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The impact of climate change on the Mediterranean diet in Italy

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INDEX

ABSTRACT

Italy is among the world's largest exporters of agri-food products and the custodian of the origin of the Mediterranean diet, which is internationally recognised as a worthy example of medical prevention and sustainability since it suggests a large consumption of plant-based foods. Nevertheless, climate change and related extreme events are becoming primary threats to the country's agricultural activity. In this regard, the prolonged drought of summer 2022 was an emblematic instance.

This study aims to estimate the percentage extent of drought severity, that occurred in June 2022, erosion and climate shifts in areas cultivated with common and durum wheat, maize, rice, olives, fruits, pulses and vegetables, distributed throughout Italy. Corine Land Cover and Eucrop maps have provided us with geographic distribution of these crops that belong to the foundation of the Mediterranean pyramid and contribute largely to Italian commerce. Next, Panagos' maps were the sources for locating current and future potential erosion, whereas adapting Beck's analyses to the study area made it possible to distinguish the different climate zones in the periods 1980>2016 and 2017>2100, under 8.5 RCP scenario. Lastly, the drought was analysed through the measurement of June 2022 Vegetation Health Index from MODIS satellite images.

Our findings show that about 50% of fields dedicated to durum wheat, common wheat, olive, fruits, pulses and vegetables are affected by severe average annual soil erosion rate, even in future projection, and drought (from moderate to extreme) in June 2022. In addition, it appears that the above-listed crops located in Piedmont, near Alba, in the Po Delta, in Tuscany, around Grosseto, in Abruzzo up to Apulia, along the Ionian coast in Basilicata, in Sicily and some provinces of Sardinia are expected to transition to an arid, steppe, hot climate; whereas, the majority of the remaining croplands would be destined for a temperate, dry summer, hot summer climate (following the Köppen-Geiger climate classification extracted by Beck's analysis).

Identifying the cultivations and areas currently and soon to be most at risk promotes a greater awareness about the dangerous effects of climate change which limits the economy and adherence to the Mediterranean model thereby affecting individual lifestyles and national culture. Undoubtedly, such information underscores the urgency of tempestive actions by policymakers and could inspire further, more localized studies of the most threatened areas and possible sustainable strategies to improve their resilience.

ABSTRACT (Italian version)

L'Italia è uno trai maggiori esportatori mondiali di prodotti agro-alimentari ed è custode delle origine della dieta Mediterranea, la quale è ormai globalmente riconosciuta come valido modello di prevenzione e di sostenibilità poiché si basa su un consumo vario e quotidiano di alimenti di origine vegetale. Tuttavia, gli estremi eventi del cambiamento climatico stanno diventando una minaccia prioritaria per l'attività agricola del Paese. A questo proposito, la prolungata siccità che ha caratterizzato l'estate del 2022 ne è un esempio emblematico.

Questo studio si propone di stimare l'estensione percentuale del grado di severità della siccità, dell'erosione e dei cambiamenti delle zone climatiche sulle aree coltivate con grano tenero, grano

duro, mais, riso, olio, frutta, legumi e vegetali, distribuite su tutto il territorio italiano. Le mappe Corine Land Cover e Eucrop hanno fornito la distribuzione geografica di queste colture, che appartengono alle fondamenta della piramide Mediterranea e contribuiscono in larga misura al mercato italiano. Le mappe di Panagos sono state la fonte per la localizzazione della potenziale erosione attuale e futura, mentre l'adattamento delle analisi di Beck all'area di studio ha permesso la distinzione delle varie zone climatiche, nei periodi 1980-2016 e 2017-2100, considerando lo scenario 8.5 RCP. Da ultimo, la siccità, è stata analizzata attraverso la misurazione del Vegetation Health Index risalente a giugno 2022.

I risultati hanno evidenziato che circa il 50% dei terreni dedicati a grano duro, grano tenero, olivi, frutteti, legumi e vegetali sono affetti da un severo tasso di erosione medio annuo, anche nella proiezione futura, e da siccità (da moderata ad estrema) nel giugno 2022. In aggiunta, emerge che le colture appena elencate disposte ad Alba, in Piemonte, nella zona del Delta del Po, in Toscana intorno a Grosseto, lungo la costa Adriatica dall'Abruzzo fino alla Puglia, lungo la costa Jonica in Basilicata, in Sicilia e in alcune province della Sardegna, in futuro, saranno caratterizzate da un passaggio verso un clima arido, stepposo e caldo; invece, la maggioranza delle restanti campagne coltive è destinata a un clima temperato, secco con estate secca (seguendo la classificazione climatica di Köppen-Geiger estratta dalle analisi di Beck).

L'identificazione delle colture e delle aree attualmente e prossimamente più a rischio promuove una maggiore consapevolezza dei pericolosi effetti del cambiamento climatico, il quale limita l'economia e l'adesione alla dieta Mediterranea incidendo così sugli stili di vita individuali e sulla cultura nazionale. Indubbiamente, poi, tali informazioni sottolineano l'urgenza di azioni tempestive da parte dei governi e possono ispirare ulteriori studi più localizzati sulle aree più minacciate e sulle possibili strategie sostenibili per migliorarne la resilienza.

INTRODUCTION

The Mediterranean diet is not a mere matter of nutrition, but rather it is part of the culture, society, history and tradition of a country, including also as its landscape. For this reason, UNESCO acknowledged the model as Cultural Intangible Heritage of Humanity in 2010 defining it as a *"set of skills, knowledge, rituals, symbols and traditions"* **(UNESCO, 2010*)*.** The birth of the term "Mediterranean diet" coincided with Ancel Keys' Seven Country study, which firstly highlighted the beneficial effect on human health of a proper and balanced lifestyle. From then on, many researchers followed up to recognize the model as a virtuous instrument to prevent many diseases. The variety of foods and a preference for plant-based ones, the promotion of seasonality, the focus on physical activity and conviviality, that aids in strengthening national identity by gathering the community and bequeathing traditional cooking practices, are the key pillars that differentiate it. Additionally, for the same reasons, the Mediterranean diet has been recently confirmed to have a very low impact on the environment, until to be defined a sustainable lifestyle. (**Dernini, S. *et al.* 2015).**

The nutritional perspective relies on the consumption of fruits, vegetables, and cereals, preferably whole grains, at each meal; olive oil as the main dietary fat source both for cooking and seasoning; a daily frequency of seeds, nuts, and dairy products; a greater weekly preference of dry pulses, eggs, fish and white meat; an extremely reduced one of red and processed meat, sweetened beverages and sweets. As for alcohol, then, red wine is accepted only on special occasions during the meal. These dietary guidelines were spread to the population through a graphical representation that takes into account the geographical, cultural and social contexts of any country. In Italy, a pyramid was proposed, in which the position of food categories in the ranks reflects their importance in the diet, and their environmental impact. **(Lăcătușu, C.-M. *et al.* 2019; Dernini, S. *et al.* 2015).**

Italy is one of the south-European countries holding the origin of this model, together with Greece, Cyprus, Morocco, Portugal, Spain and Croatia. Its climatic heterogeneity has allowed over centuries the cultivation of several crop varieties and the development of a unique biodiversity throughout the territory: both contributed to the success of the Italian agricultural sector making the country a world exporter of agri-food products. **(Ministry of Economy, 2022).** Nevertheless, the onset of climate change and related extreme events (long periods of severe drought, extremely high temperatures, absence of precipitation or their occurrence as short and intense storms) are definitively threatening the territory. Panagos, indeed, estimated the highest average rate of soil erosion in Italy at 8.59 t/ha/y. Likewise, the country has been identified as a dangerous hotspot for drought and water scarcity **(Spano, D. *et al.* 2020; Panagos, P. *et al.* 2020).** All these events could deplete crops both directly by the advancement of some growing phases, in particular, the flowering one, or by burning the fruits and indirectly by spreading pests' activity. Such only for these factors, there are obvious consequential risks in both economy, society, and individual health: the former in terms of crop yield anomalies, the second depends on the population vulnerability in overcoming water shortages, and the latter derives from more difficult access to safe food. **(European Environmental Agency, 2019; Belal, A.-A. *et al.* 2014)**

Therefore, the transition towards a drier and arid climate with more erosive rainfalls is becoming the main challenge of the entire peninsula as it was evident through the previous year when a persistent lack of precipitation was combined with a drastic rise in temperature. Specifically, during summer, 2°C above average was reached, with a peak in June that got to +3°C and the entire territory underwent -20% of rainfall, recording the highest anomaly in winter with -35%. This framework resulted in substantial depletion of the snowpack that brought the northern lakes and the Po river to a severe drought condition, compounded by a salt intrusion from the sea into the Delta and 40 km upstream. **(ISPRIA, 2022b, 2022c; Tarolli., P. *et al.* 2023).**

Given the urgency to withstand similar climatic extreme events, many researchers have already provided reliable analysis to monitor the impact of climate on the production of individual crops or to assess the efficacy in mitigation of specific agricultural procedures and/or decision-making policies. Nonetheless, to the best of our knowledge, there is no analysis on the extent of severe drought and erosion damage on Mediterranean diet crops, nor what climate shifts might suffer. Therefore, the present study aims to fill this gap by estimating the extension of severe erosion and drought in areas distributed throughout Italy and cultivated with common and durum wheat, maize, rice, olive, fruit, pulses, and vegetables which belong to the foundation of the Mediterranean pyramid and contribute largely to Italian trade. We obtained the geographic area distribution from Corine Land Cover and Eucrop maps, published by the Copernicus program; as for current and future erosion, Panagos' studies were the source, whilst the drought monitoring relied on the Vegetation Health Index measure in June 2022 (corresponding to the vegetative phase moment of plants) from MODIS satellite images.

Next, further analysis was based on exploring climate changes in the same zones adapting Beck's climate maps (from the present 1980>2016, to the future 2017>2100, under 8.5 RCP scenario). (**Beck, H.E. *et al*. 2018***)*

Our findings highlight which crop and area are as most at risk by now and in the following years promoting greater awareness about the dangerousness of climate extreme events which may compromise the economy and the adherence to the Mediterranean diet, thereby altering individual lifestyles and national culture. Furthermore, such information stresses the urgency of prompt actions by governments and could inspire further, more localized studies dealing with the discovery of soil features in those areas that are most depleted and sustainable strategies to improve their water resource management.

SECTION 1. BACKGROUND

CHAPTER 1. THE MEDITERRANEAN DIET

Food embedded in a historical, economic, and cultural system could assume many more meanings beyond nutritional aspects and the Mediterranean region worthily shows this. The latter geographically embraces all countries overlooking the Mediterranean Sea, nevertheless, just seven of them (Italy, Spain, Morocco, Cyprus, Portugal, Croatia and Greece) are the Mediterranean diet's custodians. The latter is not a mere list of food and nutrients, but rather it is the expression of different countries' cultures, lifestyles, and histories: indeed, contrary to modern belief, the term "diet" depicts food as a way of living as its Greek etymological origin (*diaita, that means "lifestyle")* already defines. The initial development probably coincides with the evolution of different civilizations which came in succession over centuries and brought their own habits through conquerors. At the same time, any culinary and production practices were transmitted over the generations and steadily adjusted according to social and environmental changes. One of the main influencing factors was religion: the occurrence of three Monotheistic faiths (Judaism, Christianism and Islam) in the area introduced new characteristics and contributed to keeping some others alive, holding them as sacred. Consequently, nowadays there is not a unique elaboration of the Mediterranean diet, but rather a single entity adapted to different national cultures: differences can lie in the selection of food - for instance, Italy is marked by high consumption of pasta, whereas Spain by the preference of fish and seafood - or in traditional cooking practices. (**Lăcătușu, C.-M.** ***et al.*** **2019)**

The agricultural landscape that characterizes the area is also part of this heritage since it promotes the link between local food and local identity. This is testified by the elaboration of geographical indication of provenance and quality geographical certifications which pursue to emphasize how the site of origin could deeply influence the quality of the final product **(Dernini, S.** ***et al.*** **2015; Burlingame, B.** ***et al.*** **2010; Capone, R.** ***et al.,*** **2021; Burlingame, B.** ***et al.*** **2015)**

UNESCO brought up this concept defining the Mediterranean diet as a "*set of skills, knowledge, rituals, symbols and traditions ranging from the landscape to the table, including the crops, harvesting, fishing, conservation, processing, preparation and, particularly, consumption of food"* **(UNESCO, 2010)** and honouring it with the title of Cultural Intangible Heritage of Humanity in 2010. The Mediterranean diet, indeed, convergences a central nutritional model, still preserved over centuries, respecting seasonality and biodiversity, conviviality, variety and practice of physical activity. **(Dernini, S.** ***et al*** **.2015; Burlingame, B.** ***et al*****. 2010 ; Capone, R.** ***et al,*** **2021 ; Burlingame, B.** ***et al.*** **2015)** Referring to the traditional Mediterranean model means dealing with a diet based on a large consumption of plant-derived foods (fruits, vegetables, whole grains, nuts and pulses) and a daily use of olive oil as the main dietary fat source both for both cooking and seasoning. Meat and eggs are consumed with very low frequencies and in small portions, whereas fish is provided with a moderate intake. Thus, any processed meats, sweets and sweetened beverages would not be pondered, however, they are not avoided, but suggested on rare occasions. Finally, red wine is another milestone of the Mediterranean diet even if it must be limited to small servings only during main meals and sporadic events throughout the week **(Lăcătușu, C.-M.** ***et al.*** **2019).** Briefly, varying food categories and specific foods within the same day on a daily basis can be regarded as the main pillar of the Mediterranean diet, and it is the basis of its role in medical prevention. **(Bach-Faig** ***et al.*****, 2011; Burlingame, B.** ***et al.*** **2010)**

Among social features, conviviality, is crucial: gathering families or communities around a table to share food or drink and culinary activities reinforces, on the one hand, the positive feeling of sociability, and, on the other, the cultural and historical identity of population. Additionally, conviviality could be considered a synonym for empathy, because many ideas and opinions can be expressed through food. Strengthening biodiversity preservation and seasonality maximizes the healthy reasons for consuming fresh products aligned with much-needed care about the protection of the environment. Lastly, the model suggests doing regular physical activity as another contributing factor of well-being. **(Bach-Faig *et al.*, 2011; Burlingame, B. *et al.* 2010)**

Then, since the early 90s, a graphic representation of these dietary patterns was created, aiming at spreading and making them more feasible: once more, the specificity of any country was preserved, so different depictions were adapted to the cultural, geographical, and socio-economical contexts. Italy, Greece and Spain, specifically, elaborated a pyramid in which the position of food all over the structure reflects the suggested frequency and portions thereof: at the extreme basis there is water; then fruit and vegetables, which should be eaten at each meal every day, are at the second level together with cereals, olive oil and nuts; moving upward there are dairy products and legumes, followed by white meat, eggs and fish; finally, around the top, there are red meat, its derivates and sweets. **(Dernini, S. *et al.* 2015)** In 2010, upon UNESCO's acknowledgement, a newly revised form of the pyramid was proposed **(Fig. 1.1)**, the innovation of which is to strengthen sustainability aspects with the aim of better pointing out the narrow connection among local food production, biodiversity, nutrition and culture. **(Bach-Faig *et al.*, 2011)**

Despite reliable evidence of the utmost relevance of conserving the Mediterranean diet as an icon of the national socio-cultural expression, Southern, Northern and Eastern Mediterranean countries are evidently shifting their adherence from the Mediterranean to the Western model. The lifestyle standardization and the less consciousness of modern generations for folk traditions have led to chaotic and hurrying lifestyles in which time to gather and cook is not included. The same countries that were identified as the cradle of the Mediterranean diet are less following the model's pillars, with a consequential increased intake of saturated and trans fatty acids, animal products, and refined sugars, at the expense of fibres and micronutrients. In addition, the basin is facing climate change which is overloading natural resources needed to cultivate foods: reduced water reservoirs, enhanced drought and soil erosion are hindering the cultivation of traditional crops. The effect is the loss of a sustainable, healthy food system and its related social culture. **(Burlingame, B. *et al*. 2015; Lăcătușu, C.-M. *et al.* 2019).**

Fig. 1.1 The new pyramid of the Mediterranean diet. [From Bach-Faig *et al.*, 2011]

1.1 The Mediterranean diet as a prevention technique

Diet is an important determinant of human health and enables the prevention of many diseases. The ongoing transition toward less healthy dietary models and the undue economic gap between developed and developing countries, which directly influences food availability, are the main social issues affecting the Mediterranean basin. Food security, indeed, is not a mere matter of a hygienic and safe domestic environment, but it also regards the dangerous consumption of an improper amount of food (in terms of energy content) due to its poor, or, oppositely, too easy accessibility or insufficient nutritional quality. The immediate effect of all these aspects is the development of malnutrition which embraces both undernutrition and overnutrition conditions: the former could be referred to as calories or specific micronutrient deficiency; the latter concerns an energy intake exceeding the per capita requirements. Both coexist in the southern Mediterranean countries, however, specifically in Italy, cases of overnutrition are more and steadily growing with a consequential increase in non-communicable diseases, such as diabetes type II, coronary heart diseases and cancer. **(Tilman, D. and Clark, M. 2014)** Nowadays, the shift and subsequent decline in adherence to the Mediterranean diet are identified as a worthy explanation for the nutritional and metabolic disorders which are affecting the region. Indeed, it is well known that change in dietary habits towards a Western model is reflected in an evidently increased consumption of animal fats or industrial seasoning, refined sugars due to sweetened beverages, and an opposite reduction in starches, fruit, vegetables and plant-derived products. **(Burlingame, B. *et al.* 2015).**

Nevertheless, the role of specific nutrients in the development of some pathologies was introduced for the first time by Ancel Keys, who paved the way for the acknowledgement of the Mediterranean diet as a reliable instrument of disease prevention**.** At the end of the '90s, Keys elaborated the renowned "Seven Country Study" which involved Italy, Spain, Greece, Netherlands, ex-Yugoslavia, Finland, Japan, and the United States, pursuing to discover a statistically significant inference between the diet, which characterizes the Mediterranean region, and the low incidence of cardiovascular diseases that distinguishes that area from American countries. Results confirmed his hypothesis: the Mediterranean diet, which is richer in polyunsaturated fatty acids through the consumption of olive oil, fish and nuts is staunchly involved in the lower occurrence of cardiovascular diseases. Then, two Spanish cohort studies, similarly, validated the primary prevention effect of this model. (**Keys, A. *et al.* 1986; Lăcătușu, C.-M. *et al.* 2019)**

The latter is driven by the possible adoption of this lifestyle as a therapeutic approach for diabetes type II, obesity and metabolic syndrome which are the underlying risk factors for many pathologies. The metabolic syndrome, especially, is a multifactorial condition characterized by hypertension, hypercholesterolemia, hyper-triglyceridemia and high waist circumference and, if left untreated, can promote the occurrence of cardiovascular disorders and cancers. It has been shown that patients following a Mediterranean diet may decrease LDL-cholesterol while favouring HDL, and achieve reduction in triglycerides, systolic blood pressure, and fasting glucose levels. (**Kastorini, C.-M. *et al.* 2011)** Moreover, a sub-analysis of the EPIC study, aligned with several meta-analyses, pointed out an inverse relationship between the Mediterranean diet and the risk of diabetes type II suggesting its possible interaction with glycaemic level control by improving evolution of plasma glucose and glycated haemoglobin levels (HbA1c). **(Lăcătușu, C.-M. *et al.* 2019).** Subsequent in-depth epidemiological studies upheld this preventive role for non-communicable diseases by assessing the extent of the benefits of the Mediterranean diet on health status according to the level of adherence. They showed that greater compliance to the pillars of the Mediterranean model significantly decreases the risk of overall and cardiovascular mortality, cancer, and the onset of Parkinson's and Alzheimer's diseases. Furthermore, an increase of two points in the adherence score could be sufficient to determine a 9% drop in overall and cardiovascular mortality and a 13% reduction in the incidence of Parkinson's and Alzheimer's diseases. **(Sofi, F. *et al.* 2008; Bhushan, A. *et al.* 2018)**

The Lion Diet Heart Study, then, was relevant to strengthen the secondary prevention effect: the authors recruited patients who had already suffered from acute myocardial infarction and treated them with a Mediterranean diet enriched in alpha-linolenic fatty acid (omega-3). The results figured out a 50% reduction in-new acute episodes of infarction and a general decline in new cancer cases and all-cause mortality (**de Lorgeril, M. *et al.* 1994)**. From then on, a second analysis of the earlier Lion Diet Heart Study and other meta-analyses concerning cancer have been conducted. All identified an inverse association between this lifestyle and both the overall cancer mortality and risk of colorectal, gastric, liver, head and gallbladder neoplasia. In addition, the model has been especially assessed for survival in breast cancer: an Italian study revealed that women who had dietary habits more closely adhering to the Mediterranean diet before the diagnosis had a better chance of promising prognosis **(Di Maso, M. *et al.* 2020; Lăcătușu, C.-M. *et al.* 2019).**

All of these health benefits do not entail individual foods, but better they derive from the synergistic action of different nutrient and bioactive compounds which could be found in several products at specific quantities. The key turning point of the Mediterranean diet is the variety of the diet itself, giving a priority to vegetable-derived products. **(Keys, A. *et al.* 1986)**

The biochemical composition of some iconic food needs an in-depth discussion. Firstly, extra-virgin olive oil has antioxidant, inflammatory, immune-modulatory, and neuroprotective activities. They are related to a great percentage of bioactive compounds (pigments, tocopherols and phenols), together with a balanced composition between mono-unsaturated and polyunsaturated fatty acids, which differentiate this oil from other oilseed or vegetable ones. This fraction is not absolute, but depends on some external factors, such as the ripening level of the olives, the cultivation system and the process of extraction. **(Mazzocchi, A. *et al.* 2019)** However, the importance of olive oil in cardiovascular disease prevention was upheld by Estruch's study, which demonstrated that a Mediterranean diet enriched with extra-virgin olive oil could be able t reduce the over-all risk among highly exposed people thanks to the presence of polyunsaturated fatty acids. Researchers attributed a similar positive role also to nuts, which take large amounts of the abovementioned fatty acids together with minerals (calcium, phosphorus, and magnesium), B-group vitamins, and fibers. They contribute to improving triglycerides levels, and protecting from Reactive Oxygen Species (ROS), which are responsible for cells' oxidative stress. Ultimately, they proved to successfully reduce LDL cholesterol. **(Estruch, R. *et al* 2013; Shannon, O.M. *et al.* 2018; Bitok, E., 2018)**

As well as olive oil and nuts, also whole grains, fruits, vegetables and pulses are recognized as fundamental components for human health: they have low energetic density, high-quality nutritional profile, and high amount of fibers and antioxidant compounds. These latter are part of 5000 different bioactive compounds that actively maintain wellness status: among others, carotenoids such as lycopene in tomatoes, and polyphenols as flavonoids, are the most representative, since they perform an important anti-inflammatory activity, regulate LDL-cholesterol levels and glucose metabolism. **(Serra-Majem, L. *et al.* 2019)**. Lastly, everyday and sufficient consumption of whole grains and pulses assures the exploitation of the good effects of fiber aligned with those of minerals and vitamins.

