced through the increase of soil organic matter, which favors productivity over time, improves soil structure and water holding capacity and is therefore considered a win-win option, for mitigation and adaptation (Smith and Oleson 2010). However, considering the high level of abandonment of agriculture registered in the region on inland areas along decades (Almeida et al. 2009) and the risk of abandonment predicted for some municipalities on western areas (Alves et al. 2017), the conversion to forest seems to be a very good option, in particular for securing sustained water resources (Kohm and Franklin 1997). Moreover, agroforestry and forestry could give an important contribution to improve carbon sequestration and reduce soil erosion, a risk that will increase under future climatic scenarios, considering the increase in water deficit and the higher frequency and intensity of extreme rain episodes.

In what regards sustainable food security, the need to diversify sources of food supply should be acknowledged, by considering food system relocalization as a way to construct food system resilience. City region food systems (CRFS) can be advocated as an adaptation strategy in the context of CC for its capacity to endure and adjust to failures in the mainstream food system, in the event of natural or man-made disruptions in food supply or price volatility (Ruhf 2015).

Also, solutions to achieve food security under climate change consider currently “demand restraint” options in what regards food consumption, as measures for mitigation and adaptation. Animal protein-intensive diets are at the forefront in terms of GHG emissions and water consumption. This “climate friendly” dietary transition requires policies and actions to shift eating patterns, which need to target health, and sustainability-relevant consumption practices (Garnett et al. 2015).

However, the National Climate Change Adaptation Strategy, does not consider the food system, either from the perspective of diversifying food supply through CRFS or from a demand restraint perspective.

Final Remarks

Current challenges about climate change are related to the definition and implementation of measures that promote resilient societies concerning the new climatic context. Once agriculture provides basic services, namely food supply, it is important to conceive measures that contribute to adapt such sector to projected changes on climate, one of the main limiting factors for the activities in this sector.

Under this focus, and despite the fact that this is an exploratory study, the approach produced interesting results under the aim of assessing changes on suitability to agriculture in the Central Region of Portugal associated to projected climatic scenarios. The model, combining variables related to soil properties, topographic parameters and water deficit, revealed a worrying decrease on the edaphoclimatic suitability for rainfed agriculture under future climatic scenarios, especially for the RCP 8.5 scenario. Considering such predictions and increasing pressure on water resources, it is important to adopt a set of strategies that reinforce the capacity of agriculture to adapt, increasing resilience, and reduce vulnerability.

Although the fact that such approach does not consider requirements for specific crops, it can be helpful on the definition of context/structural measures, pointing out guidelines for action. But, if the model is produced for higher spatial resolution, spatially explicit results create the change to set measures adjusted to specific areas, and include other variables in the analysis.

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