Briefly, the Mediterranean diet is scientifically approved as one of the best prevention techniques to reduce severe pathologies and the onset of the most common risk factors, markedly obesity and low chronic inflammation. Its strength lies in the proposal of a varied diet which ensures a daily introduction of antioxidants, vitamins, minerals, mono-unsaturated and poly-unsaturated fatty acids, polyphenols and more general fibers, which are all inversely correlated to the development of respiratory pathologies, stroke, lung and prostate cancers and infections in addition to the abovementioned findings **(Abar, L. *et al.* 2016; Aune, D. *et al* 2016)**

1.2 The Mediterranean diet as a sustainable strategy

By now, it is undeniable the role of food production as one of the main sources of impact on the environment: fertilizer application, land use changes, deforestation for grazing or feed crop cultivation, tillage operations and drainage of wetlands deeply contribute to CH_4, NO_2 and CO_2 emissions into the atmosphere, all detrimental factors that contribute to the rising of the global temperature. More specifically, methane derives from the digestion process of ruminant livestock or over the anaerobic decomposition of organic material in paddies; nitrous oxide arises from fertilizers; carbon dioxide is released by tillage operations, agriculture residuals burning, transports, and conversion of natural land into a cultivated one. Agriculture is also involved in water resource depletion due to irrigation and withdrawals**. (Willett, W. *et al.* 2019)** Moreover, the attempt to globally homogenize the food system aims to achieve higher yields and is leading to the spread of monocultures for feed and human consumption. As a consequence, the result is the abandonment of the rotation system and local crop varieties that could be more resilient to the environment, along with depletion of biodiversity. The latter does not concern only the loss of wildfire habitats andspecies in extinction, but it forces smaller farmers to leave or to convert their fields to follow the market trends. **(Burlingame, B. *et al.* 2010)**

Bearing in mind these considerations, many authors have provided a quantification of the impact of specific food or products in terms of GHG emissions, and water and soil exploitation. The best reliable methodology is the measure of Life Cycle Assessment (LCA): it detects energy and environmental loads considering the entire value chain from growing and raw material processing, through manufacturing, packaging and transportation until distribution, use, possible re-use and final disposal. Results could be shared by synthetic indicators which make them better understandable **(Burlingame, B. *et al.* 2010):**

a) Carbon Footprint: it analyses the impact associated with a product or service in terms of CO_2 equivalent emissions taking into account also those greenhouse gases that are naturally converted into CO_2.
b) Water Footprint: it measures the water use (in m^3) of water consumed and/or polluted by the entire chain
c) Ecological Footprint: it refers to the quantity of biological land (in m^2 or global hectares) which can provide sufficient resources needed to produce the food and absorb emissions deriving from the manufacturing system

Additionally, the LCA method elaborates estimations referring to different units of measurement (per serving, per unit of energy, per gram of protein) based on the quantity and the frequency of human consumption. For instance, fruit and vegetables that are consumed not for their protein or caloric content but more for their micronutrient profile, should be evaluated per serving, unlike legumes or root crops which are more protein or caloric dense; thus to compare them they must be referred to the same and the accurate unit. At the same time, the nutritional content of food would depend on the production as well: grass-fed beef has a superior amount of fatty acids and vitamins compared to products derived from grain-fed cattle. The reliability of the LCA lies in its analysis of the entire process since its standardization and a generalization of the measure would not be proper: many factors and aspects are involved in food production and each one impacts to a different extent. The main is the development thereof: as an example, seafood caught by trawling has 3 times more emissions than those fished without that system; more, GHG emissions from rice are 5 times more per gram of protein than those from wheat due to its cultivation system. **(Tilman, D. Clark, M. 2014)**

As it is well-known, many studies agree that plant-based products are less impacting since they exploit fewer amounts of water and soil per all the available units of measurement compared to deforestation, air and water pollution, loss of topsoil and depletion of biodiversity. Indeed, vegan and vegetarian models are estimated to reduce emissions per capita by 55%. Thus, the Mediterranean diet - that suggests the replacement of ultra-processed foods with natural ones and red meat with alternatives such as fish, pulses, eggs, and less frequently white meat - is a reliable strategy to reduce the environmental effects of food production and can effectively contribute to mitigating climate change. Certainly, as previously mentioned, the applied cultivation methodology plays a pivotal role: an intensified use of fertilizers or pesticides, coupled with extreme exploitation of groundwater reservoirs for irrigation, negatively impacts the planet even if vegetables are the production target. So, sustainable technical strategies should be adopted and they should embed changes in irrigation, fertilization, manure management, and feed conversion. (**Aguilera, E. *et al.* 2020; Willett, W. *et al.* 2019)**

Nevertheless, the term "sustainable diet" refers also to those diets that promote food security and a healthy life for current and future generations; in addition, they must be respectful of biodiversity, culturally acceptable, accessible, economically fair and nutritionally adequate. Therefore other two aspects are involved in sustainability: the cultural and the healthy sides of the food. The former is an important vehicle to transmit the connection between food and the environment and to emphasise the utmost relevance of seasonality; the latter involves food security which, as discussed above, regards the availability and the affordability of food to meet the nutritional requirements of the population. Low-impacting and low-emitting food, indeed, does not mean is a healthy one: the dilemma is to seek a diet with the minimum impact and the maximum nutritional fitting. **(Burlingame, B. *et al.* 2010 ; Aguilera, E. *et al.* 2020; Dernini, S. 2015; Tilman, D. Clark, M. 2014)**

The Mediterranean model fits perfectly these prerequisites, in addition to those overhead referred to emissions, by preserving the social and historical aspects of food bequeathing traditional recipes and techniques, and promoting high nutritional quality ensuring great diversity and respect for seasonality. **(Dernini, S. 2015)** The Double Pyramid **(Fig. 1.2)**, elaborated by the Barilla Centre for Food and Nutrition, reported the Mediterranean diet on one side and the extent of food impact on the other, so once more, fruit and vegetables and all plant-based products have been recognised as those less forcing the natural resources, as well as those with the highest nutritional profile from macro and micronutrient points of view**. (Burlingame, B. *et al.* 2010)**

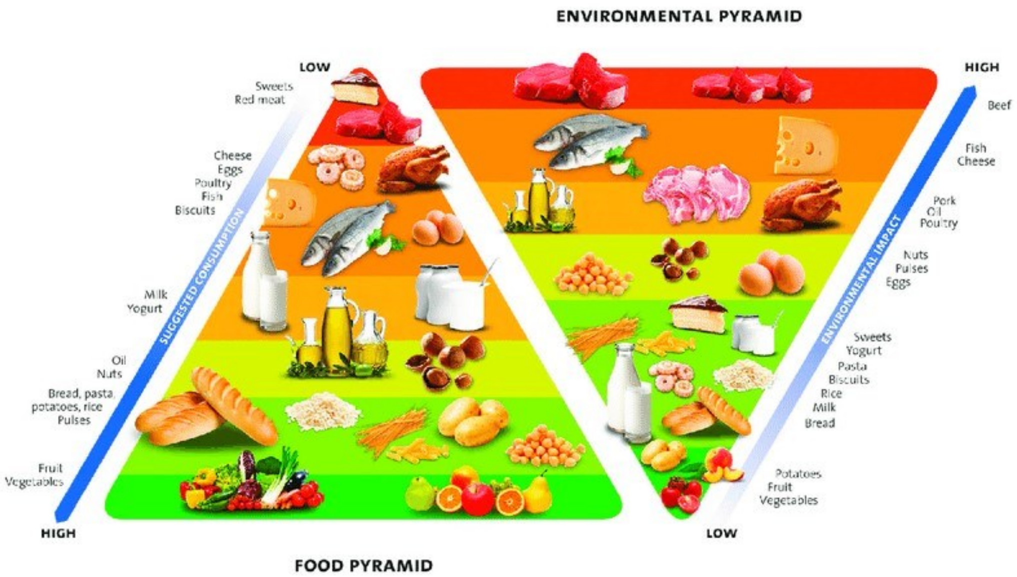


Fig. 1.2 The Double Pyramid *[from Ruini, L.F. et al. 2015]*

The current transition from the traditional Mediterranean model towards an unhealthy one enriched in saturated fatty acids and sugars and poor in fibre and micronutrients is not only increasing the burden of malnutrition and diet-related noncommunicable diseases, but it is worsening environmental degradation. **(Burlingame, B. *et al.* 2010; Capone, R. *et al.* 2021)** Zhang and colleagues have estimated that a standard citizen who adheres to the traditional Mediterranean pattern should emit 2.31 kg CO_2 eq per capita, whereas actual diet in Mediterranean countries on average would lead to 4.46 kg CO_2 equivalents per capita/day, roughly the double. Therefore the ongoing dietary shift is reducing the Mediterranean diet's potential benefits to mitigate climate change (**Zhang, J. and Chai, L. 2022)**

To sum up, the combination of more sustainable agricultural production practices together with mostly plant-based dietary patterns emerge as the best options. Nevertheless, the dietary aspect has the greater relevance, for it has the potentiality to reduce GHG emissions until 80% by 2050. **(Willett, W. *et al.* 2019)**

In conclusion, conservation of the traditional Mediterranean diet would preserve popular culinary, gathering and production activities. This way it will reinforce the cultural identity of the society, as well as fit the nutritional and healthy requirements of the entire community with low-impact products.

CHAPTER 2. CLIMATE CHANGE IMPACT ON AGRICULTURE

2.1 Introduction: what is climate change?

The United Nations Framework Convention on Climate Change (UNFCC), in its first article, defines climate change as: *“a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods”*. The term “climate” means long temperature, precipitation, pressure, and humidity trends in the surrounding environment. **(UNFCC, 1992)**
One of the most renowned causes of climate change is the emission of greenhouse gases into the atmosphere, mainly Organic Carbon (CO_2), Methane (CH_4), Nitrogen (N_2) and Fluorinated gases because they can hold the sun’s heat resulting in temperature rise. **(Abbass, K. *et al.*, 2022)** Before the industrial revolution, the source of these emissions was accountable to natural events, such as volcanoes, forest fires, and seismic activities. For some centuries, anthropogenic practices are coming up besides giving a deep contribution to climatic catastrophes which can damage local and global infrastructure, human health, and total productivity. Burning fossil fuels and agricultural residuals, deforestation, national and domestic transportation sector, fuel-based mechanization, and intensive agriculture are the most impacting ones: for instance, the latter contributes by itself to 30-40% of GHG emissions. **(Abbass, K. *et al,* 2022)**
International governments focused more and more attention on this challenging issue, as it is demonstrated by the foundation of the Intergovernmental Panel on Climate Change (IPCC) in 1988 by World Meteorological Organization and United Nations Environment Program (UNEP). It aims at providing a comprehensive Assessment Report reviewing the entire updated scientific, technical and socio-economic knowledge about climate change, its risks, and possible future **(IPCC).** Specifically, the experts identified 4 possible future scenarios denominated as Representative Concentration Pathway (RCP) and sorted according to the level of mitigation applied by governments by 2100 **(CoastAdapt website, 2017):**

- 2.6 RCP is based on the application of the strongest effort which leads to the only use of renewable energy sources, sustainable transports, and the development of emission capture technologies: it predicts an increase of global temperature by 1.0 °C and a rise of sea level by 0.4 m.
- 4.5 RCP is created upon a medium-high level of mitigation through the application of renewable energy sources and a mix of renewable urban transports with traditional ones: it forecasts an increase in global temperature by 1.8 °C and a rise of sea level by 0.47 m.
- 6.0 RCP is set upon medium effort which includes a mix of renewable energy sources and traditional ones, also for domestic vehicles: it shows a growth of global temperature by 2.2°C and a rise of sea level by 0.48m.
- 8.5 RCP is based on a very low effort level which results in the use of coal-fired power as an energy source and only cars as domestic transportation: this would cause an increase in global temperature by 3.7 °C and a rise of sea level by 0.63 m **(CoastAdapt website, 2017).**

Then, in 2015, the Conference of Parties (COP-21) brought all nations together for the first time to undertake ambitious measures to withstand the impact of climate change. The core goal was to keep the global temperature below 2 °C and to struggle with the maintenance of the temperature increase at 1.5 °C **(Abbass, K. *et al,* 2022).** Although the updated knowledge, the period from 2011 to 2020 was the hottest one ever registered since the global temperature rose 1.1°C above the level of 2019. **(United Nations, 2022)**

The temperature rise is, however, the beginning of the story because climate change produces direct and indirect impacts crossing the society, economy, and ecosystems. They are often underestimated in terms of damages and costs because cascading events could occur very far from an extreme event origin, so the consequences could be conferred to other factors. For instance, if the drought is sufficiently extensive, the drop in agricultural production can lead to a global rise in food prices which, in turn, may affect surrounding businesses causing unemployment, disrupted international trade, loss of income, diseases due to poor water and air quality, food insecurity, and malnutrition. Other indirect consequences are those affecting public water supply, energy production, waterborne transportation, tourism, human health, and loss of biodiversity. **(United Nations, 2021)**

2.1.1 Drought

Drought is generally one of the main kind of manifestations of climate change and its most reliable definition is that proposed by the IPCC, which describes it as *"a period of abnormally dry weather long enough to cause a serious hydrological imbalance"* **(IPCC, 2012).** So, it is considered an unusual and temporary deficit in water availability combined with insufficient water resources to satisfy requirements **(European Environment Agency, 2019)**. Thus, it doesn't mean water scarcity or aridity: the first is a long-term structural imbalance between water availability and demand, for instance, it can occur after the overuse of water resources; the second is a seasonal or fully dry climate. **(United Nations, 2021)**

Drought, additionally, has different origins: it may result from a shortfall of precipitation over a certain period, inadequate timing or ineffectiveness of the precipitation, and/or a negative water balance due to increased atmospheric water demand as a result of high temperatures or strong winds. Furthermore, a lack of snow- or glacier-melt due to a drop in winter precipitation can cause or exacerbate drought. **(United Nations, 2021)**

For this reason, the scientific literature has sorted it in:

- meteorological drought refers to a deficit in precipitation;
- soil moisture drought refers to a decrease in soil moisture including all the resulting effects on the natural ecosystem, building infrastructure through soil mechanical process and health due to heat waves;
- agriculture drought, similar to the previous one, indicates a loss of soil moisture, owing to reduced precipitation and/or increased evapotranspiration, but the term concerns only the negative consequences on plants' growth;
- hydrological drought is linked to anomalies in streamflow, lake, and/or groundwater level **(IPCC, 2012)**

The original cause, then, influences the duration, according to which "megadrought" and "flash drought" can be distinguished: the former is extreme and long-lasting, persisting for decades, while the latter is characterized by short periods (usually less than 3 months) of high temperatures and/or

strong winds, resulting in increased evapotranspiration and rapid depletion of soil moisture that can lead to major impacts, especially in the agricultural sector. **(United Nations, 2021)**
Water scarcity and drought are certainly intertwined. On the one hand, an increase in drought frequency, severity, or both, can threaten already water-scarce regions or create new ones. On the other hand, water scarcity significantly alters the possibility to cope with drought. Moreover, it should be considered that human activities have a deep role in the onset of water scarcity: a large request from groundwater and human-made reservoirs, for instance, can temporally mitigate drought impacts, but simultaneously can reduce resilience to future episodes, particularly those of soil drought. **(United Nations, 2021; Caretta, M.A. *et al.* 2022)**
The entire framework could be also worsened by the temperature rise which can exacerbate drought: the increase in evapotranspiration would dry out the upper soil layer, decreasing the soil moisture and enhancing heatwaves. This mechanism will result in a feedback loop where the drier the soil, the higher the intensity of heat waves and the higher the impact on crops. It is also true for wetter regions, where drier dry seasons or shorter and more intense rainfall can lead to soil moisture deficits, flash floods, rapid surface run-off, and less water infiltration. **(United Nations, 2021)**

Given all these factors, agriculture is the most vulnerable sector because the entire cycle of plant growth depends on environmental factors and ecosystems have a complex relationship with the supply of water: drought may reduce plant productivity and enhance dehydration stress in wildlife. Humans play a pivotal role in this process through land use change, which is an important long-term operation that alters water balance and influences drought indirectly by influencing evapotranspiration, infiltration, and surface run-off fluxes and directly through tile drainage and tillage which can further deplete soil moisture. **(United Nations, 2021)**
Furthermore, the irrigation practice can threaten hydrological drought due to water extraction either from the water surface, altering directly stream-flow, or groundwater. The latter, in particular, is an important source accounting for 38 to 50% of global irrigation water demand and for one-third to one-half of the global population's domestic use. Thus, intensive pumping leading to a significant lowering of its levels causes damage to economic activities and water supply in those regions which were already affected by water scarcity. **(United Nations, 2021)**
Moreover, the last report published by IPCC concluded that unsustainable use of groundwater storage couldn't be recovered either by an increase in precipitation. **(Caretta, M.A. *et al.* 2022)**

2.1.2 Soil erosion

Soil erosion is a geological process in which earthen materials (soil, rocks, and sediments) are moved by natural forces such as water or wind over time, so the rate of soil loss exceeds that of formation normally bringing about the birth of a new terrestrial area. On the contrary, if it excessively and quickly carries on, it can cause reduced soil productivity until desertification and water eutrophication which decreases its quality. **(Caretta, M.A. *et al.* 2022; Natural Resource Defence Council, 2021)**
The term "soil erosion" means the loss of the topsoil, which is the most fertile layer and its rate depends on soil structure, vegetation, and intensity of wind and rain which are the most renowned natural causes**. (Natural Resource Defence Council, 2021).** However, deforestation to create more grazing is also one of the first causes because the absence of vegetation encumbers the water absorption by converting it into runoff fluxes and depleting soil nutrients; if these were completely

wasted, desertification would occur. The latter is the last step when a fertile field turns into a less or non-productive one, and in Europe, its main culprits are salinization, soil compaction, loss of soil biodiversity, landslides, and rainfall erosivity **(European Environment Agency, 2019; Caretta, M.A. *et al.* 2022).**

The highest mean annual rate of soil loss due to erosion is 8.59 t/ha in Italy, followed by 7.46 t/ha in Slovenia and 7.19 t/ha in Austria; instead, the lowest one was found in Estonia and Finland. As a whole, 6% of European agricultural areas suffer from severe erosion, namely it exceeds 10 t/ha/y **(Panagos, P. *et al.* 2020)**. Vineyards and olive groves among permanent crops, and orchards, among arable lands, are the most affected. **(European Environment Agency, 2019)**.

Certainly, it should be considered that both erosion and desertification depend, also, on soil type, topography, land use, and land management: indeed, in urbanized areas, agricultural practices are one of the main accounted factors because they can speed up the process by removing the vegetation soil cover, increasing field size, abandoning terraces and using heavy machinery inappropriately. **(European Environment Agency, 2019; Caretta, M.A. *et al.* 2022).**

2.2 Analysis of climate change in Europe in 2022

The Mediterranean region together with Southern Australia, Sub-Saharan Africa, Southern South America, some areas in China, the Southwestern United States of America, and North-eastern Brazil has been identified as a hotspot: these are regions often or severely affected by drought with extreme risk of land degradation and desertification **(United Nations, 2021).** The Mediterranean basin includes countries surrounding the semi-enclosed Mediterranean Sea, among which the most relevant are Italy, Spain, Greece, the Middle East, and the North of Africa. The reason for its vulnerability lies in its unique biodiversity and specific ecosystem which are deeply altered by warming, which is 20% higher than elsewhere in the world, and drought, which causes an increase in water demand for agriculture. Irrigation is expected to grow from 4% to 18% by the end of the century, according to the RCP 4.5 and RCP 8.5 scenario, respectively **(European Environment Agency, 2019**), and the Food and Agriculture Organization (FAO) has stated that this practice may lead to a water deficit of 28-47% by 2030, mainly in Tunisia and Algeria. (**Spano, D. *et al.,* 2020; Ali, E. *et al.,* 2022)**

Since 1950, southern Europe has been remarkably affected by drought which gets worse in recent years compared to northern **(European Environment Agency, 2019).** In 2022, the intertwining of persistent lack of precipitations and the higher-than-average temperatures lessened surface soil moisture and brought about a sequence of heatwaves from spring onwards. (**Copernicus Climate, 2022).** The measure of both the Standardized Precipitation Index (SPI) and the Soil Moisture Index Anomaly (SMIA), indeed, revealed a stressing condition for crops and vegetation and, in particular, the SMIA figured out large parts of the region with a value below -2 that corresponds to the driest class **(Toreti, A. *et al,* 2023).** Regarding the temperature, all seasons were warmer than the respective average whose peak was reached in summer with +1.4°C. Moreover, southern and western Europe experienced more than 5 days of “very strong heat stress” and, in some cases, more than 10 days of “extreme heat stress”, a warning for human health. **(Copernicus Climate, 2022).**

The scientific literature is trying to provide predictions of future European weather conditions. Firstly, it highlighted the close relationship between global warming and hydrological drought frequency affecting river flows by pointing out that if the former achieves 3°C, the latter would double in 20% of Mediterranean sub-regions. The southwestern Europe, particularly, is expected to suffer from stronger and more persistent extremely low river streams than northern. **(Fig. 2.1) (European Joint Research Centre, 2020a).**

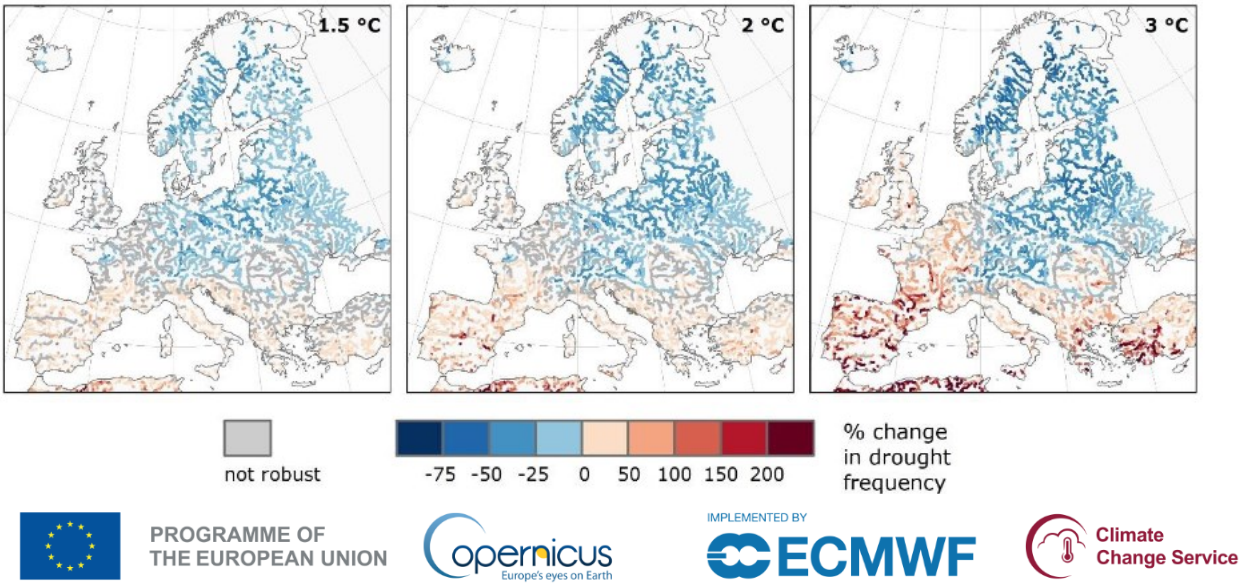


Figure 2.1 Projected change in hydrological drought frequency compared to baseline (1981-2010). The red colour means an increase in frequency; while the blue, a decrease. [*European Joint Research Centre. (2020a)]*

2.3 Analysis of climate change in Italy in 2022

Given its position and its complex topography, Italy is a climatically interesting country because it experiences both the influence of the arid climate coming from North Africa and the rainy one deriving from Central Europe. **(Spano, D. *et al.* 2020)** Consequently, there is high seasonal variability with alternation between rainy winters and dry summers; the latter, then, is characterized by low air humidity, high solar radiation, and high rates of evapotranspiration **(Sofo, A. *et al.* 2008).** Furthermore, Italy has already been identified as a country with a medium-high level of soil erosion whose annual mean soil loss rate reaches 8.59 t/ha **(Panagos, P. *et al.* 2020).** This issue would exacerbate, water scarcity that is, at the same time, its cause: the country exploits 30-35% of its hydrological reservoirs, whose 85% derive from groundwater and 15% from superficial water, thus reducing the soil moisture. The removal of water is even heavier in the north-west and the south of the country. **(Spano, D. *et al.,* 2020)**

As well as other European countries, it has additionally experienced a steady temperature rise over recent years: the most important national and regional observatories have recorded an increase of more than 1.1° C during the 1980-2010 period compared to the temperature average of 1970-2000. Nevertheless, last year was the most dramatic because of the occurrence of a huge temperature rise combined with a deep lack of precipitation, as overmentioned in the previous chapter. Observing seasonal data, the highest anomaly was in summer (+2°C), with a peak in June which get to 3°C over the average, followed by autumn (+1.3°C) and winter (+0.38°C). **(Fig. 2.2)** Thus, it was the hottest year since 1961. **(ISPRIA, 2022a)**

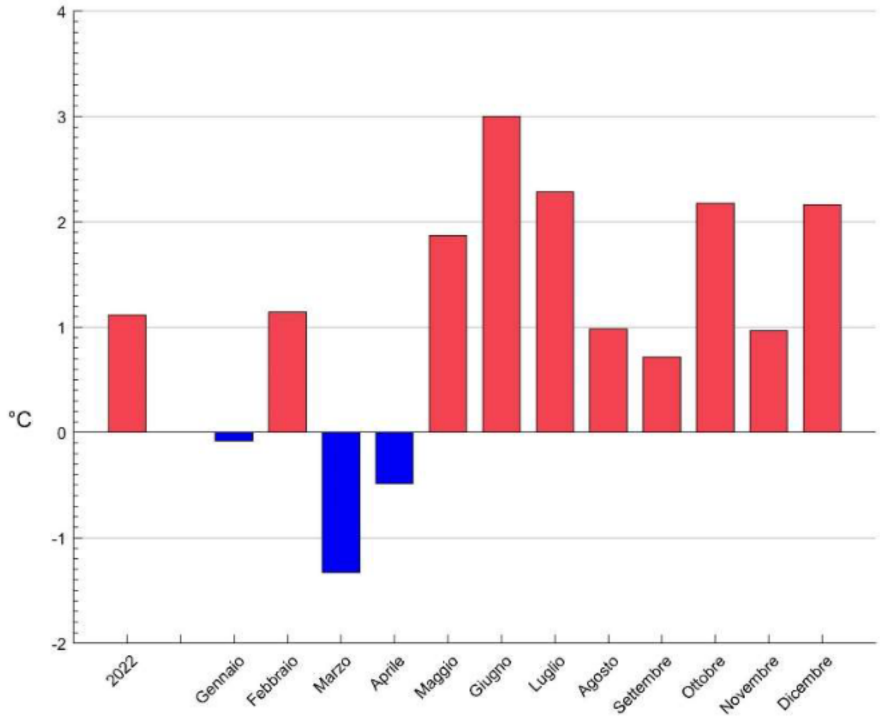


Fig. 2.2 Monthly anomalies of average temperatures in 2022 compared to climate average of the 1991-2020 period [*Extracted from ISPRIA, 2022a****]***

Regarding precipitation, the territory underwent -21% compared to the average for the 1991-2020 period: in this case, spring was the driest season characterized by -35% of rainfall, then winter (-32%) and autumn (-12%); indeed August was the rainiest month **(Fig. 2.3) (ISPRIA, 2022a).** Consequently, mountainous and rivers were severly undermined: the Alps experienced a very strong snow depletion as highlighted by the Snow Water Equivalent Index (SWEI), which measures the amount of water within the snowpack and showed a near absence of snow below 2000 m **(Fig. 2.4) (Toreti, A. *et al.* 2023).** Likewise, the Standardized Volume Index (SVI) revealed since April a moderate or severe drought condition (equivalent to -1.5 value) for most the northern lakes, specifically Maggiore lake, Como lake, and Garda lake. Additionally, the analysis by the Authority of District Basin of Po River (ADBPO) underlined that in September they were filled at 15%, 5%, and 28% apiece of their full capacity. **(ISPRIA, 2022b)**

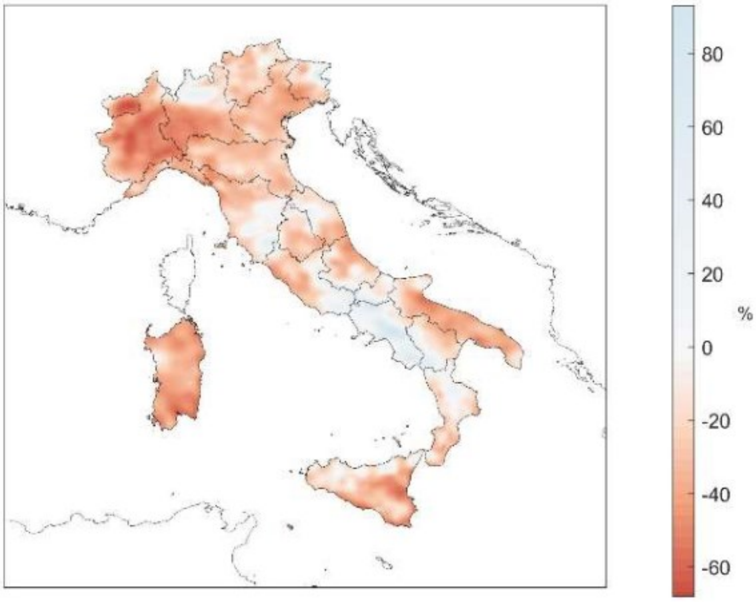


Fig. 2.3 Anomalies in precipitation, expressed in percentage, over 2022, compared to the average of the 1991-2020 period. *[Extracted from ISPRIA, 2022a]*

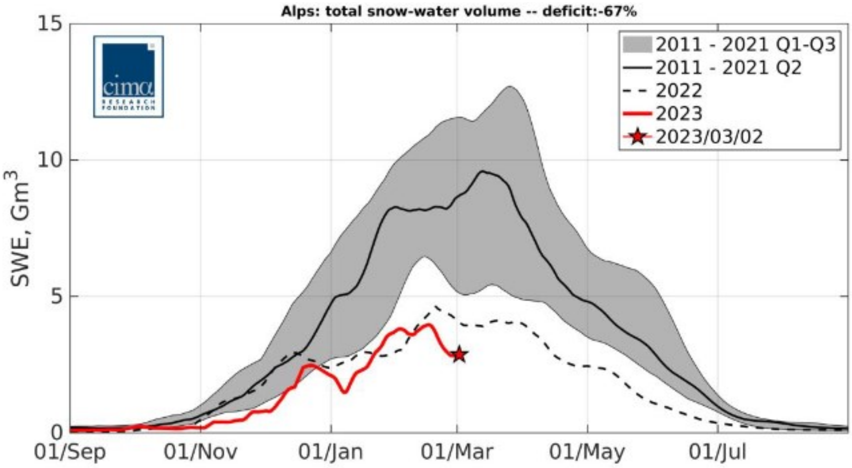


Fig. 2.4 Total Snow Water Equivalent for the total 2022-2023 (red line) and 2021-2022 (black dashed line) compared to the 2011-2021 period. The grey area encloses the range between the first and the third historical quartiles. *[Extracted from Toreti, A et al, 2023]*

The Standard Flow Index (SFI) measuring the discharge reported that the Po River remained steady below the values -1 and -2.5 corresponding to a "moderate" and "extreme" hydrological drought, respectively. The minimum level, specifically, was measured in July in the Pontelagoscuro section where the flow reached 114 m^3/, thus being inferior to 450 m^3/s threshold that assures the least recological functionality of the river **(ISPRIA, 2022c).**
This worrying framework led to a second tough issue: the saline intrusion into the Po Delta from the Adriatic Sea. Many studies recorded in June a water salinity up to 40 km upstream from the delta and a salt level higher than 2 g/L, which is the cut-off defined by FAO as the maximum amount of salt tolerated for irrigation practice **(Tarolli, P. *et al.* 2023)**

Therefore, climate change is moving snowpack to higher altitudes and decreasing snow and glacial reservoirs; this, in turn, will alter the discharge to a 40% deficit in rivers that already have a reduced flow. The latter effect would also derive from the increasing evapotranspiration consequential to the upward temperatures, and a greater anthropogenic extraction for irrigation **(Spano, D. *et al.,* 2020).**

2.4 The impact of climate change on plant growth cycle

Given the factors and the issues discussed so far, ongoing and projected changes in mean temperature and precipitation and the frequency of extreme weather events are already influencing crop yields and livestock all over the world, with further possible worsening **(Baruth. B. *et al.* 2022).**
The soil and climate change have a double-way relationship because soil and forestry can act as emitters and absorbers of greenhouse gases. On the one hand, plants (cultivated or not) can store CO_2 exceeding from the air, converting it into sugars that are stored in the underlying layers as food for microorganisms. Through this process, the soil can remove about 2.6 Gt of CO_2 equivalents per year. On the other hand, climate change directly alters the soil by increasing the rate of land degradation and by enhancing the frequency of intense precipitation. Furthermore, crops are inherently vulnerable to any climatic factors even if the extent of the damage depends on the location, the site, and the type of the crop **(Chatzopoulos, T. *et al.,* 2021; Anderson, R. *et al.* 2020).** Any factors stressing critical steps of the plant life would determine the advancement of the maturity date which, in turn, would shorten the growth cycle itself and damage grain filling. Consequently, the growing season would be lengthened resulting in organ fragility, reduced pollen germination, low photosynthetic efficiency, and a short time for biomass assimilation. **(Chatzopoulos, T. *et al.* 2022)**
The interference of flowering time, then, could hinder the interaction between plants and pollinators depleting productivity and biodiversity: for instance, a forward shift in spring may cause the blooming of trees before pollinators' eggs open. **(European Environment Agency, 2019).**

GHG emissions are the most evident impacting factor, in particular, CO_2 has a double-faced role in crop development. Some crops, identified in the literature as C3 crops, including wheat, seem to take advantage of higher CO_2 concentrations by achieving higher yields; while, C4 crops, among which there are maize and legumes, seem to not be sensitive at all. Nevertheless, C3 crops have been found to have lower nutritional content in terms of protein, zinc, and iron. **(Anderson, R. *et al.* 2020)**. The ability of a crop to live with raised CO_2 atmospheric emissions can contribute to drought stress resilience because, at increased CO_2 concentrations, the plant would need fewer opened stomata for gas exchange and, hence, it would lose less water through evapotranspiration enhancing water use efficiency **(Anderson, R, *et al.* 2020)**.

The second climate hazard is the temperature rise ensuing from drought or heat waves: these are directly responsible for reducing nutrient uptake and photosynthetic efficiency, forcing the plant to find some biochemical strategies to withstand the stress **(European Environment Agency, 2019).** Similarly, even in case of water excess as waterlogging or flooding, plants develop morphological changes, such as adventitious roots and root aerenchyma, to conserve gas exchanges and not suffer from anoxia or root system diseases. **(Anderson. R, *et al.* 2020)**.

Nonetheless, climate change also has indirect impact on agriculture, mainly by strengthening the pests' activity: rain, high air humidity, high soil moisture, and warmer temperatures enhance the virulence of the infections, especially in cooler regions where they were previously limited by cold (**European Environment Agency, 2019)**. At the same time, more frequent frost events during the vegetative season could also bring about the upgrading of diseases as frost-damaged plant tissues are exploited by pathogens to penetrate inside, as occurred for bacterial canker of kiwifruit **(Sangiorgio, D. *et al.* 2020).** Parallelly, the simple upward trend of atmospheric gas concentrations cause chronic stress to the crops, weakening their resistance to infections and facilitating their onset. To give some examples, elevated CO_2 concentrations increase the virulence of *Fusarium graminearum* populations on wheat, but, conversely, they would decrease that of *Peronospora manshurica* on soybeans plants; then, daily temperature fluctuations as little as 5°C have been demonstrated to make potatoes more vulnerable to *Phytophthora infestans* and, broadly, to the invasion of new taxa **(Sangiorgio, D. *et al.* 2020; Anderson. R, *et al.* 2020)**.
Moreover, a bigger and denser canopy derived from CO_2-induced growth may hinder the penetration and efficacy of pesticides on the foliage altering its persistence and enhancing pathogens' adaptiveness **(Sangiorgio, D. *et al.* 2020)**
In tropical areas, on the contrary, drier seasons would curb pest development, inducing serious risks of crop damage in the field and storage, such as in the case of maize and wheat that are expected to suffer from aflatoxin contamination or such as the northwards movement of olive fruit fly**.** However, as well as any direct effect of climate change, the hazards associated with pathogens would be lower at a warming of +1.5°C than at +2°C **(European Environment Agency, 2019).**
Therefore, knowledge of the climatic variables affecting pest temporal and spatial development along with crop management procedures and cultivar choices remain essential for outbreak control, mainly for crops requiring longer growth periods, such as orchard ones **(European Environment Agency, 2019; Anderson, R. *et al.* 2020)**.

Finally, it's paramount to consider the narrow relationship between agriculture, livestock, and climate change because the latter may also directly influence animal welfare, through heat stress that can lessen reproductive efficiency and increase the incidence of diseases. Indirectly, then, declines in crop yield due to extreme weather events would reduce food availability for animals, decreasing the slaughter and the manufacturing of derived products **(European Environment Agency, 2019).**
All these current impacts on agriculture, especially the extension of the growing season and the occurrence of aridity, are converting land use areas by opening access to new cultivations, where they were previously unsuitable, and replacing the typical local ones: higher latitudes would experience intensification of agriculture, whereas the lower ones would undergo a decrease in yield. Therefore, the predicted effect is the northward shift of some crops: for instance, maize and wheat have begun to be harvested in Russia and Canada **(Anderson, R, *et al.* 2020)**; as well as olive trees and grapevines are appearing in Denmark and other northern European countries similar to melons and tomatoes. **(Bednar-Friedl, B. *et al.* 2022)**
Besides the clear economic consequences which would damage countries that rely on their local production, many other aspects should be considered, such as a more likely change of the diet. The latter doesn't concern only food, because food encompasses the tradition, history, culture, and art of society, as evidence by the Mediterranean diet **(European Agriculture Rural Development, 2022).**
Furthermore, the land use changes would enhance the undue gap between developed and low-income

countries, because the former could better withstand climate change by intensifying the latter's inaccessibility to safe food and proper nutrition **(Anderson, R. *et al.* 2020).**

2.4.1 European agricultural loss in 2022

The agri-food sector covers 1.4% of the European GDP (an unit that measures the monetary value of final goods and services in a country in a given period of time) and it makes the region a leader in export trading: specifically, it accounts for 7% of all EU exports and 5.6% of imports **(OECD, 2018).** The total Utilised Agricultural Area (UAA) extends to 157.4 million hectares, whose 17% located in France, 15% in Spain, 10% in Germany, 9.4% in Poland, and 8% in Italy **(Eurostat, 2022b).** Nonetheless, the region is already experiencing the consequences of the above-discussed climate change manifestations because it has lost 1.5 million hectares since 2010 **(Eurostat, 2023a)**.

Among others, the Mediterranean basin is expected to suffer relatively more from higher air temperature, enhanced frequency of heatwaves (40 or 50 more than other regions), halved water availability, and, consequently, increased demand for irrigation **(European Joint Research Centre, 2020b).** The latter may range from small rises (<20%) considering the best emission scenarios (RCP 2.6 and RCP 4.5) to heavy ones over 20% under the RCP 6.5 and over 25% under the worse RCP 8.5, by 2100 **(Baruth, B. *et al.* 2022).**
Similarly, erosivity by wind and superficial run-off, and drought frequency are fated to grow: the former should be intensified by an upward trend of rain erosivity between 22 to 35% by 2050 **(Panagos, P. *et al.* 2021);** the latter would jeopardize 65% of the region under 4.5 RCP scenario, up to 80% in 8.5 RCP one. **(European Joint Research Centre, 2020b).** Thus, the final consequence may be complete infertility, followed by land abandonment, which clearly would damage higher proportions of permanent crops, especially orchards, olive groves and vineyards that are the most diffused. **(Eurostat, 2023).** Not by chance, future projections highlight a decrease in arable land extension by 8.4 million ha, conversely to an increase in pasture land by 2%, by 2050. **(Panagos, P. *et al*, 2021)**
The northern part of Europe, on the contrary, could exploit the lengthening of the growing season and shortening of the frost period to introduce new crop species, such as olive trees and grapevines, as occurred in Denmark, Finland and Sweden, and achieve higher yields for potato, wheat and maize. On the other hand, it will cope with a northwards shift of the olive fruit fly infection and black rot fungus in fruit trees due to warming. **(European Environment Agency, 2019).**

Given the already critical Mediterranean vulnerability, the wrecking of the agri-food sector during last year is the most worrisome result related to climate change: Spain, Portugal, France, Germany, Hungary and North Italy were the most weather-affected **(Baruth, B. *et al.* 2022).**

i. Olive oil

European Union can boast 50% of the total world olive growing area reaching almost 6,266 million hectares **(Patsios, S.I. *et al.* 2021).** Olive groves, indeed, are particularly suitable to the dry and arid climate of Southern Europe since they can tolerate very low water potential (up to 6-8 MPa). These conserve a high ratio between leaves and roots thereby extracting soil water until -2.5 MPa, and maintaining a full rehydration capacity. Moreover, they preserve a slight photosynthetic activity during heat stress through the stomata closure which, together with an osmotic adjustment using the accumulated carbohydrates and other osmolytes, allows the persisting storage of nutrients in the root system **(Vitagliano, C. *et al.* 2002; Sofo, A. *et al* 2008).**

Nonetheless, the atmospheric conditions that have marked recent years, especially 2022, deeply damaged the production of oil over time. First of all, the prolonged warmer-average spring influenced the inflorescence, flowering, pollination, and fruit setting: indeed, in many areas, some inflorescences were burnt by the excessive sun radiation and sirocco wind. Heat waves, also, led the plant to water stress particularly when the absence of precipitation occurred during fruiting. A long-lasting water deficiency, in fact, would decline the nitrogen absorption that negatively influences the bud's growth, the synthesis of a proper amount of oleic and linoleic acid which are fundamental for the production of high-quality oil, and the development of a sufficient berry and pit weight to extract oil **(CREA, 2023c)**. The irrigation practice could be helpful if it is exploited at proper time, otherwise, it couldn't be able to restore berries before harvesting, anymore **(Greven, M. *et al* 2009).**
These ongoing issues together with a difficult handling of irrigation requirements because of the very low water reservoir levels were responsible for significant shortages in olive oil production during 2022: generally, Europe lost 39%. More in detail, Italy and Spain, which are the two leading countries, reached -54% and -27%, respectively, instead France dropped 38%, and Portugal 39%. **(European Agri-food Data Portal, 2023)**

Also, future projections by the European Environment Agency revealed a dangerous advancement of the flowering date from 10 to 34 days in southern countries by 2100 which would worsen the impact on yield and enhance the northward shift **(European Environment Agency, 2019).** The latter may take place within the same country, for instance in Italy, olive cultivations are already moving toward northern higher altitudes **(CREA, 2023c).** Parallelly, the northern migration of olive fruit fly, which is the second most dangerous threat in southern Europe, is also expected. On the contrary, warmer conditions could hamper the reproduction of other pests, as in the case of the *Bactrocera oleae* that stops laying eggs at warmer conditions and after 10 days of more than 38°C its eggs, laid on the plant, can't survive. Therefore, the rise in temperature may mean that it is no longer a problem in the Mediterranean basin. **(Gratsea, M. *et al*. 2022)**
Despite all these threats, the introduction of intensive irrigation system may lead to the expansion of European area holding olive trees. **(European Agricultural Rural Development, 2022).**

ii. Cereals

The European cereal sector embraces mainly maize (*Zea mays L.*), wheat (*Triticum L*, both *Triticum Durum* and *Triticum Aestivum*) and rice (*Oryza Sativa*); the other coarse grains, such as barley and sorghum have a much smaller influence on international trade **(OECD-FAO, 2022).** The distribution of cultivation is more located in southern countries: according to the USDA analysis, France covers the greatest percentage of maize and wheat production (21% and 27% respectively); Italy is the second one in Europe for maize, holding 11%; instead, Germany is the second leader in wheat harvesting of which takes 17%. Regarding rice, certainly, Italy has an undisputed dominance owning 50% of the entire European paddy fields **(USDA, 2014).** The European Union is a paramount world cereal exporter accounting for 14% by 2030, especially for wheat **(OECD-FAO, 2022).** The relevance of cereals production is also related to its relationship with livestock because maize, together with barley and less with soft wheat, is the main ingredient of animal feed **(ISMEA, 2023a).**

However, as well as olive fruits, wheat and maize underwent a shortening of cycle growth due to the anticipation of the maturation process to some extent depending on the harvesting time. The occurrence of the maize's sowing in April would expose this crop to more severe heat stress that could cause an advancement of 40 days; whilst durum and common wheat, which are sowed in autumn, would expect a shorter anticipation of around 30 days. Then, a difference between common and durum wheat could be also identified according to the elevation rather than the latitudes: both are experiencing longer growing seasons in the northern area compared to central and southern ones **(Mereu, V. *et al.* 2021)**

During 2022, the European cereal sector was undermined: Spain, France and Italy specifically lost 20%, 30% and 23% of maize production; as regards durum wheat France was the deepest affected with -16% followed by Italy (-9%); instead, Spain dropped the highest amount of soft wheat compared to other countries registering a decline of 28%. **(European Agri-food Data Portal, 2023)** **.** Concerning the rice field, Italy was the most damaged country in Europe recording a reduced yield of 60% **(Coldiretti, 2022)**

iii. Fruits and vegetables

From an agronomical and farm management perspective, the term "vegetables" means horticultural crops, namely annual species settled in arable lands for not more than one production season; instead, fruits are perennial crops, so they are permanently sowed in a field for more than two years usually as bushes or trees. Both categories are sorted into subgroups: according to data collected in 2017, vegetables' total area comprises 27% tomatoes, peppers, aubergines, melons, courgettes, 20% root, tuber and bulb vegetables, and the remainder of leafy and stalked vegetables; whilst, the fruits are distinguished in nut orchards which account for 34% of the total area, pome fruits (19%), such as apples and pears, stone fruit orchards (18%) which include peach and cherries, citrus fruits (15%) and the residual are berries, tropical and subtropical fruits (e.g. figs and bananas) **(Eurostat, 2019).**

The distribution of fruit cultivation is concentrated in Spain which is the leader by holding 40% of the entire European area, divided principally into nuts and citrus, Italy is the second one with 17%, and Poland with 9.5%. Regarding fresh vegetables, Italy boasts dominance keeping 17.8% of the total European planted lands, followed by Spain (17%), France (11.8%) and Poland (10.8%). More specifically, tomatoes and onions are the two most cultivated fresh vegetables and they account for 8% of the European fresh vegetables area: the key tomatoes-producing countries are Italy, Spain and Poland; whereas those of onions are Netherlands, Poland and Spain **(Eurostat, 2019).**

Although the extension of the agricultural fields dedicated to fruits and vegetables respectively comprises only 1.9% and 1.2% of the total European utilised land, the relevance of the European countries in international trading is undoubtful. Member states export these products within and outside Europe. The data referred to 2017 reveal that among fruits, citrus and the pome fruits in intra-Europe trades are the highest; while among vegetables, the most valuable are tomatoes. The countries, specifically, more involved in this marketing are Spain which mainly deals with citrus fruits, apricots, cherries and peaches, the Netherlands which accounts for the greatest share in tomatoes, and Italy for apples, pears and quinces. In terms of the total value of extra-Europe exports, the main destinations are Switzerland (22.9%), Belarus, the United States and the United Arable Emirates **(Eurostat, 2019).** Bear in mind that the fruit and vegetable percentages analysed so far include also the amount of fresh products which would be destined to several processes (freezing, dryness, preservation methodologies such as canned vegetables, juices and prepared meals), the majority of which takes place in Italy, Spain, Germany and France **(Eurostat, 2019).**

Similarly to previous sectors, the temperature rise, the extension of the drought period, the lack of precipitation, and the saline intrusion in the aquifer altered the soil moisture, encumbered the irrigation practices, increased the evapotranspiration, and promoted pest infections, especially that of soil-bore fungal taxa such as *Penicillium spp* **(CREA, 2023a; Singh, B.K. *et al.* 2023).**
All these factors depleted the production, mainly during 2021 and 2022 with different frameworks. During 2021, the biggest issues were frosts and hail which followed warmer spring that had boosted the opening of new buds **(European Environment Agency, 2019);** whereas, in 2022 the heaviest challenge was the steady record-breaking of the spring when temperatures, that shot up 40°C since May onwards, burnt the fruits **(ISMEA, 2023b).**
The more depleted crops were apples, oranges, peaches and nectarines, and tomatoes. Specifically, last year Spain lost 15% of its apple yield, 26% of peaches and nectarines, and 9% of tomatoes; Portugal dropped 20% of apples and 26% of peaches; France and Italy were mostly affected in orange cultivations whose production declined for 16% and 19%, respectively. Also, Hungary and Greece experienced a loss in this sector: -32% in apples and -20% in tomatoes apiece **(European Agri-food data portal, 2023).**

Given this critical framework, this present study aims to estimate the percentage of area extension of seven selected Italian crops, milestones of the Mediterranean diet, that are experiencing erosion, drought and climate shifts now and in the future.

SECTION 2. The case study

CHAPTER 1. MATERIALS AND METHODS

1.1 The study area: Italy

Italy is a peninsula located in the Centre-South of Europe, bordered to the north by the Alps, which join it with central-western Europe. It is at the centre of the Mediterranean sea, specifically surrounded by the Adriatic sea in the east, the Ionian sea in the south, and the Tyrrhenian sea in the west, which divide the region mainly from Balkans, North Africa, and Greece. The area extends for 302,000 km^2 and includes two bigger islands, Sicily and Sardinia, and over 70 smaller islands **(ISTAT, 2014)**. According to the last evaluation, Italian demography counts 58,850,717 inhabitants **(ISTAT, 2023).**

The territory is characterized by almost 40% of the hilly landscape, 35% of mountains divided in Alps' chains in the north (in the Valle d'Aosta and Trentino Alto-Adige regions) and Apennines, which look like a backbone in the Centre, and 20% of plains **(ISTAT, 2014).** The latter could have several origins: the majority are alluvial plains, such as the Po Valley; some others derive from the rise of the sea bottom, such as the Tavoliere plain in Apulia; the remaining ones are volcanic **(Wikipedia, 2023).**

The Po Valley owes its name to the longest river in the country which delimitates the area and flows from the Monviso, in the Alps, to the Adriatic Sea. It is a key site for agriculture thanks to its extension since it crosses all northern regions and the presence of the Po river and other streams, like the Adige, which is the second in length.**(ISPRIA, 2011).** Over 1000 lakes, including those artificial, are widespread throughout the country, and the most important are Garda Lake, Maggiore Lake, and Como Lake placed in the just mentioned plain **(Wikipedia, 2023).**

The territory is politically divided into 21 regions and it is characterized by a huge number of small towns and villages: according to the new Eurostat classification, 68% of municipalities are defined as low urbanized, thus they are prevalently rural, whereas only 3% are highly urbanized **(ISTAT, 2014).**

Rural regions are classified by Eurostat and Organization for Economy Cooperation and Development (OECD) into**:**

- Rural regions with specialised intensive agriculture: they accounted for 22% until 2009, and they are mostly located in northern and central plains around urban cities
- Intermediate rural regions: mainly in hilly and mountainous areas and represented 34% of the national territory
- Rural regions with development problems: they are few and are placed in the south or small islands. On average, they suffered from a gap in the endowment of public/private services. **(OECD, 2009)**

The country is one of the leaders in the worldwide agri-food sector being the 5th European food exporter and the 9th in the world thanks to its strategic position: 70% of Italian products reach other

European countries, 17% American ones, and 10% arrive in Asia. More specifically, it is the second global exporter of apples and wines, the 8th of cereals and the 3rd of cheeses **(CBRE, 2022).** Not by chance, it boasts 845 certified products sorted in PDO (Protected Denomination of Origin), PGI (Protected Geographical Indications), and TSG (Traditional Specialty Guaranteed) **(Ministry of Economy, 2022).**

This study focuses on some fundamental Italian crops belonging to the key Mediterranean pillars, specifically, it analyses wheat (both durum and common ones), maize, rice, dry pulses and vegetables among arable lands; olive and fruit trees among the ligneous crops.

The last agricultural census, referred to the 2020 and published by Istat in 2021, highlighted a decline of 2.5% of the Total Utilised Agricultural Area (UAA) and 30% of the number of farms, from 2010. Wider dynamism is evident by observing the individual regions: Valle d'Aosta, Friuli-Venezia Giulia, Veneto, Lombardy, Liguria, Lazio, Apulia and Sardinia increased their UAA, whereas Tuscany, Basilicata, Trentino Alto-Adige recorded a drop. Briefly, the decrease is less evident in north-eastern and north-western regions, conversely to a slight increase in the islands **(ISTAT, 2022a).**

Nevertheless, the distribution of the crops previously mentioned throughout the entire UAA coincided in the 6th and 7th censuses: arable lands cover more than half of the agricultural area, of which 25% are cereals (wheat and maize mainly), 2.1% legumes, and 2% horticulture; ligneous crops correspond to 17% which is split into 5% of vineyards, 8% olive groves, 3% fruit trees and 0.9% citrus fruits. The percentages at the farm level, on the other hand, slightly changed from 2010 to 2020: according to the latest analysis, 64% of farms cultivate arable lands divided into 29% for cereals, 4.7% for legumes and 7% for horticulture; 70% is dedicated to permanent crops of which 22.8% vineyards, 55% olive groves, 13.8% fruit trees and 4% citrus fruits **(ISTAT, 2022a).**

As discussed earlier, the Mediterranean basin is recognised for its extreme vulnerability to climate change, which is already affecting the Italian ecosystem and is worsened by intensive agricultural methods. Italy suffers from loss of biodiversity, soil erosion due to heavy mechanisation which compresses the soil, water scarcity due to a massive application of fertilisers, whose minerals seep into surface and groundwater resources, and an increasing exploitation of extraordinary irrigation. Furthermore, most of the forest areas, which normally covers only 32% of the territory, are still at risk of landslide. **(OECD, 2009)**

The geographical distribution of crops was extracted from the Corine Land Cover and Eucrop maps: both were updated in 2018 and provided detailed insights about land use and land cover changes throughout the nation **(Copernicus, 2018).** Then, Panagos' erosion maps, Beck's climate analyses and Vegetation Health Index measure were adopted to better explore the current and future impact of climate change on croplands.

1.2 Corine Land Cover map

The Corine Land Cover (CLC) map is part of the Copernicus Land Monitoring Service, coordinated by the European Environment Agency (EEA), and it refers to the land cover/land use status of 2018. The opened access dataset, available on the European website, is based on Sentile-2 and Landsat-8 satellite images which have 10-m and 15-m spatial resolution, respectively. The map has been considered extremely reliable by the literature for its high resolution and accuracy (>85%). **(Copernicus, 2018a)**

Originally, the standard nomenclature embraces 44 land cover classes grouped into a three-level hierarchy, whose the first is sorted into five main categories:

1) artificial surfaces,
2) agricultural areas,
3) forests and semi-natural areas,
4) wetlands,
5) water bodies.

Among them, we dealt only with the second category which is in turn divided into three subgroups:

- ❖ Arable land: it refers to lands cultivated with plants annually harvested that are part of a rotation system, and it is subdivided into:
  a) Non-irrigated arable lands: harvested non-permanent crops such as cereals, leguminous crops and fallow lands, which are under a rotation system and normally rainfed or sporadically irrigated by sprinkler-irrigation with non-permanent devices.
  b) Permanently irrigated arable lands: arable crops permanently or periodically irrigated using a permanent infrastructure such as irrigation channels and drainage networks. The greenhouses placed in areas characterized by the Mediterranean climate are also included.
  c) Rice fields: surfaces periodically flooded with irrigation channels, embracing also fields left fallow for 1-3 years.
- ❖ Permanent crops: they aren't under a rotation system and include:
  a) Vineyards: areas covered by >50% of vines
  b) Fruit trees and berry plantations: characterised by fruit trees and shrubs, and nuts orchards. They could be single or mixed fruit species in association with permanent grass.
  c) Olive groves
- ❖ Pasture: they are permanent fodder lands (at least 5 years) where herbaceous or sown species are cultivated and mechanical approaches are applied. They are exploited for grazing pastures. **(Copernicus, 2018b)**

Arable lands embrace all cereals (common and durum wheat, maize, sorghum, barley, and rice), dry pulses, protein crops, industrial crops (such as oilseeds), biofuels, and vegetables: nevertheless, we clipped the agricultural areas only of rice fields through the adoption of the QGIS software (version 3.28.4), because it was the most accurate. Likewise, within the permanent crop section, we extracted fruit trees and olive groves.

Italy is one of the main drivers for rice, olive oil and fruit exports in the world: more specifically it is the first country for rice production in Europe, and the second for olive oil and fruit marketing after Spain. **(Eurostat, 2019)**

The Po Valley in particular holds a large percentage of these cultivations along with southern regions. Rice fields, indeed, are mostly spread in the provinces of Vercelli and Mantova, in Piedmont and Lombardy, respectively, and also in Emilia-Romagna, Veneto and in eastern and northern Sardinia **(Fig. 1.1) (Arcieri, M. and Ghinassi, G. 2020)**. Similarly, olive trees could be found in the north around the Garda lake as well as in the Apulia region, where 70% of the lands are dedicated to this crop, and a lesser extent in Umbria and Sicily. Moreover, all of them produce a great amount of certified extra virgin olive oil. **(Fig. 1.2) (ISTAT, 2022a)**

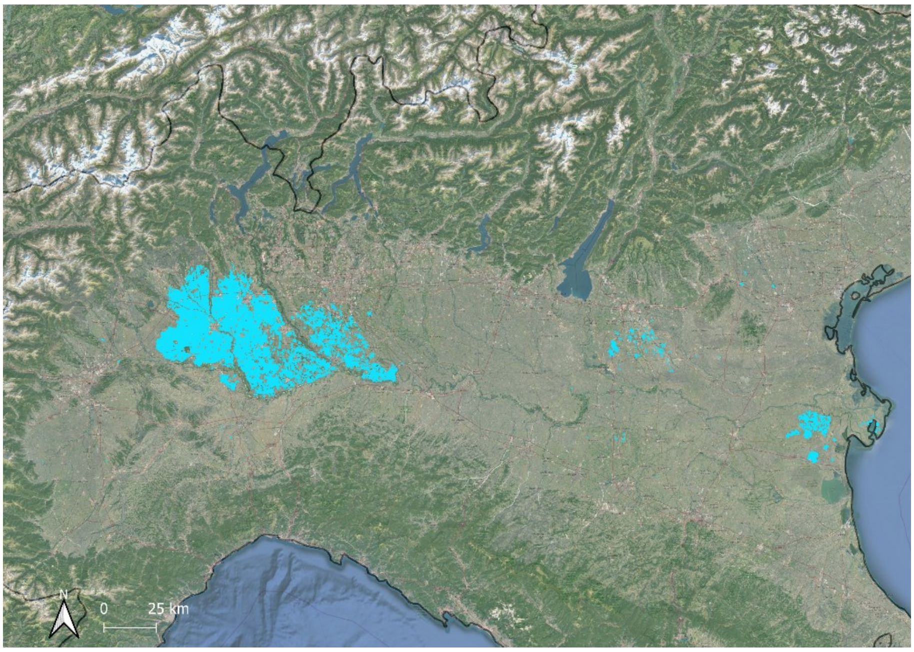


Fig. 1.1 The rice fields distribution in the north of Italy *[Adapted to the study area from Copernicus, 2018*]

Fig. 1.2 The olive trees distribution over all of Italy [*Adapted to the study area from Copernicus, 2018]*

In the CLC, actually, the fruit category includes nut orchards and citrus fruits in addition to pome fruits, thus they are not distinguishable in the map **(Fig. 1.3-1.4),** but through the ISTAT census it's possible to differentiate their localization: the former are mainly in Lazio by the extension of the area and in Piedmont by the number of farms; citrus fruits are starkly more concentrated in Sicily where half of the surface is dedicated to; whilst, pome fruit cultivations are widespread throughout the territory. **(ISTAT, 2022a)**

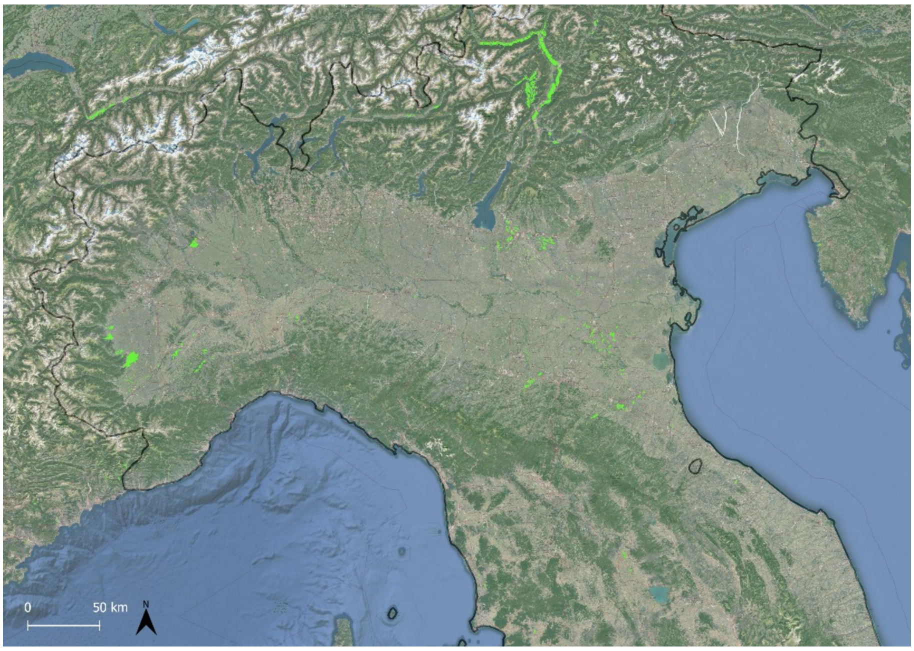


Fig. 1.3 The fruit trees' distribution in the north of Italy *[Adapted to the study area from Copernicus, 2018]*

Fig. 1.4 The fruit trees' distribution in the south of Italy *[Adapted to the study area from Copernicus, 2018]. The geographical position of Sicily doesn't respect real coordinates for convenience.*

1.3 Eucrop map

The Eucrop map was published by the Joint Research Centre of the European Union and it is freely available on the website of European Joint Research Centre. It covers 28 European countries, so it doesn't include Norway, Switzerland and some Balkans. It was elaborated upon the Sentinel-1 SAR sensor and LUCAS survey (Land Use/Land Change Area Frame Survey): both have been used as reliable sources of information for crop type mapping and remote sensing research. To achieve a more accurate Earth Observation, a new LUCAS module was designed by d'Andrimont and colleagues resulting in the elaboration of 3 levels for the land cover (which collect 66 classes embracing several crop types) and for the land use. Thus, all the polygons of the LUCAS survey were reclassified to provide the identification of four vegetation groups **(d'Andrimont *et al.*, 2021a)**:

1. Arable land (identified in the original map with the code 200) which in turn includes
   A) Cereals: common wheat (211), durum wheat (212), barley (213), rye (214), oats (215), maize (216), rice (217), triticale (218), other cereals (219)
   B) Root crops: potatoes (221), sugar beet (222), other root crops (223)
   C) Non-permanent industrial crops: other non-permanent industrial crops (230), sunflower (231), rape and turnip rape (232), soya (233)
   D) Dry pulses and vegetables and flowers (240)
   E) Fodder crops except for temporary grassland (250)
   F) Bare arable land (290)
2. Woodland and shrubland (300): corresponds in LUCAS to all fruit trees, olive groves and vineyards.
3. Grassland (400): permanent and temporary
4. Bare land and lichens (500)

D'Andrimont's resulting map has a resolution of 10-m pixels.

The accurate validation followed three modalities: the first measured the precision at pixel level; the second dealt with the comparison of the Eucrop map with the Geospatial Aid Application data which is based on farmers' communications; the last evaluated the areas described in the map with the corresponding ones analysed by official national statistics. The elaboration isn't without limitations: regarding LUCAS data the authors didn't distinguish between rain-fed and irrigated lands, thus the monitoring of irrigated maize was underestimated in Spain and southern Italy, and they didn't consider rice fields altering the evaluation in northern Italy. **(d'Andrimont *et al.*, 2021a)**

For our purpose, we decided to exploit this map to extract the extension of common wheat, durum wheat and maize from the cereal subcategory and that of pulses and vegetables from the homonymous class, since they are more detailed than that proposed by the previous Corine Land Cover which collects cereals and vegetables together with many other crops.

Maize, durum and common wheat are chosen due to their relevance as primary ingredients of animal feed (the maize) and of the most renowned Italian bakery products, namely pasta and bread (common and durum wheat). These crops, however, are mostly involved in the depletion of forests and biodiversity because they have been more and more intensively managed by farmers to achieve higher yields, indeed an increased field concentration (from 3.5 ha/farm to 3.75 ha/farm) occurred over twenty years. **(ISMEA, 2022a; Eurostat, 2023a)**

The Po valley once again holds most of the cultivations: Lombardy, Veneto, Piedmont, and Emilia-Romagna own the greatest part of maize and common wheat, instead, durum wheat is extensively placed in Apulia, Sicily and Campania **(Fig. 1.5-1.6) (Mereu, V. *et al.* 2021).** This distribution reflects also that of animal husbandry: 77% of maize production is destined for livestock farming which is concentrated mainly in the north and is characterized by cattle (44%), poultry (26%) and caprine (14%) **(ISMEA, 2022a; Eurostat, 2023b)**

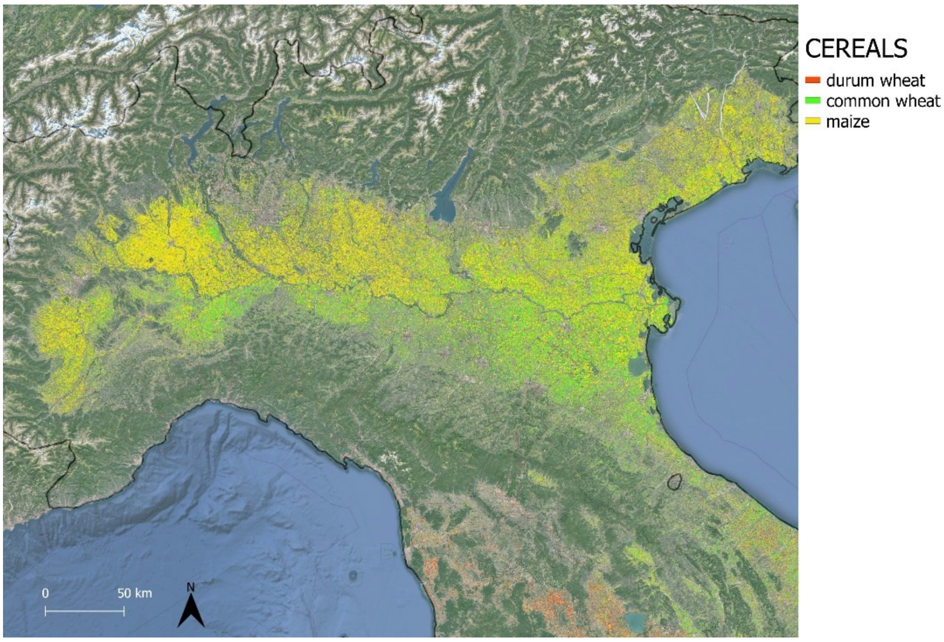


Fig. 1.5 Distribution of cereals in the north of Italy [*Adapted to the study area from EU Joint Research Centre]*

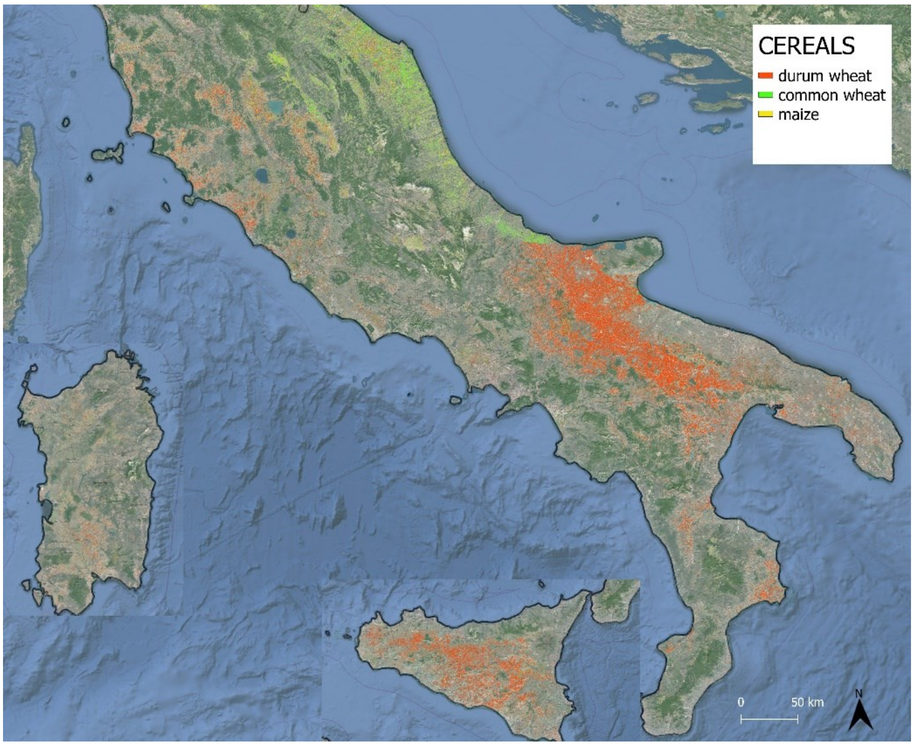


Fig. 1.6 Distribution of cereals in the centre-south of Italy [*Adapted to the study area from EU Joint Research Centre****].** The geographical location of Sicily and Sardinia doesn't follow real coordinates for convenience.*

The second category, which we focused on starting from this map, merges dry pulses, vegetables and flowers, nevertheless, we will deal only with pulses and vegetables since they have equally a pivotal role in Italian marketing and an utmost relevance in the Mediterranean diet: the country is the first in Europe by the extension of the area dedicated to vegetables (17.8% of the total European land) followed by Spain and France; as well as it is one of the most important in tomatoes harvesting of which it can boast many denominated varieties. **(Eurostat, 2019)** The ISTAT census allowed us to successfully localize specific areas that are difficultly distinguishable on the map due to their far distance: Emilia-Romagna exceeds the other regions by the extension, whereas in the south leading regions are Apulia and Sicily **(ISTAT, 2022a)**

1.4 Erosion map

The erosion by water is acknowledged as one of the most worrying threats in Europe, as abovementioned in the first section of this work. Therefore, the adoption of the last updated Panagos' map, which was published in 2020 on the free access European Soil Data Centre website and based on data referring to 2016, pursued to display the most reliable depiction of the current soil erosion in Italy.

Originally, Panagos et al improved the version of the USLE equation, which was the most used erosion model, providing the revised form (RUSLE, so Revised Universal Soil Loss Equation) that estimates annual soil loss by sheet and rill erosion and has become the official method. The proposed equation is:

$E = R \times K \times C \times LS \times P$

E is the annual erosion rate (t/ha/y); R is the rainfall-runoff erosivity factor (MJ mm ha/h/y); K is the soil erodibility factor (MJ t ha h/ha/MJ/mm); C is the cover-management factor (dimensionless); LS are the slope length and the slope steepness factors (dimensionless); P is the support practices factor (dimensionless). **(Panagos, P. *et al* 2015)**

The last Panagos' analysis relied on the most recent data available at the European scale and aimed at monitoring the real efficiency of European political measures which were applied over the years. Thus, they modified data referred to dynamic factors of the equation, namely the R, C and P factors, compared to their first elaboration in 2015. The R factor corresponds to the recorded European rainfall erosivity since it would have been difficult to efficiently quantify the erosivity modifications over the short 2010-2016 period; the C factor deals with the land cover and management practice changes in arable land (tillage, cover crops and plant residues) which were extracted from European dataset directly collected by Member States; P factor is based on the most recent data elaborated by LUCAS survey and considers the grass margins and stone walls as valuable strategies to protect from soil erosion. On the contrary, the K and LS factors were maintained: the former derived from 20,000 sampling points of the LUCAS survey; whereas, the latter was based on Digital Elevation Model at 25 m. The spatial scale, also, was conserved at 100 m because it is considered by the authors as the proper compromise between the low resolution of K, R and P factors and the high one of LS and C factors. **(Panagos, P. *et al.* 2020)**

We are surely aware of the limits which could derive from this tool: the C and R factors, especially, are the most variable, so they could be misclassified. The authors themselves declared the necessity of a more dynamic model at the continental scale to improve estimates of vegetation changes through the exploitation of detailed remote sensing analysis and specific datasets on crop types, soil characteristics and soil loss. **(Panagos, P. *et al.* 2020)**

According to the results, Europe undergoes an average soil loss rate of 2.45 t/ha/y, thus a marginal decrease occurred between 2010 and 2016. Italy, together with Spain and Greece, is figured out as the most critical country within the Mediterranean basin reaching the highest average soil loss (8.59 t/ha/y). **(Panagos, P. *et al.* 2020)**

The elaboration of the map specifically for Italy followed the eight ranges proposed by Panagos using t/ha/y as a unit of measurement: <0.5; 0.5-1; 1-2; 2-5; 5-10; 10-20; 20-50; >50. Furthermore, the severe level corresponds to the loss of more than 11 t/ha/y as fixed by policymakers **(Panagos *et al.*, 2020)**. The latter occurs, particularly, starting from the centre of Piedmont along the Po river flow, moving down along the Adriatic coast up to southern regions covering Basilicata, Calabria and the entire Sicily. Also the Tyrrhenian coast is similarly affected. The Alps are another worrying framework where small areas seem to experience a moderate-high soil erosion rate due to their steep topography: not surprisingly, these mountains have been already classified as highly at risk of soil erosion due to the easy depletion of their soil moisture. **(European Environment Agency, 2019).** Conversely, the Po Valley and the Apulia region are characterized by a low-medium average loss of 0.5-1 and 1-2 t/ha/y. Lastly, Sardinia has a wide condition marked by intermediate soil erosion rates (2-4 t/ha/y and 4-10 t/ha/y) **(Fig. 1.7)**

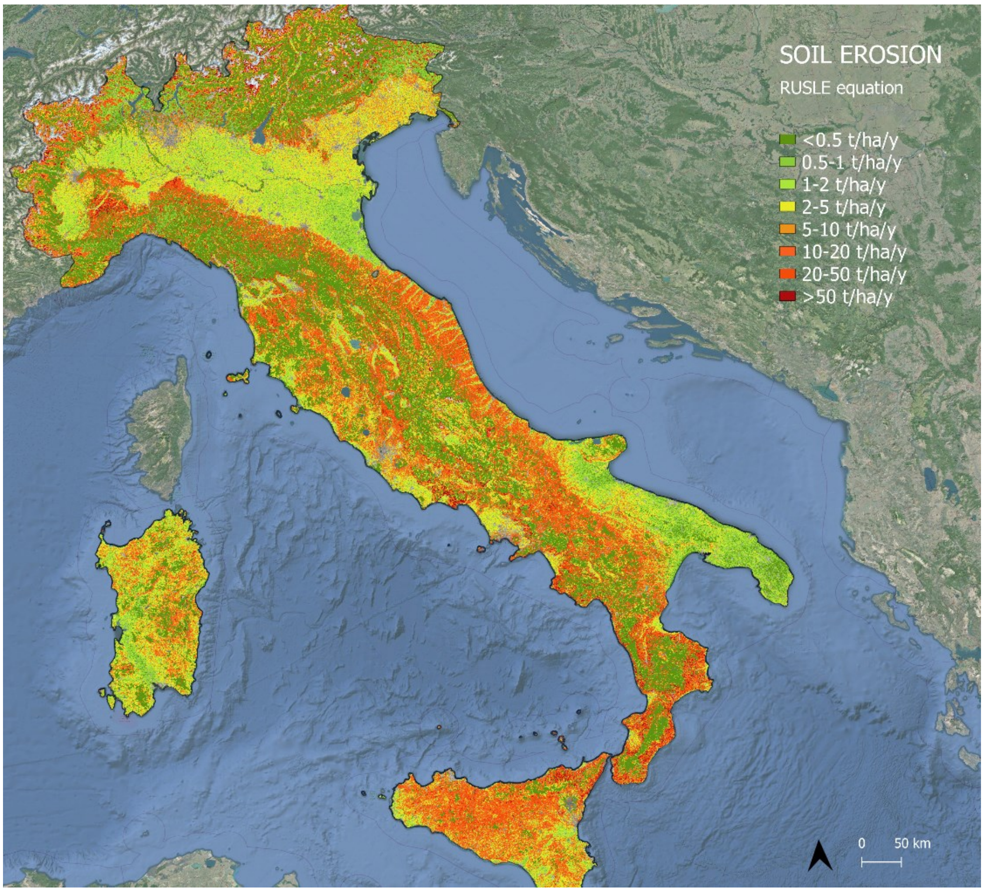


Fig. 1.7 Current Italian soil erosion map. *[Adapted to the study area from Panagos, P. et al. 2020]*

1.4.1 Future Erosion map

We exploited, also, the prediction of the European soil erosion by water in 2050 provided by the same authors, who simulated different RCP scenarios (RCP2.6, RCP4.5 and RCP8.5), and available on the abovementioned European website after a request form. They again applied the RUSLE equation adjusted at the continental scale and modified with the projections of future rainfall erosivity and land use change. More specifically:

- pedological and topographic conditions are assumed as static over time, thus they were preserved from the previous research which is considered as baseline;
- rainfall erosivity was predicted using 19 Global Climate Models (GCMs) from the Coupled Model Inter-Comparison Projects (CMIP5) WorldClim dataset applied for the abovementioned three different RCP scenarios;
- land use changes were forecasted from the combination of the Common Agricultural Policy Regional Impact Analysis (CAPRI) model with the Land Use and Management (LANDUM) model which empirically estimates the cover-management factor (factor C): this is the key information because less erosive crops should determine less water erosion rates. **(Panagos, P. *et al* 2021)**

In this regard, the limits lie in the already known uncertainties of the RUSLE equation and the used projections modelling, in particular, the CAPRI model simplifies reality by basing its outcomes only upon specific conditions. **(Panagos, P. *et al* 2021)**

The results underline the increase in soil loss compared to the baseline: under the 2.6 RCP scenario, the third quarter of the entire European Union (including the UK) should experience an upward; whilst, under 8.5RCP the percentage shoots up covering 84% of the study area. The only exception concerns the Mediterranean regions which may have a slight reduction. The estimated expansion of the soil erosion area, thus, should rank between 3.07 t/ha (2.6 RCP) and 3.76 t/ha (8.5 RCP) which correspond to a range of +13% and+22.5% respectively; consequently, the percentage of the agricultural lands influenced by severe erosion may move from 6.6% to 8.5% according to the 8.5 RCP. Furthermore, the areas subjected to medium-low erosion rates should decrease by 9% due to the opposite increase of 4% of high erosion classes. The authors, then, interestingly separated the climate change effect from the land use change discovering that the latter influences the average soil loss by around 3%, thus, considering only climate shifts, the soil erosion rates should grow more (from+15.7% to +25.5%). **(Panagos, P. *et al* 2021)**

Briefly, a switch between European countries is expected: the countries with current low erosion rates are destined to experience the largest increase; on the contrary, Italy, together with others already affected by severe erosion, should undergo very small differences, also under the worse scenario. **(Panagos, P. *et al* 2021)**

Despite some missing data, we extracted the map elaborated under the least mitigated scenario through QGIS software: the results were the same as the anticipated ones i.e. the Italian framework should remain similar to the baseline. Therefore, the areas which may preserve extreme erosion rates (ranking between 20 to 50 t/ha/y or over 50 t/ha) will be those along southern Padan plain, the Adriatic and Mediterranean coasts, some small parts in the Alps and some others widespread in the north of the Po valley. Almost all the southern regions would be included, except for the Apulia region and, to a lesser extent, Sicily and Sardinia. **(Fig. 1.8).**

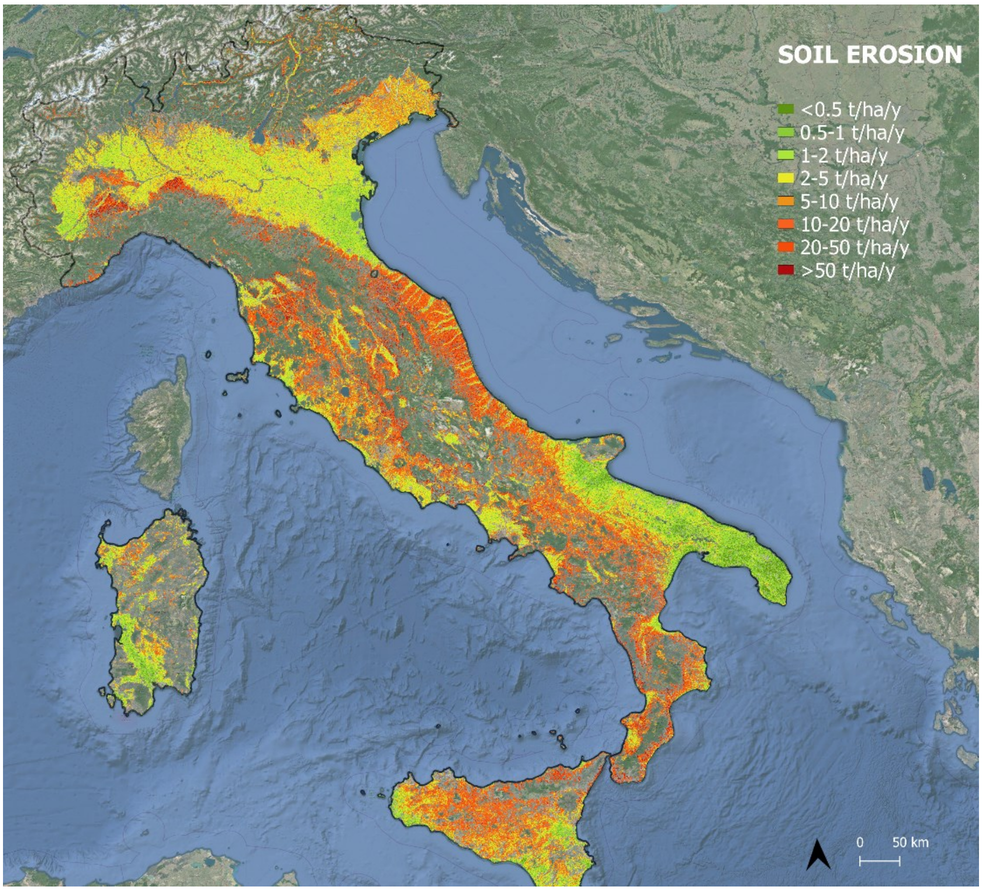


Fig. 1.8 Future Italian soil erosion map *(Adapted to the study area from Panagos, P. et al., 2021)*

1.5 Vegetation Health Index

The Vegetation Health Index is a reliable and widely used drought index for remote sensing analysis from the LUCAS survey. Our choice lies in the origin of VHI which is recognised as stronger and more robust than other indices since it is based on the MODIS satellite images and derives from a combination of two components: the Vegetation Combination Index (VCI) and the Temperature Condition Index (TCI). The former derives from the NDVI index (Normalized Difference Vegetation Index), includes information from visible and near-infrared portions of the electromagnetic spectrum, and monitors the vegetation water stress providing insights about the duration and severity of spatial characteristics of the considered drought event. Instead, the latter relies on the thermal infrared portions deriving from either top-of-atmosphere brightness temperature or Land Surface Temperature (LST), assesses the temperature stress due to heat or excessive wetness showing the deviation of the analysed month's temperature from the maximum recorded, and detects the drought-affected area before the onset of degradation. **(Amalo, L.F. *et al.* 2017; Bento, V.A. *et al.* 2018; Belal, A. *et al.* 2014).** More in detail, the measure of VCI ensues from the following equation:

$$VCI_j = (NDVI_j - NDVI_{min}) / (NDVI_{max} - NDVI_{min}) \times 100$$

where the $NDVI_{max}$ and $NDVI_{min}$ are the maximum and minimum NDVI values in a multi-year dataset and the 'j' is the NDVI value for the current month.

ON the other hand, the calculation of TCI is based on: $TCI_j = (TCI_j - TCI_{min}) / (TCI_{max} - TCI_{min}) \times 100$ where TCI_{max} and TCI_{min} are the maximum and minimum TCI values in a several-year dataset and the 'j' is the TCI value for the current month.

Therefore, the VHI's equation is the following one: $VHI = \alpha \times VCI + (1 - \alpha) \times TCI$ where α is the weight to measure the contribution of the VCI and TCI for assessing the status of drought and, generally, it is set as 0.5 because it is difficult to distinguish the contribution of the surface temperature from that of the NDVI measuring drought stress. Then, a classification was developed in 5 levels that moves from the highest VHI values to the lowest: no drought, mild, moderate, severe and extreme. **(Amalo, L.F. 2017; Bento, V.A. *et al.* 2018; Belal, A. *et al.* 2014)**

The VHI index provides many advantages: it allows selecting the preferred area of interest; it distinguishes the variation in short-term weather from the long-term one thank to the addition of TCI because it detects subtle changes in plant health when drought proliferates and moisture reduces; it studies vegetation status and thermal condition and identifies the spatiotemporal characteristics of agriculture by classifying the drought according to its severity. These features make this index more reliable than a simple evaluation of meteorological changes precipitations, such as the Standardized Precipitation Index or Standardized Deficit Index (which is obtained by the difference between evapotranspiration and precipitation measures), mainly in the Alps. (**Bachmair, S. *et al.* 2018)** We are also aware of the presence of some limits: authors noticed that a larger area could be better covered by the spatial resolution of MODIS data; this indicator is more worthy for rainfed crops rather than for irrigated ones and more suitable to low latitudes where water is the main limiting factor because, at higher and wetter points from the equator, other mechanisms could interfere. **(Amalo, L.F. 2017; Bento, V.A. 2018; Belal, A. *et al.* 2014)**

To provide a better evaluation of the framework that dramatically affected Italian agriculture last year, we considered the VHI monthly elaboration referred to June 2022 when plants are in vegetative phase and the harvest of durum wheat is scheduled. We uploaded and worked the MODIS data in Google Earth Engine, then clipped the territory of our interest in QGIS.

The resulting map **(Fig. 1.9)** displays a severe drought condition covering the north of Italy especially most parts of Padana plain, particularly the north-east, central and southern Tuscany, the Apennine and Tyrrhenian coast, the Murgia plain bordering Apulia and Basilicata, southern Apulia and Sicily. Less dramatic small areas were in the Alps, northern Tuscany, central regions along the Adriatic coast, western coast of Sicily and eastern one of Sardinia.

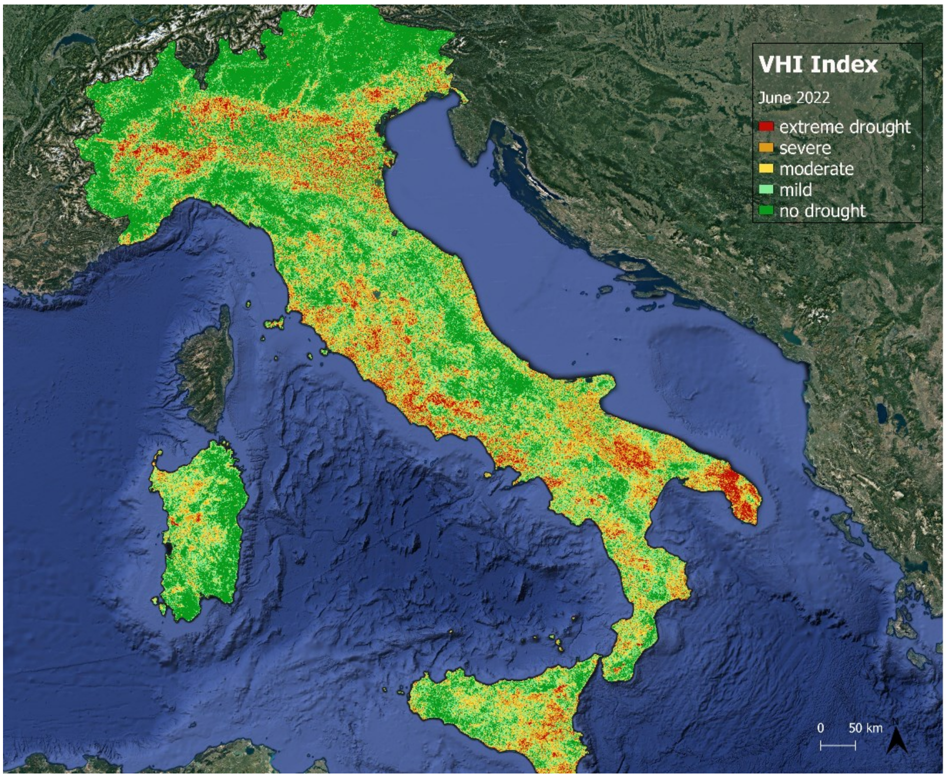


Fig. 1.9 Drought condition based on VHI index referred to June 2022

1.6 Climate zone maps

Many researchers proposed maps dealing with present and future climates, anyway, Beck and colleagues provided the most precise ones with 80% of accuracy, compared to 66% or 70% of Kottek and Peel **(Kottek, M., *et al.* 2006; Peel, M. C., *et al.* 2007)** and 1 km of resolution. Beck's work is free-access available on the GloH2O website and relies on the Köppen-Geiger's climate classification, which is acknowledged as a valuable tool to monitor the distribution of plant growth or to elaborate vegetation models. The Köppen-Geiger's system sorts climate according to fixed thresholds related to the seasonality of monthly air temperature and precipitation and elaborates five principal classes and 30 sub-classes **(Beck, H.E. *et al*. 2018)**:

A- Tropical (A): it is subdivided into:
- Rainforest (f)
- Monsoon (m)
- Savannah (w)

B- Arid (B):
- Desert (W)
- Steppe (S)

  Both are in turn distinguished into:
  - Hot (h)
  - Cold (k)

C- Temperate (C):
- Dry summer (s)
- Dry winter (w)

- Without dry season (f)

  All of them are in turn divided into:
  - Hot summer (a)
  - Warm summer (b)
  - Cold summer (c)

D- Cold (D): follows the previous grouping except for the addition of “very cold winter (d)”

E- Polar (E):
- Tundra (T)
- Frost (F)

Despite Beck et al. adopting the same classification, there are some differences in the selection of parameters compared to those proposed by Köppen-Geiger:

1. Temperate (C) and cold (D) climates are distinguished by using 0°C as the threshold rather than 3°C;
2. The choice between arid desert (W) and arid steppe (S) depends if the 70% of precipitation occurs in summer or winter
3. The sub-climates dry summer (s) and dry winter (w) are assigned if more precipitation falls in winter or in summer. **(Beck, H.E. *et al.,* 2018)**

The present climate map displays the 1980-2016 period and it is based on 3 datasets for air temperature climate (WorldClima V1, V2 and CHELSAVI 1.2) and 4 for precipitation which are those listed before with the addition of CHPclim V1. The future one, instead, results from the combination of 32 CMIP5 climate models and the exploitation of monthly historical and future air temperature and precipitation datasets considering the 2017-2100 period under the 8.5 RCP scenario. Undoubtedly, the authors were aware of model biases which could bring to measure climate change anomalies not geographically coherent with the baseline, as well as, in the presence of significant heterogeneities in precipitation change and/or warming below the model resolution, the future projection could be under or over-estimated. **(Beck, H.E. *et al.,* 2018)**

To achieve the purpose of the study, the Italian present and future climate maps were extracted from the global one through the QGIS software.

A temperate climate (C) is spread out with dry winter (Cw) along the central Apennines chains and no dry season (Cf) in the Po Valley and along the Adriatic coast as far as the Molise region. On the contrary, a temperate dry summer climate (Cs) characterizes the coast overlooking the Tyrrhenian Sea and both Sicily and Sardinia. All of these, then, are also described by polar tundra (ET) and small cold dry summer (Da) areas together with Calabria. Regarding mountains, both the Alps and the Apennines show a tropical climate (A); whereas the Apulia region differentiates from others being marked by arid, steppe, cold (Bsk) together with the zone of Grosseto, in Tuscany. **(Fig. 1.10)**

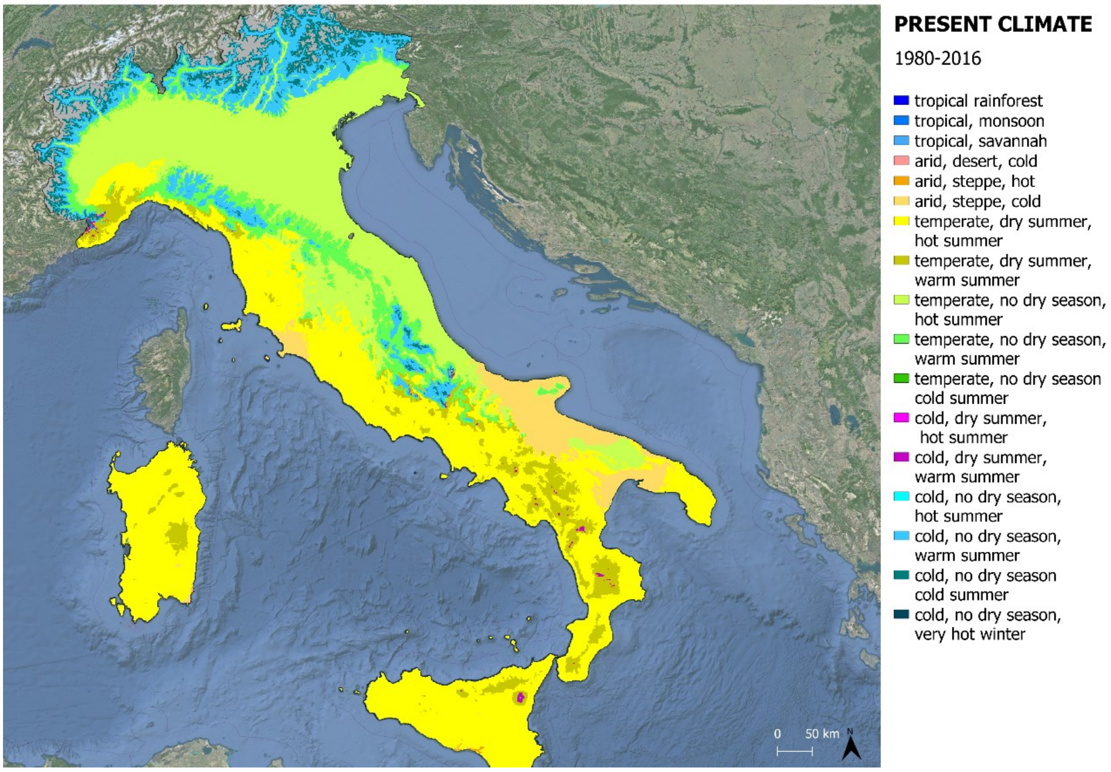


Fig. 1.10 Italian present climatic map (1980-2016 period) *[Adapted to the study area from Beck et al, 2018]*

The projection **(Fig. 1.11),** instead, highlights huge changes in the central and southern regions. Whereas the Alps may largely conserve their tropical climate (A) except for some areas in the north of Piedmont and Lombardy where a temperate dry winter (Cw) is expected, the tropical (A) and temperate dry winter (Cw) near the Apennines would be completely substituted with temperate dry summer (Cs). The latter should entirely cover the country from central zones in Piedmont, through Liguria and all the central regions overlooking the Mediterranean sea up to Calabria. Thus, only along the river flow, the Po Valley still preserves a temperate dry winter (Cw); nevertheless, its Delta is worryingly destined to experience an arid, steppe, hot climate (BSh). The same would worsen the framework by occurring along the Adriatic coast from the Marche region to Basilicata, roughly in half of Sicily and also near the Grosseto province in Tuscany.

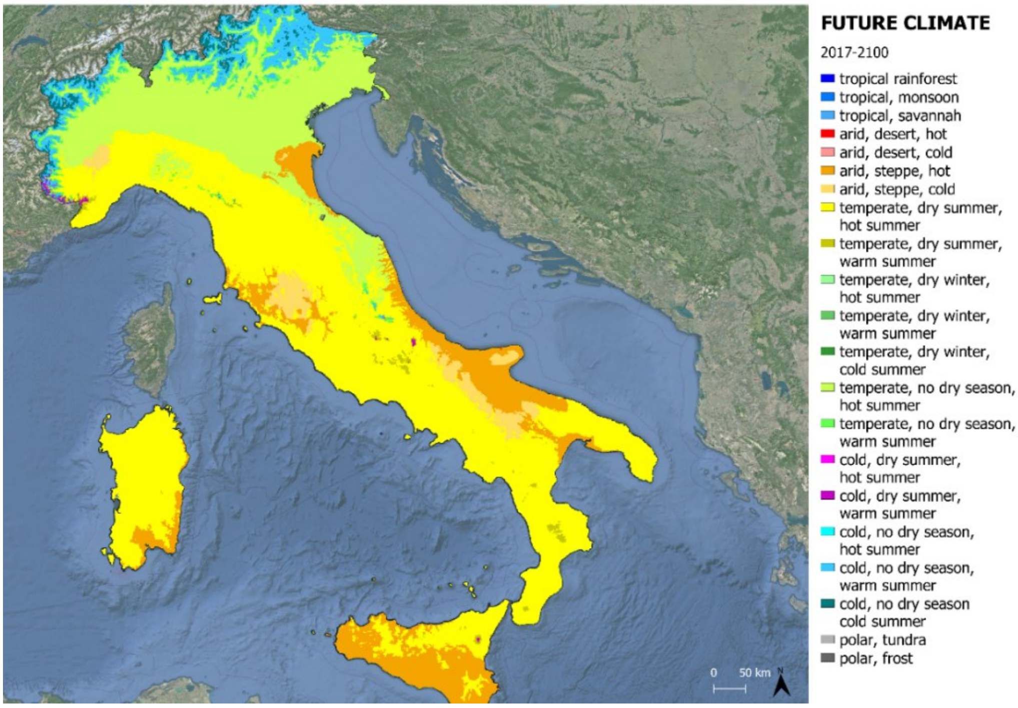


Fig. 1.11 Italian future climatic map of Italy under 8.5 RCP scenario (2017-2100 period) *[Adapted to the study area from Beck et al. 2018]*

CHAPTER 2. RESULTS

After ensuing the maps described and reported above, we estimated the extent (in percentage) to which areas cultivated with selected crops are affected by all classified levels of erosion and VHI and by climate shifts. The geographical distribution of individual crops throughout Italy was obtained from the Corine Land Cover and Eucrop maps; while, as for present and future erosion and climatic zone changes, the source were the Panagos and Beck's studies. Lastly, drought assessment relied on the VHI measure of June 2022. All these data were processed with QGIS software to develop results.

The chapter is divided into subchapters according to the environmental condition considered and, then, each of them analyses more in details single investigated crops (common wheat, durum wheat, maize, rice, olive trees, fruit orchards, pulses and vegetables) through brief dedicated sections in which separate maps allow the area localization.

2.1 Erosion mapping

The following **tables 2.1.1 and 2.1.2** distinguish the area extension in percentage specified for each crop and divided for current and future erosion levels from <0.5 t/ha/y (no erosion) to >50 t/ha/y (extremely severe erosion). Although the highest level is counted over 50 t/ha/y, policy makers fixed the threshold of most severe condition over 10 t/ha/y. **(Panagos, P. *et al.* 2020).** The ranges and colours are the original ones provided in the Panagos' study.

SOIL EROSION	*<0.5 t/ha/y*	*0.5-1 t/ha/y*	*1-2 t/ha/y*	*2-5 t/ha/y*	*5-10 t/ha/y*	*10-20 t/ha/y*	*20-50 t/ha/y*	*>50 t/ha/y*
Common wheat	3.65%	9.63%	25.18%	33.83%	11.56%	9.30%	6.60%	
Durum wheat	5.29%	8.11%	13.26%	21.06%	17.65%	20.66%	13.26%	
Maize		9.95%	29.48%	41.19%	10.10%	3.69%	2.43%	
Rice	3.40%	12.70%	38.90%	40.80%	3.70%			
Olive	9.45%	10.69%	12.42%	12.58%	10.93%	15.82%	21.83%	6.29%
Fruit	5.13%	8.70%	18.40%	28.58%	15.79%	11.50%	9.26%	2.64%
Pulses & Vegetables	4.71%	9.57%	17.47%	23.58%	14.83%	16.58%	12.14%	1.11%

Table 2.1.1 Summary of area extension (in percentage) of specific crops divided into current erosion levels. The colour used to fill the cell corresponds to that used in the maps' legend.

FUTURE EROSION	*<0.5 t/ha/y*	*0.5-1 t/ha/y*	*1-2 t/ha/y*	*2-5 t/ha/y*	*5-10 t/ha/y*	*10-20 t/ha/y*	*20-50 t/ha/y*	*>50 t/ha/y*
Common wheat		6.90%	21.50%	38.20%	14%	8.40%	8.80%	
Durum wheat	3.55%	9.38%	14.34%	22.16%	18.69%	21.29%	10.12%	
Maize		6.90%	24.04%	46.69%	13.93%	4.17%	2.95%	
Rice		9.12%	29.77%	51.58%	7.40%			
Olive	5.53%	11.33%	13.54%	13.39%	10.98%	16.61%	23.22%	5.39%
Fruit	3.75%	10.93%	20.42%	28.55%	15.33%	10.52%	8.49%	2.01%
Pulses& Vegetables	3.50%	9.90%	17.80%	25.70%	15.50%	16.30%	10.70%	

Table 2.1.2 Summary of area extension (in percentage) of specific crops divided into future erosion (2050, under 8.5 RCP) levels. The colour used to fill the cell corresponds to that used in the maps' legend.

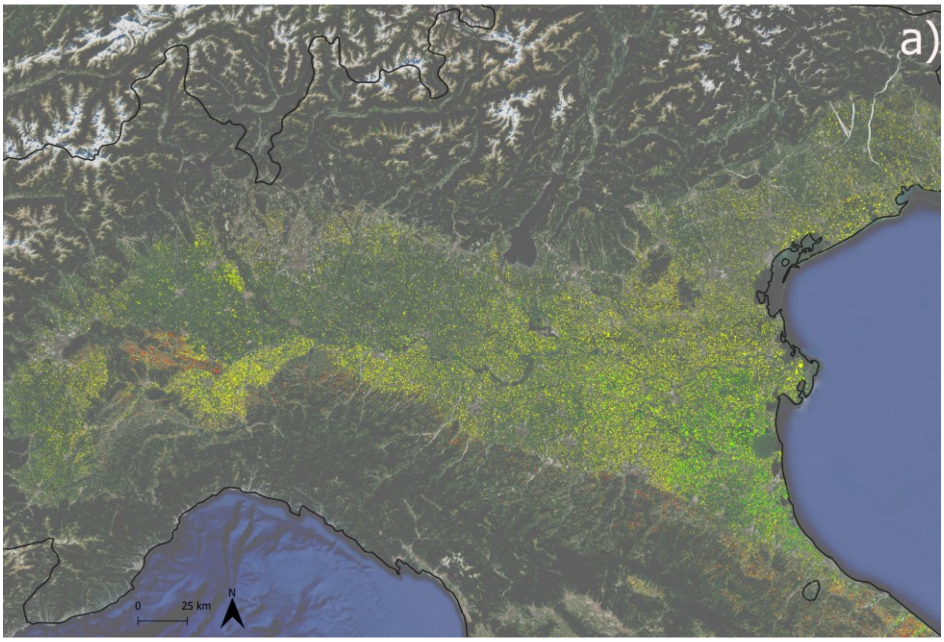
a. Common wheat

Our findings show that half of common wheat fields, whose distribution was extracted by Eucrop map, are already experiencing a medium soil erosion: specifically 25.18% undergoes a loss between 1-2 t/ha, 33.83% between 2-5 t/ha **(Tab. A)**. This condition crosses mainly the Po Valley from north-east to north-west. Within the northern regions, the only exception is the Delta of the Po river where an extremely low erosion rate is found. **(Fig. 2.1a)**

On the contrary, 11.56% of these cultivations are affected by the loss of 5-10 t/ha/y, 9.30% by 10-20 t/ha/y and 6.6% by 20-50 t/ha/y **(tabA).** In this regard, the most worrying sites are along the Po river flow, from the Alessandria province in Piedmont, through Piacenza, in Emilia-Romagna, and then along the entire Adriatic coast, from Marche to Molise, since they hold the majority of fields damaged by severe and extreme erosion. Additionally, one inland cluster of severe erosion is visible around the Trasimeno Lake in Umbria. **(fig. 2.1a)**

COMMON WHEAT	*<0.5 t/ha/y*	*0.5-1 t/ha/y*	*1-2 t/ha/y*	*2-5 t/ha/y*	*5-10 t/ha/y*	*10-20 t/ha/y*	*20-50 t/ha/y*	*>50 t/ha/y*
Current erosion	3.65%	9.63%	25.18%	33.83%	11.56%	9.30%	6.60%	
Future erosion		6.90%	21.50%	38.20%	14%	8.40%	8.80%	
Δ	-3.65%	-2.73%	-3.68%	+4.37	+2.44%	-0.9%	+2.2%	

Tab. A Summary table of area extension (in percentage) of maize divided into each level of current and future soil erosion. The last row measures the difference.



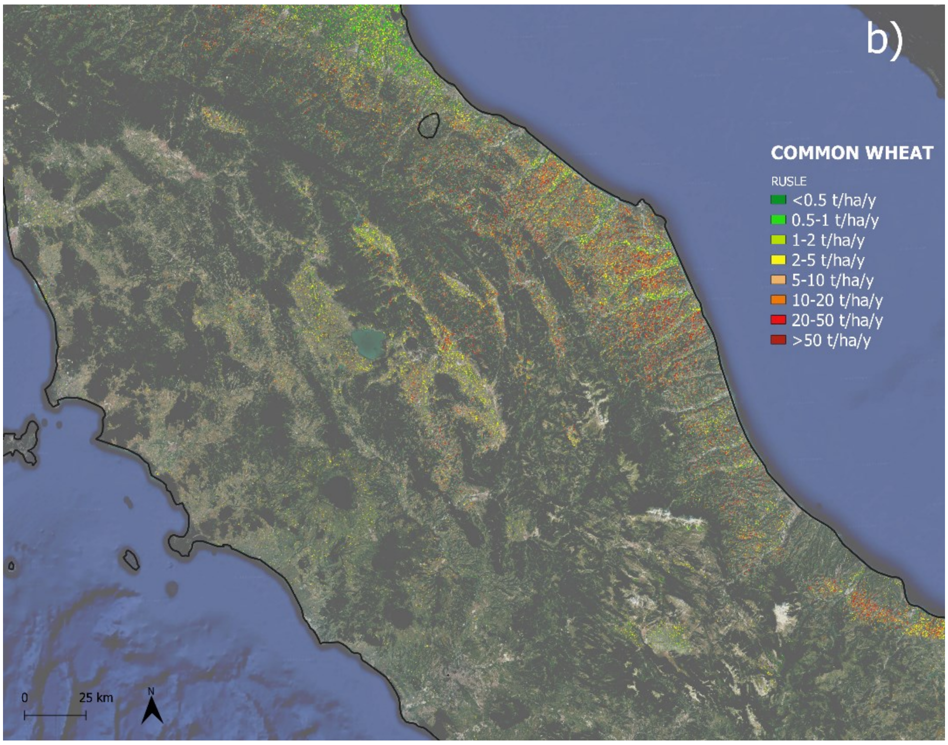


Fig. 2.1a Northern (a) and Central (b) distribution of common wheat cultivation distinguished by the intensity of current erosion.

The Panagos' analysis dealing with future erosion reported results similar to those of 2016, just as ours are roughly analogous to the previous ones: the only differences are visible in the percentage extent **(Tab. A).** Interesting changes regard the halving of sites that are experiencing meagre erosion rates (considering both <0.5 t/ha/y and 0.5-1 t/ha/y classes): they will decrease from almost 13% to 6%. Consequently, the severe level (20-50 t/ha/y) is expected to increase from the current 6.9% to 8.8%. The moderate ranks (1-2 t/ha/y and 2-5 t/ha/y) should remain stable continuing to cover about 60% of all cultivated fields, whereas the 5-10 t/ha/y one may lose 0.9%.

b. Durum wheat

The durum wheat cultivation, whose spatial distribution was again provided by the Eucrop map, is more widespread in southern country with some occasional fields in the centre: this dislocation reflects the crop's need to grow at certain environmental conditions, being able to resist hot stress**.(Accetturo and Alpino, 2023)**

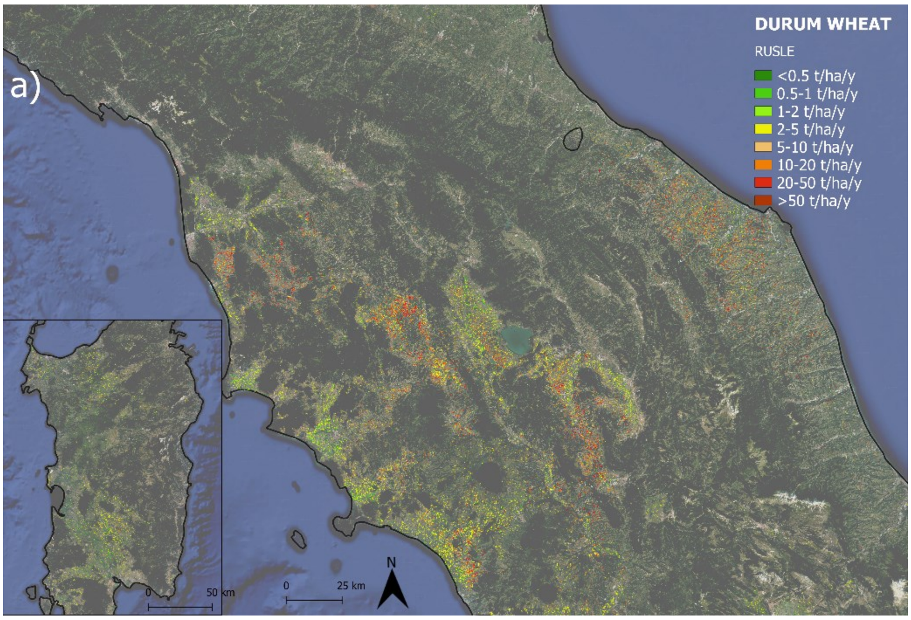
Our analysis finds out that, compared to common wheat, larger percentages of durum wheat cultivations are placed in fields affected by medium-high and severe soil erosion: 17.6% lose 5-10 t/ha/y, 20.66% 10-20 t/ha/y and 13.26% 20-50 t/ha/y. **(Tab B)** As is evident in **Fig. 2.1b**, most of these of concern are in the south, mainly between the Apulia and Basilicata and in the central areas of Sicily. But they are also set along the Adriatic coast, in Marche, in northern Tuscany, around Siena, Umbria, in the provinces of Perugia and Terni.

Lower erosion levels are visible quite clearly in entire Apulia, from Foggia to Lecce, and less so around Catania, in Sicily **(fig. 2.1b)**: in general, indeed, 5.3% of durum wheat areas are not experiencing soil erosion (<0.5 t/ha/y); 8.11% are characterized by low erosion (0.5-1 t/ha/y), 13.26% and 21.06% by 1-2 t/ha/y and 2-5 t/ha/y, respectively, which correspond to low-medium classes. **(Tab B)**

In the future, the framework will not markedly change even considering the worse scenario (8.5 RCP), thus we didn't identified substantial geographical differences. Similarly to common wheat, the durum wheat fields involved in the least erosion level (<0.5 t/ha/y) should slightly decrease from 5.3% to 3.55%; whilst an increase, albeit minimal, is expected in all other classes. The areas characterized by 0.5-1 t/ha/y range may cover 9.38% (+1.27%), those in the 1-2 t/ha/y and 2-5 t/ha/y ranks may grow by +1.08% and +1.1% apiece. Likewise, unfortunately, the medium-high erosion rate (5-10 t/ha/y) and one of the most severe (10-20 t/ha/y) should move upward: the former would progress from 17.6% to 18.69% (+1.1%), whereas the latter from 20.66% to 21.29% (+0.63%). On the contrary, the extent of the extreme erosion level (20-50 t/ha/y) is predicted to decrease from 13.26% to 10.12% (-3.14%). **(Tab. B)**

DURUM WHEAT	*<0.5 t/ha/y*	*0.5-1 t/ha/y*	*1-2 t/ha/y*	*2-5 t/ha/y*	*5-10 t/ha/y*	*10-20 t/ha/y*	*20-50 t/ha/y*	*>50 t/ha/y*
Current erosion	5.29%	8.11%	13.26%	21.06%	17.65%	20.66%	13.26%	
Future erosion	3.55%	9.38%	14.34%	22.16%	18.69%	21.29%	10.12%	
Δ	-1.74%	+1.25%	+1.08%	+1.1%	+1.1%	+0.63%	-3.14%	

Tab. B Summary table of area extension (in percentage) of maize divided into each level of current and future soil erosion. The last row measures the difference.



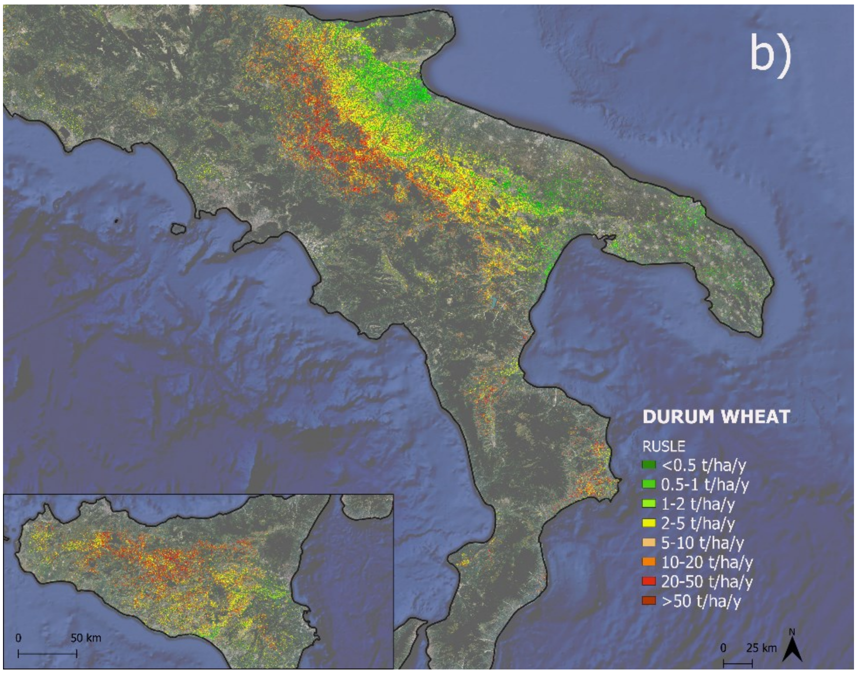


Fig. 2.1b Central (a) and Southern (b) extension of durum wheat cultivations distinguished by the intensity of current erosion. *The geographical position of Sardinia and Sicily doesn't respect the real coordinates for convenience.*

c. <u>Maize</u>

Po Valley coupled with the Adriatic coast holds all Italian maize cultivations as displayed by the Eucrop map **(Fig.1.5-1.6)**. Analysis of the current erosion level highlights that the majority of fields have low to medium erosion rates: 9.95% lose 0.5-1 t/ha/y, 29.48% 1-2 t/ha/y, and 41.19% 2-5 t/ha/y; while 10.10% belongs to the 5-10 t/ha/y erosion class, and only 3.69% and 2.43% to 10-20 t/ha/y and 20-50 t/ha/y apiece **(Table C)**. The figure **2.1c** displays that northern regions experience low and medium-high erosion rates: more precisely, the central areas of Lombardy, eastern Piedmont and the Po Delta are marked by low levels of soil loss; whereas, medium-high levels are found in Piedmont, around the Cuneo and Vercelli provinces, in Lombardy, around Pavia and Mantova, in Veneto, near Rovigo, and severe ones in the province of Alessandria, in Piedmont, in the Verona and Padova provinces in Veneto as far as Udine in Friuli Venezia Giulia. The Adriatic coast, from Marche to Abruzzo, takes also almost entirely fields affected by severe soil erosion.

MAIZE	*<0.5 t/ha/y*	*0.5-1 t/ha/y*	*1-2 t/ha/y*	*2-5 t/ha/y*	*5-10 t/ha/y*	*10-20 t/ha/y*	*20-50 t/ha/y*	*>50 t/ha/y*
Current erosion		9.95%	29.48%	41.19%	10.10%	3.69%	2.43%	
Future erosion		6.90%	24.04%	46.69%	13.93%	4.17%	2.95%	
Δ		-3.05%	-5.44%	+5.5%	+3.83%	+0.48%	0.52%	

Tab. C Summary table of area extension (in percentage) of maize divided into each level of current and future soil erosion. The last row measures the difference.

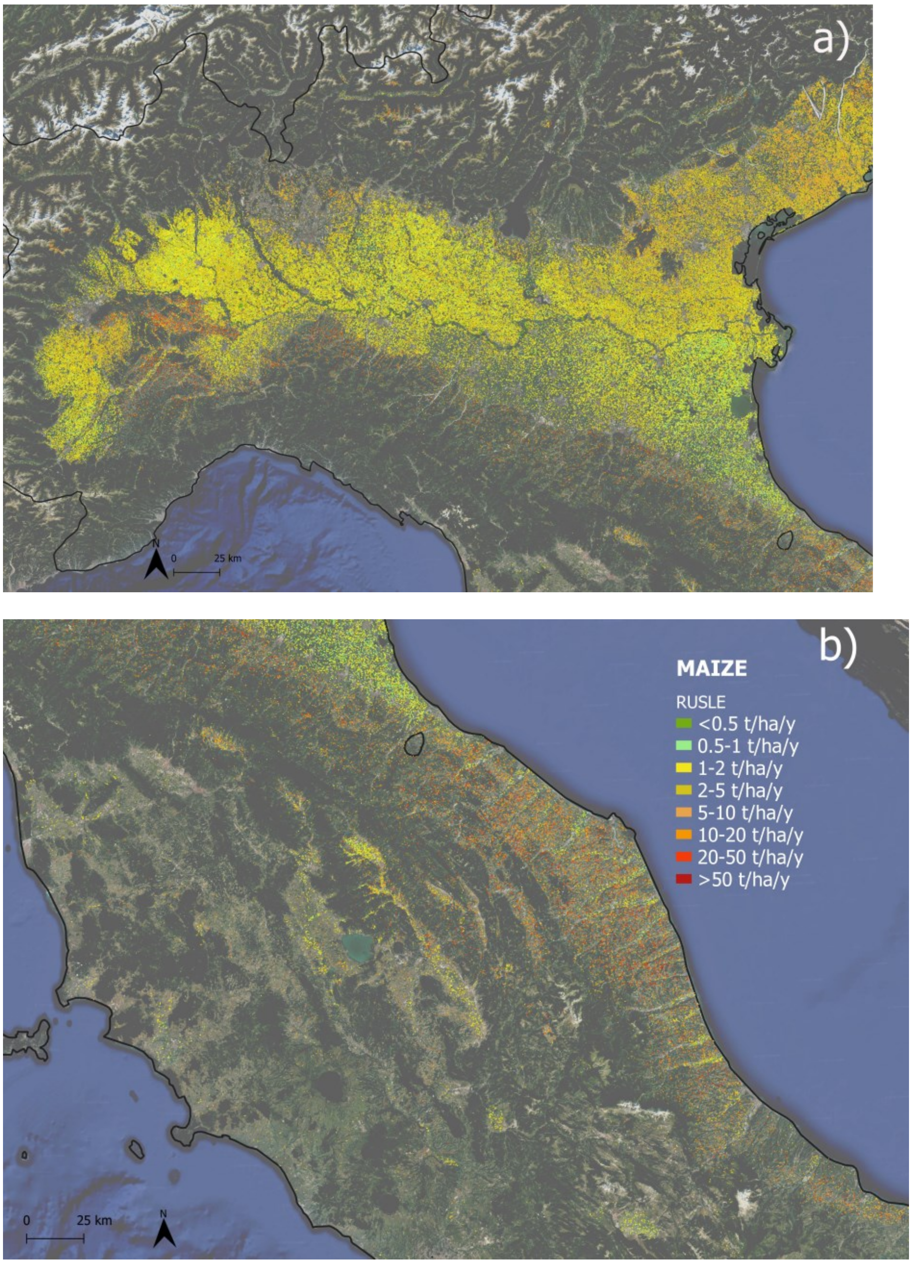


Fig. 2.1c Northern (a) and Central (b) distribution of maize cultivation distinguished by the intensity of current erosion.

The future projection shows weak increases in the extension of those areas currently undermined by medium and severe soil erosion and a consequent drop of those characterized by low levels: the 4th erosion class (2-5 t/ha/y) should grow from 41.19% to 46.69% (+5.5%); the 5th (5-10 t/ha/y) from 10.10% to 13.93% (+3.83%); the 6th and the 7th (10-20 t/ha/y and 20-50 t/ha/y) may increase only by 0.48% and 0.52%. On the contrary, the lowest levels (0.5-1 t/ha/y and 1-2 t/ha/y) may drop by 3.05% and 5.44%, respectively. **(Tab. C)**

d. <u>Rice</u>

The analysis of soil erosion extension in rice fields, the location of which was extracted from the Corine Land Cover map, points out that paddies currently undergo low-medium levels of soil erosion. 3.4% of dedicated areas is losing <0.5 t/ha/y, 12.7% 0.5-1 t/ha/y, 38.9% 1-2 t/ha/y and are placed, as a whole, around the Delta of the Po river and in Sardinia, which is absent from the map due to scarce visibility. The largest portion (40.8%), instead, belongs to the middle class (2-5 t/ha/y) and is located in the northwestern paddies of Vercelli, in Piedmont, and Pavia, in Lombardy. Finally, only 3.7% is in the 5-10 t/ha/y range, and again concerns northern fields, mainly those surrounding the province of Mantova **(Table D) (Fig. 2.1d)**

Nevertheless, the forecasted future erosion shows larger decreases in the lower rates than in the other crops: indeed, the 2nd (0.5-1 t/ha/y) and 3rd (1-2 t/ha/y) classes should decline by 3.58% and 9.13% individually, with a consequent greater increase of the 4th (2-5 t/ha/y) and 5th levels (5-10 t/ha/y) (+10.78% and +3.7%). At the same time, the highest ranks (10-20 t/ha/y, 20-50 t/ha/y and >50 t/ha/y) should still not be reached. **(Tab. D)**

RICE	*<0.5 t/ha/y*	*0.5-1 t/ha/y*	*1-2 t/ha/y*	*2-5 t/ha/y*	*5-10 t/ha/y*	*10-20 t/ha/y*	*20-50 t/ha/y*	*>50 t/ha/y*
Current erosion	3.40%	12.70%	38.90%	40.80%	3.70%			
Future erosion		9.12%	29.77%	51.58%	7.40%			
Δ	-3.4%	-3-28%	-9.13%	+10.78%	+3.7%			

Tab. D Summary table of area extension (in percentage) of rice divided into each level of current and future soil erosion. The last row measures the difference.

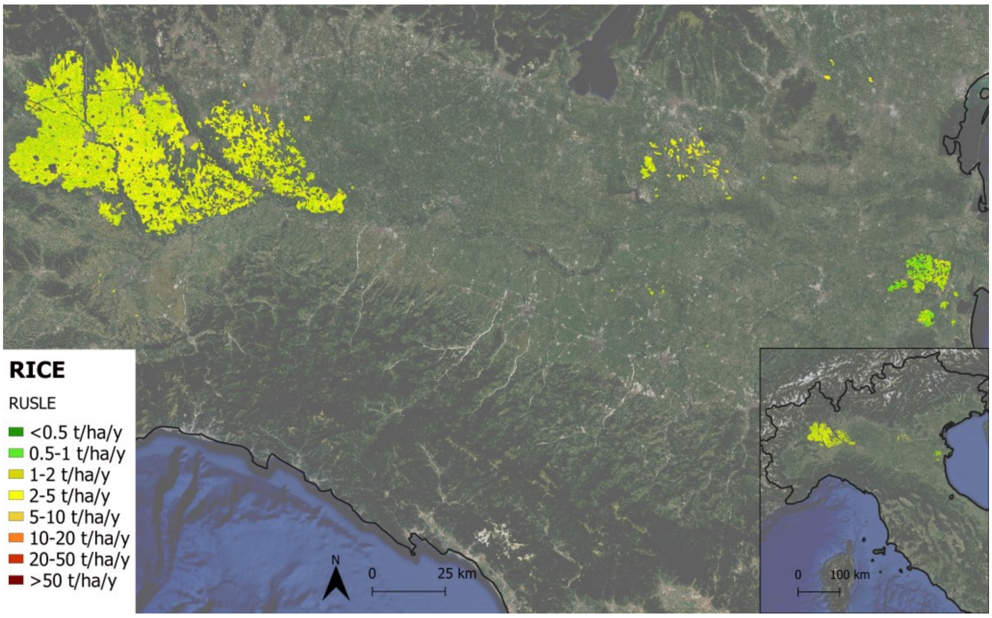


Fig. 2.1d Paddies distribution in Northern regions distinguished by the intensity of current erosion*. The rice fields in Sardinia aren't reported for their insufficient visibility.*

e. <u>Olives</u>

According to our results, olive trees show the worst condition, as more than half of the fields are experiencing the highest levels of erosion, even in the future. More specifically, 54.87% are divided into 10.93% losing an average of 5-10 t/ha/y, 15.82% missing 10-20 t/ha/y, 21.83% 20-50 t/ha/y and 6.29% >50 t/ha/y. In this regard, the most affected zones are Liguria, near the Imperia province, northern Tuscany, around Lucca, Umbria, near Perugia, Calabria, around Vibo-Valentia and Crotone, Campania, near Capua and Caserta, northern Sicily from Messina to Palermo, including Agrigento on the southern coast, and northern Sardinia, near Sassari. Cultivations surrounding Garda lake are also involved, although they aren't reported in the map for convenience and due to their unclear visibility. **(Fig. 2.1e)** The remainder (45.14%) is distributed within the other ranges: 9.45% are not subjected to erosion (<0.5 t/ha/y), 10.69% belong to the extremely low class (0.5-1 t/ha/y), 12.42% to the low (1-2 t/ha/y) and 12.58% to a low-medium one (2-5 t/ha/y) **(Tab. E).** These meagre average soil losses are identified throughout Apulia and southern Sardinia, near Cagliari **(Fig.2.1e)**

Looking ahead, differences in the framework are visible only in percentages, as we registered slight widespread variations in all classes: the lowest and the highest levels (namely the 1st and the 8th ranges) are the only ones decreasing respectively by 3.92% and 0.92%; the 2nd (0.5-1 t/ha/y) may grow by 0.64%, the 3rd (1-2 t/ha/y) by 1.12%, the 4th (2-5 t/ha/y) by 0.81%, the 5th (5-10 t/ha/y) by 0.5%, the 6th (10-20 t/ha/y) by 0.79%, the 7th (20-50 t/ha/y) by 1.39%. This means that olive groves would be destined for largely suffer from erosion. **(Tab. E)**

OLIVE	*<0.5 t/ha/y*	*0.5-1 t/ha/y*	*1-2 t/ha/y*	*2-5 t/ha/y*	*5-10 t/ha/y*	*10-20 t/ha/y*	*20-50 t/ha/y*	*>50 t/ha/y*
Current erosion	9.45%	10.69%	12.42%	12.58%	10.93%	15.82%	21.83%	6.29%
Future erosion	5.53%	11.33%	13.54%	13.39%	10.98%	16.61%	23.22%	5.39%
Δ	-3.92%	+0.64%	+1.12%	+0.81%	+0.5%	+0.79%	+1.39%	-0.92%

Tab. E Summary table of area extension (in percentage) of olive trees divided into each level of current and future soil erosion. The last row measures the difference.

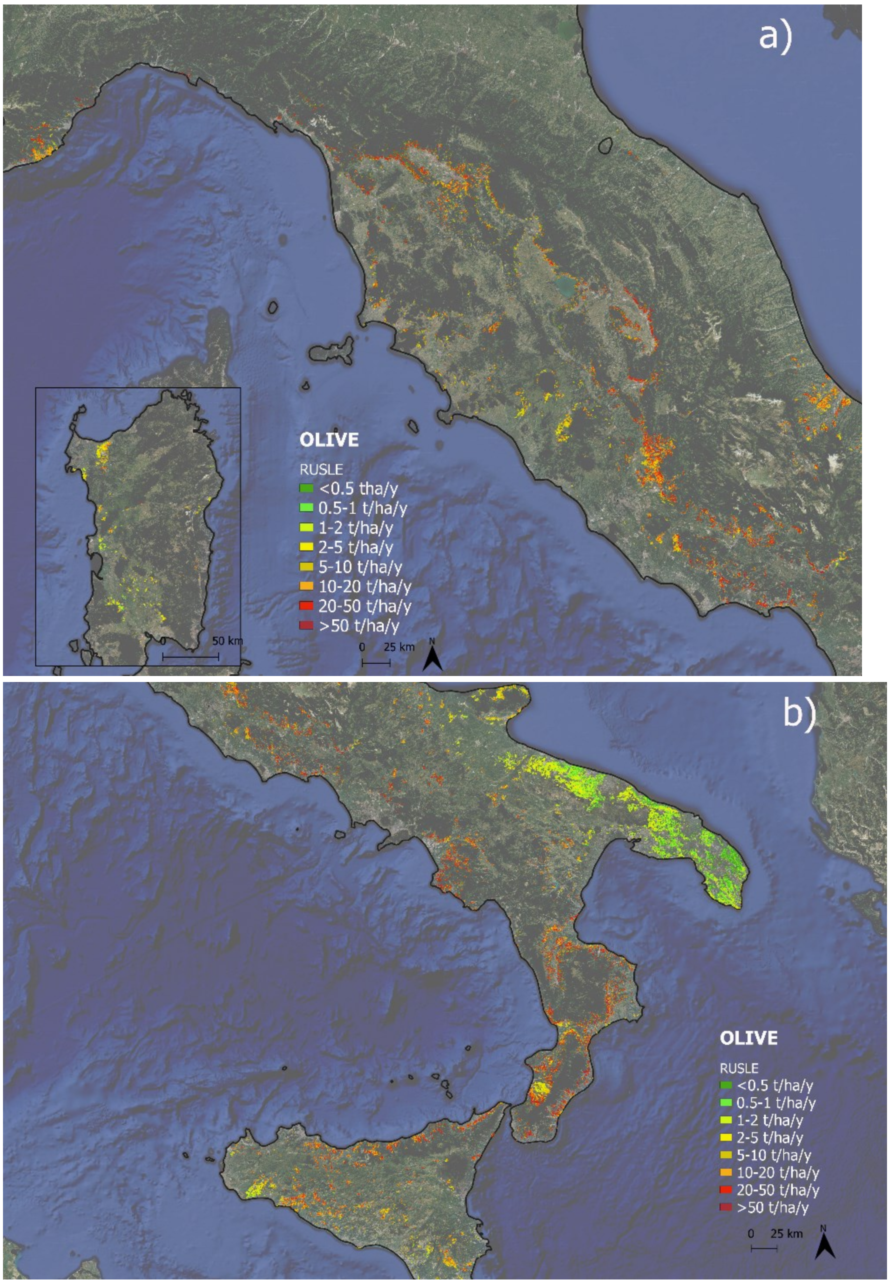


Fig. 2.1e Olive tree distribution in Central (a) Southern (b) Italy and Sardinia (a) distinguished by the intensity of current erosion. *For convenience, the geographical position of Sardinia doesn't follow the real coordinates and for insufficient visibility, the olive trees around Garda lake aren't reported in the map.*

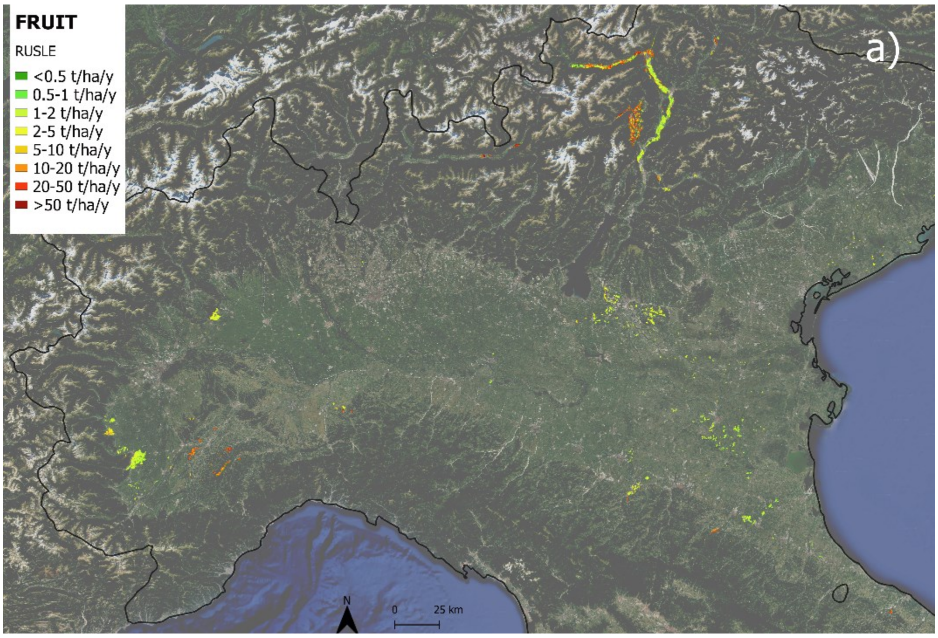
f. <u>Fruits</u>

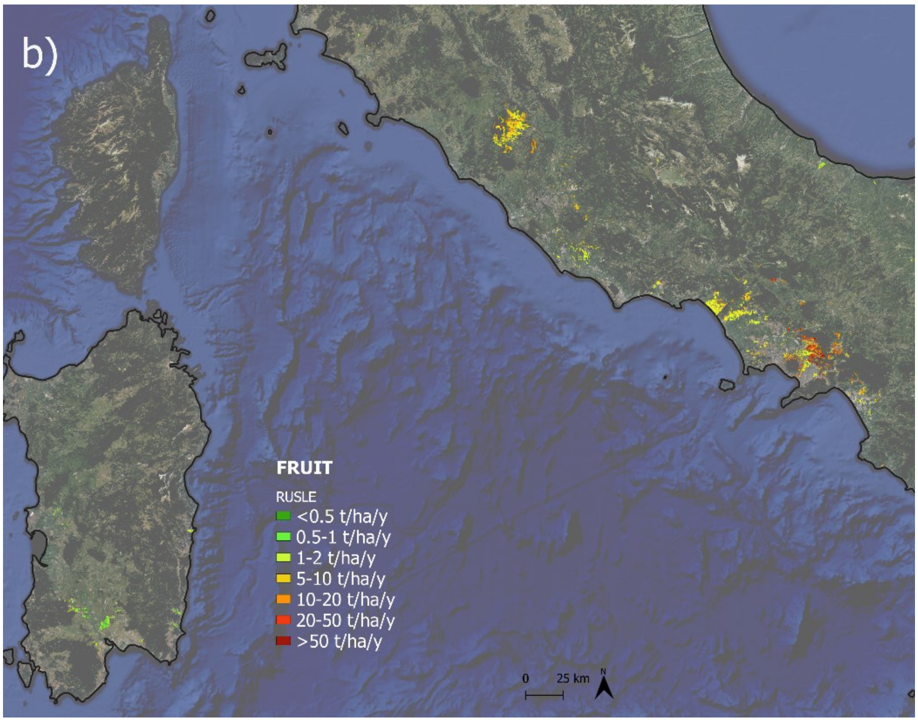
Although areas devoted to fruit orchards cover all levels of erosion, similarly to olive trees, most fall into the minor ones: 60.81% are split into 5.13% which don't undergo soil erosion (<0.5 t/ha/y), 8.70% losing 0.5-1 t/ha/y, 18.40% 1-2 t/ha/y, 28.58% 2-5 t/ha/y. The remaining 39.19% indicate fields subjected to medium-high and severe erosion rates: 15.79% drop 5-10 t/ha/y, 11.50% 10-20 t/ha/y, 9.26% 20-50 t/ha/y and 2.64% >50 t/ha/y. **(Tab. F)** Interestingly, great of these critical situations are located in the northern regions close to Bolzano (in the Trentino region) and around Tortona (in Piedmont). Then, the central zones are in medium-high and severe conditions, mainly near Viterbo in Lazio and Avellino in Campania. In the south, the least affected areas are in Apulia, Basilicata and less in Sardinia and Sicily together with more depleted ones in northern Sicily, near Messina and in Calabria along the Ionian coast. (**Fig. 2.1f)**

The future scenario doesn't change as there is a gradual shift toward middle classes with hope for a reduction in the higher ones: indeed, the no-erosion level should decrease by 1.38%, whereas the 2nd and 3rd ranks may increase by 2.23% and 2.02% respectively. All others would drop slightly: the 4th range could decline by 0.03%, the 5th by 0.46%, the 6th by 0.98%, the 7th by 0.77% and the 8th by 0.63%. **(tab. F)**

FRUIT	*<0.5 t/ha/y*	*0.5-1 t/ha/y*	*1-2 t/ha/y*	*2-5 t/ha/y*	*5-10 t/ha/y*	*10-20 t/ha/y*	*20-50 t/ha/y*	*>50 t/ha/y*
Current erosion	5.13%	8.70%	18.40%	28.58%	15.79%	11.50%	9.26%	2.64%
Future erosion	3.75%	10.93%	20.42%	28.55%	15.33%	10.52%	8.49%	2.01%
Δ	-1.38%	+2.23%	+2.02%	-0.03%	-0.46%	-0.98%	-0.77%	-0.63%

Tab. F Summary table of area extension (in percentage) of fruit trees divided into each level of current and future soil erosion. The last row measures the difference.





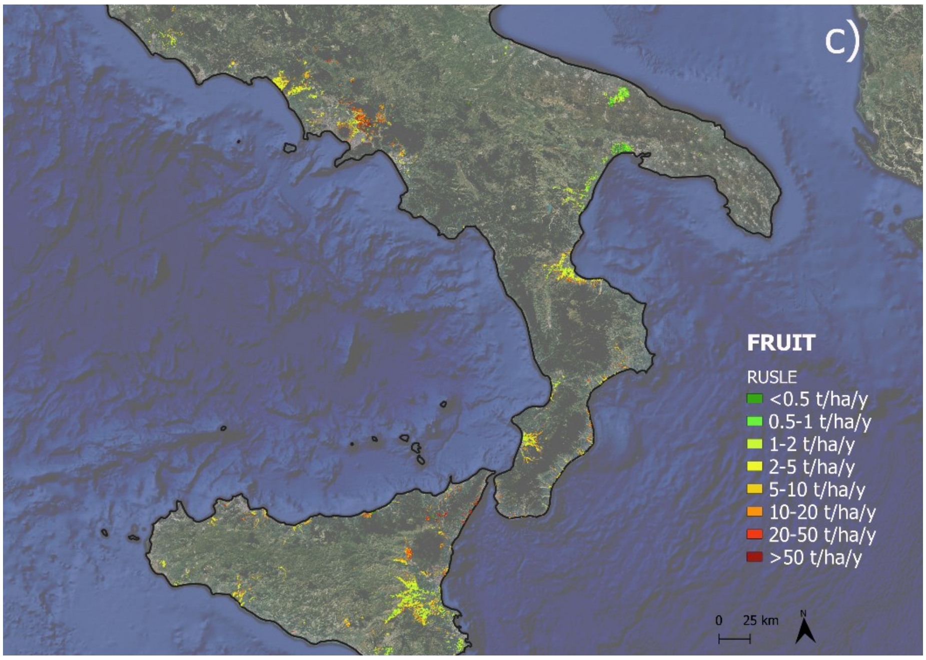


Fig. 2.1f Fruit trees' distribution distinguished by the intensity of current erosion in the North (a), Centre (b) and South (c) of Italy and in Sardinia (b)

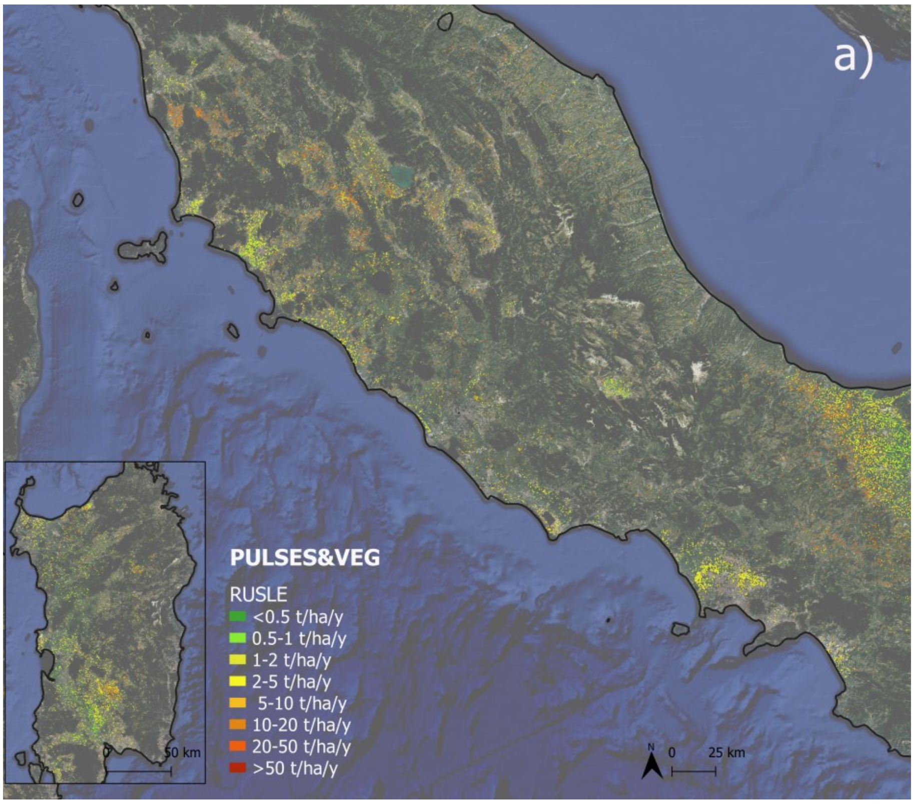
g. <u>Pulses & Vegetables</u>

Lastly, we took from the Eucrop map the dislocation of pulses and vegetable cultivations, which are scattered throughout the country with main concentrations in southern and northern regions. Analysis of current soil erosion showed that these crops are also placed in fields affected by medium-high to extreme erosion. Indeed, 14.83% suffer a loss of 5-10 t/ha/y, 16.58% of 20-10 t/ha/y, and 1.11% of >50 t/ha/y. Hopefully, the majority is less damaged: 4.71% have not erosion condition (<0.5 t/ha/y), 9.57% cover the range 0.5-1 t/ha/y, 17.47% lose 1-2 t/ha/y and 23.58% 2-5 t/ha/y **(tab. G)**. As discussed for previous crops, the highest erosion levels are found in central zones, more around Siena and Livorno, in Tuscany, and in the south in Basilicata and Calabria, alongside the Ionian coast. In Sicily, the framework is somewhat more worrisome because almost all fields are depleted by severe erosion rates. On the contrary, less dramatic situations are throughout the Po valley, which for convenience are not reported on the map due to their poor visibility, in central regions, in northern Apulia, near the Foggia province, and in southern Sardinia. **(Fig. 2.1g)**

Once again the future prediction doesn't show significant variations from the current state. There would be a further increase in the middle classes: +0.33% for the 2nd (0.5-1 t/ha/y) and 3rd (1-2 t/ha/y) ranges, +2.12% for the 4th (2-5 t/ha/y), and +0.67% for 5-10 t/ha/y rank. All others are destined to decrease: the no erosion condition may reduce by 1.2%, together with the 6th rank (10-20 t/ha/y) that should drop by 0.28%, the 7th (20-50 t/ha/y) by 1.44% and the most severe (>50 t/ha/y) that might b completely recovered **(Tab. G).**

PULSES& VEGETABLES	*<0.5 t/ha/y*	*0.5-1 t/ha/y*	*1-2 t/ha/y*	*2-5 t/ha/y*	*5-10 t/ha/y*	*10-20 t/ha/y*	*20-50 t/ha/y*	*>50 t/ha/y*
Current erosion	4.71%	9.57%	17.47%	23.58%	14.83%	16.58%	12.14%	1.11%
Future erosion	3.50%	9.90%	17.80%	25.70%	15.50%	16.30%	10.70%	
Δ	-1.2%	+0.33%	+0.33%	+2.12%	+0.67%	-0.28%	-1.44%	-1.11%

Tab. G Summary table of area extension (in percentage) of pulses and vegetable cultivations divided into each level of current and future soil erosion. The last row is the measure of the difference.



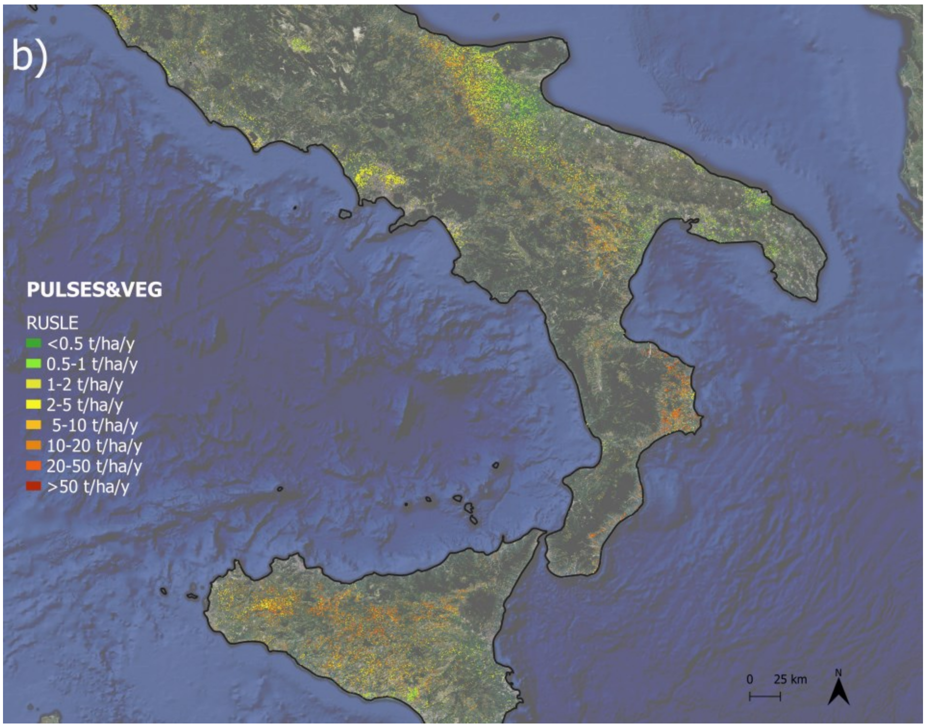


Fig. 2.1g The distribution of pulses and vegetables in Central (a), southern (b) Italy and Sardinia (a) distinguished by the intensity of current erosion. *For convenience and insufficient visibility, the distribution in northern regions isn't reported and the geographical position of Sardinia doesn't respect real coordinates.*

2.2 VHI mapping

This section reports the extent of each crop cultivated area distinguished by specific VHI level detected as of June 2022. Despite the reliability of Panagos' erosion analysis which actually refers to 2016 data, in this case, the framework provided and debated is more up-to-date, thus it properly displays the severity of drought that occurred in Italy at the beginning of summer 2022, when wheat harvest is scheduled and other crops lie in vegetative phase. Our findings are summarized in the **tab. 2.2** and show durum wheat as the main suffering cultivation among those selected since about 67.1% of its fields were characterized by moderate to extreme drought. Common wheat would then be the second in gravity because 13.10% were affected by extreme level, 19.5% severe and 23.5% moderate one. Other investigated crops revealed a similar situation with an almost equal distribution among mild and highest classes. The analysis will be deepened later.

VHI	*extreme*	*severe*	*moderate*	*mild*	*no drought*
Common wheat	13.10%	19.50%	23.50%	21.60%	22.30%
Durum wheat	10.46%	27.48%	29.18%	20.45%	12.44%
Maize	7.77%	12.18%	18.11%	21.70%	40.25%
Rice	3.11%	4.97%	8.46%	15.19%	68.27%
Olive	10.12%	16.13%	27.47%	27.40%	18.88%
Fruit	11.64%	18.92%	25.22%	23.89%	20.32%
Pulses & vegetables	8.99%	22.15%	27.68%	22.94%	18.25%

Tab.2.2 Summary of area extension (in percentage) of specific crops divided into VHI levels. The reported colours are the same used in the following maps' legend.

a. <u>Common wheat</u>

The VHI measure reveals that over June 2022 a large part of common wheat cultivations in southern Piedmont, around Tortona, in northern Lombardy, around the Po Delta, and in central regions were subjected to extreme, severe and moderate drought conditions. Specifically, the most worrisome areas in the north can be found from the Alessandria province, in Piedmont, through Cremona and Monza, in Lombardy, to the northeast, in Treviso, in Veneto, and Udine, in Friuli-Venezia Giulia, but also as far south as Emilia-Romagna, near Ferrara and Ravenna, Marche and Umbria from Urbino to Norcia. **(Fig. 2.2a)** These zones held 56.1% of fields of which 13.1%, 19.5% and 23.5% underwent extreme, severe and moderate intensity of drought, respectively.

The remainder is split into 22.3% without drought and 21.6% in the mild class **(tab. A).** These less dramatic categories were widespread in Vercelli, in northeastern Piedmont, around Milano, in Lombardy, near Pordenone, in Friuli-Venezia Giulia, southern Veneto, along the Adriatic coast, near Ancona, in Marche, and Termoli, in Molise. **(Fig. 2.2a)**

VHI	*extreme*	*severe*	*moderate*	*mild*	*No drought*
Common wheat	13.10%	19.50%	23.50%	21.60%	22.30%

Tab. A Detailed common wheat results (from tab 2.2)

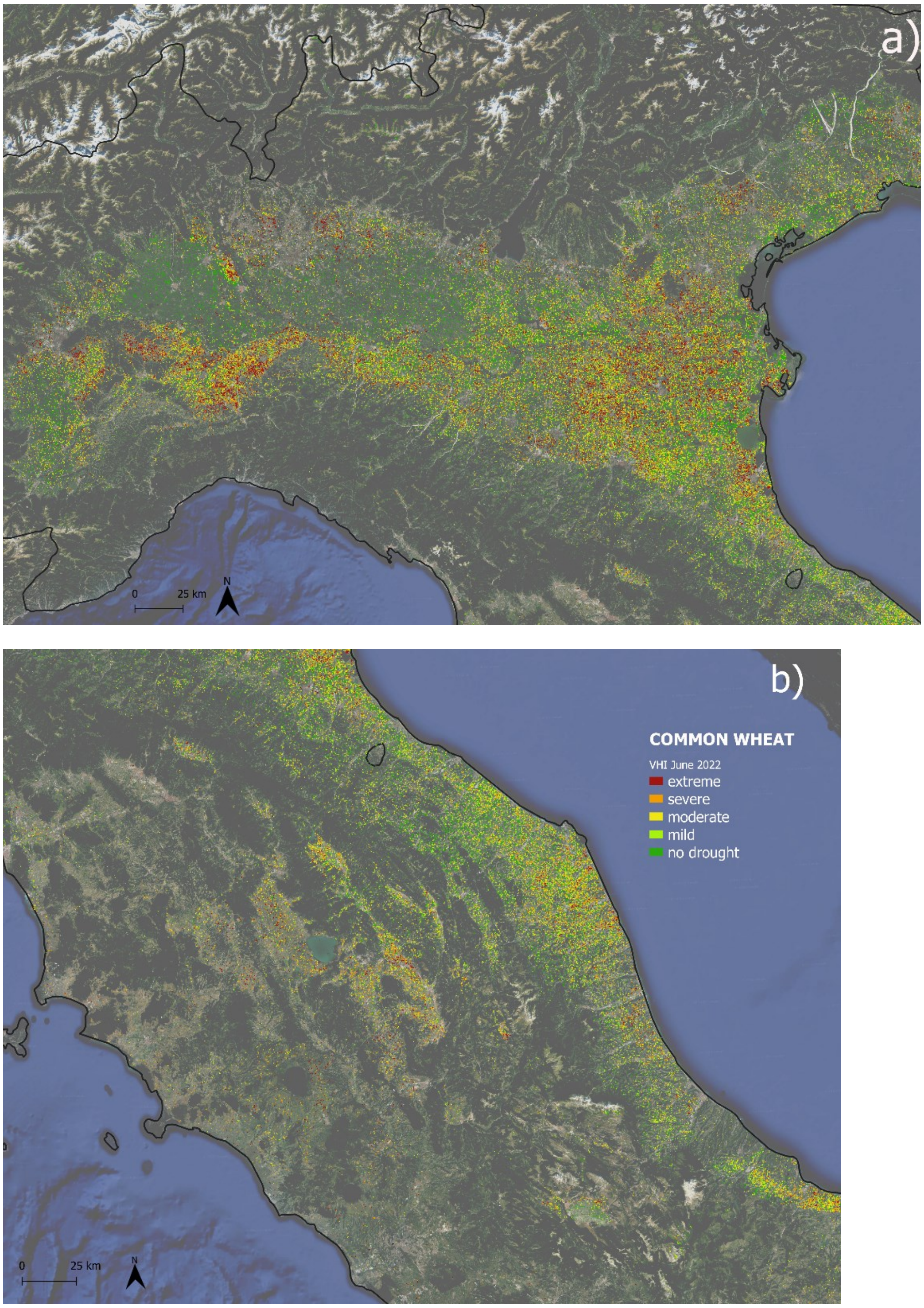


Fig. 2.2.a Common wheat distribution in the north (a) and centre (b) of Italy differentiated by VHI intensity level of June 2022.

b. <u>Durum wheat</u>

Our results demonstrate that durum wheat was the most affected since 67.1% of the fields were characterized from moderate to extreme drought, whereas only 12.44% resulted to be in a no-drought condition. The most dramatic frameworks were principally located in central Tuscany, near Siena, Montepulciano and Grosseto, in the central areas of Umbria, around Perugia, in Lazio, near Viterbo and Tarquinia, in Apulia, around the province of Brindisi and in the Murgia plain up to Matera, in Basilicata, along the Ionian coast, in north-eastern and south-eastern parts of Sicily, around Bronte and Catagirone, and some scattered in northern Sardinia. **(Fig. 2.2b).** The mild class, that covered 29.18%, and drought-free frameworks were spread in northern Tuscany, near Lucca and Arezzo, in Marche, near Ancona and along the Adriatic coast, in northern Apulia at the border with Molise, some again throughout the Ionian coast, in northern Calabria, in central-south Sicily around Caltanissetta and Corleone. **(Fig. 2.2b) (Tab. B)**

VHI	*extreme*	*severe*	*moderate*	*mild*	*No drought*
Durum wheat	10.46%	27.48%	29.18%	20.45%	12.44%

Tab. B Durum wheat detailed results from tab 2.2

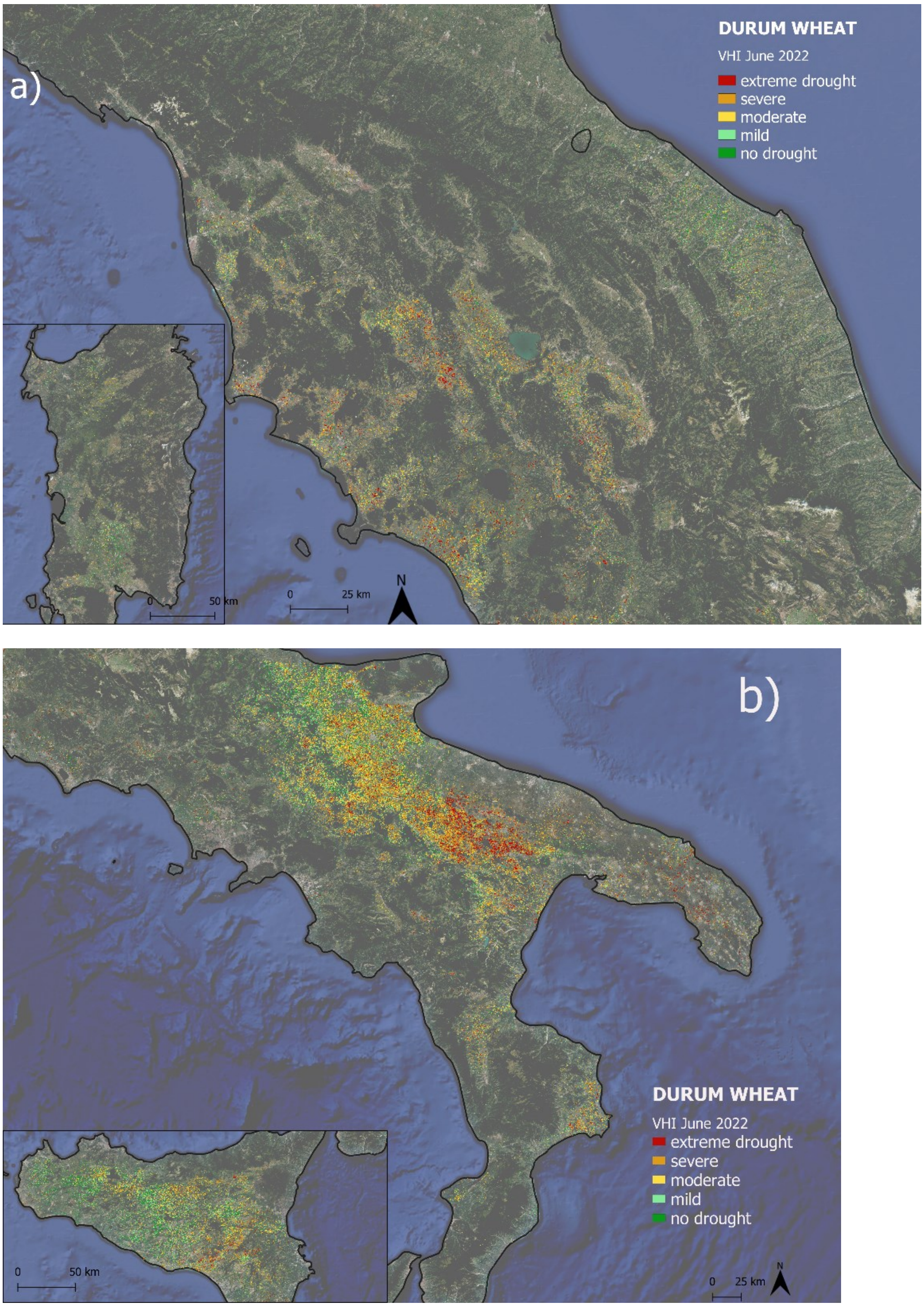


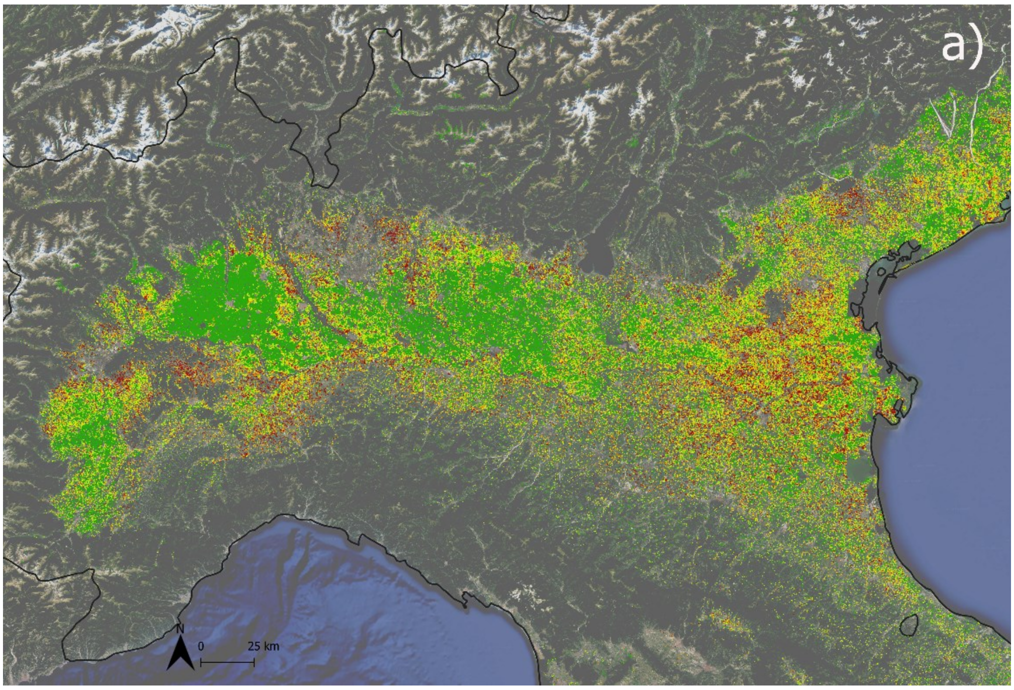
Fig. 2.2b Durum wheat cultivations in the centre (a) and south (b) of Italy and in Sardinia (a) differentiated by VHI intensity level of June 2022. *For convenience, the geographical position of Sicily and Sardinia doesn't respect real coordinates.*

c. <u>Maize</u>

Maize, conversely to wheat, was less undermined by intense drought which covered about 35% of the fields, split into 7.77% extreme, 12.18% severe, and 18.11% moderate levels; while 40.25% of the areas resulted to be drought-free in June 2022. **(Tab. C)** Geographically, the most damaged areas were around Torino and Alessandria, in Piedmont, northern and southern Lombardy, around the Po Delta, near Treviso, in Veneto, Udine, in Friuli-Venezia Giulia, in Emilia-Romagna around Piacenza and Ferrara, and internally in Umbria, near Perugia. On the contrary, the mild damaged cultivated areas - that covered 21.7% of fields- and those unaffected were placed in northern and western Piedmont, around Saluzzo and Vercelli, in central areas of Lombardy, near Milano and Mantova, in Veneto up to Friuli-Venezia Giulia, and scattered along the Adriatic coast, from Marche to Abruzzo **(Fig. 2.2c) (Tab. C)**

VHI	*extreme*	*severe*	*moderate*	*mild*	*No drought*
Maize	7.77%	12.18%	18.11%	21.70%	40.25%

Tab. C Maize detailed results from tab 2.2



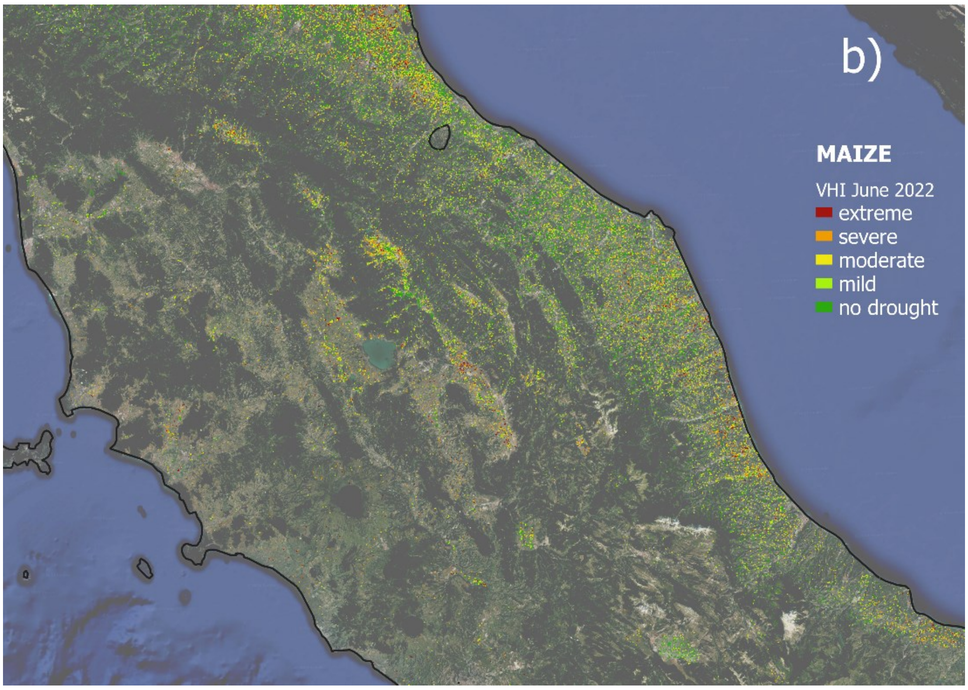


Fig. 2.2c Maize cultivations in Northern (a) and Central (b) Italy differentiated for VHI intensity level of June 2022.

d. <u>Rice</u>

More than half of rice paddies (68.27%) resulted to be not covered by drought, however, more than 15% fall within extreme (3.11%), severe (4.97%) and moderate (8.46%) ranks. Lastly, the mild class held 15.19% of fields. **(tab. D)**

These values are visible in the **Fig. 2.2d** which displays almost all rice fields set in Vercelli and Biella, in Piedmont, which are the two leaders in rice production, and in Oristano, in the western coast of Sardinia, with the highest values of VHI, that correspond to the minimum level of drought. Critical frameworks, instead, were spread around Trecate and Mortara, in Piedmont, near Mede, Garlasco and Pavia, in Lombardy, and in the Po Delta, between Ferrara, in Emilia-Romagna, and Porto Viro in Veneto.

VHI	*extreme*	*severe*	*moderate*	*mild*	*No drought*
Rice	3.11%	4.97%	8.46%	15.19%	68.27%

Tab. D Rice detailed results from tab 2.2

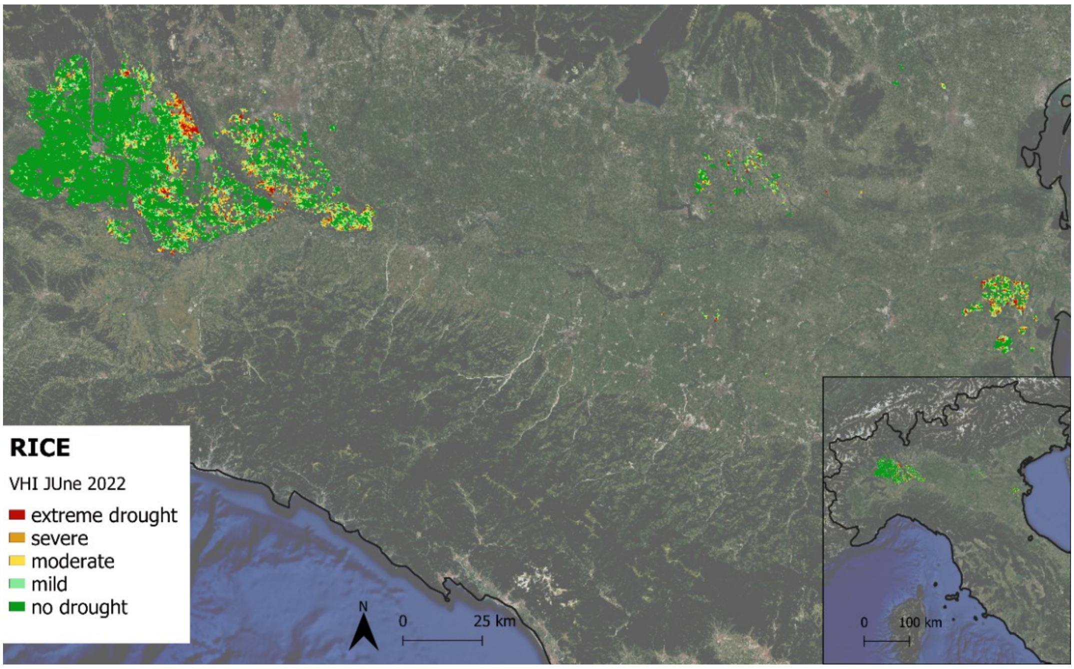


Fig. 2.2d Rice field distribution in northern regions differentiated by VHI intensity level of June 2022

e. Olives

The majority of olive trees were affected by moderate and mild drought conditions (both accounted for 27.4%), while a quarter can be distinguished into 10.12% of extreme and 16.13% of severe levels. Less than 20% was found, instead, no drought-damaged. **(tab. E.)**

Olive groves stressed by more intense drought (moderate, severe and extreme classes) are greatly visible around the Garda lake, in the province of Imperia, in Liguria, near Pistoia, Firenze and Grosseto, in northern Tuscany, around Foligno, in Umbria, in the areas of Viterbo, Monterotondo and Frosinone in Lazio, in Abruzzo along the Adriatic coast, in Apulia, around Barletta, in the Murgia plain and in the entire province of Lecce up to Gallipoli, in Calabria, near Catanzaro and Crotone, in Sicily, near Ragusa, and northern Sardinia, around Sassari. Regarding the least critical level, the framework without drought was generally widespread around Finale Ligure, in Liguria, near Lucca and Arezzo, in Tuscany, in Umbria, near Perugia, in Abruzzo, near Chieti, in Molise, in Apulia, near Bari and Ostuni, in northern and southern Calabria, in Sicily along the northern coast up to Palermo and southern from Mazara del Vallo to Agrigento, and in central-south of Sardinia. All these areas are reported in the following **Fig. 2.2e**, except for that surrounding Garda lake.

VHI	*extreme*	*severe*	*moderate*	*mild*	*No drought*
Olive	10.12%	16.13%	27.47%	27.40%	18.88%

Tab. E Olive detailed results from Tab. 2.2

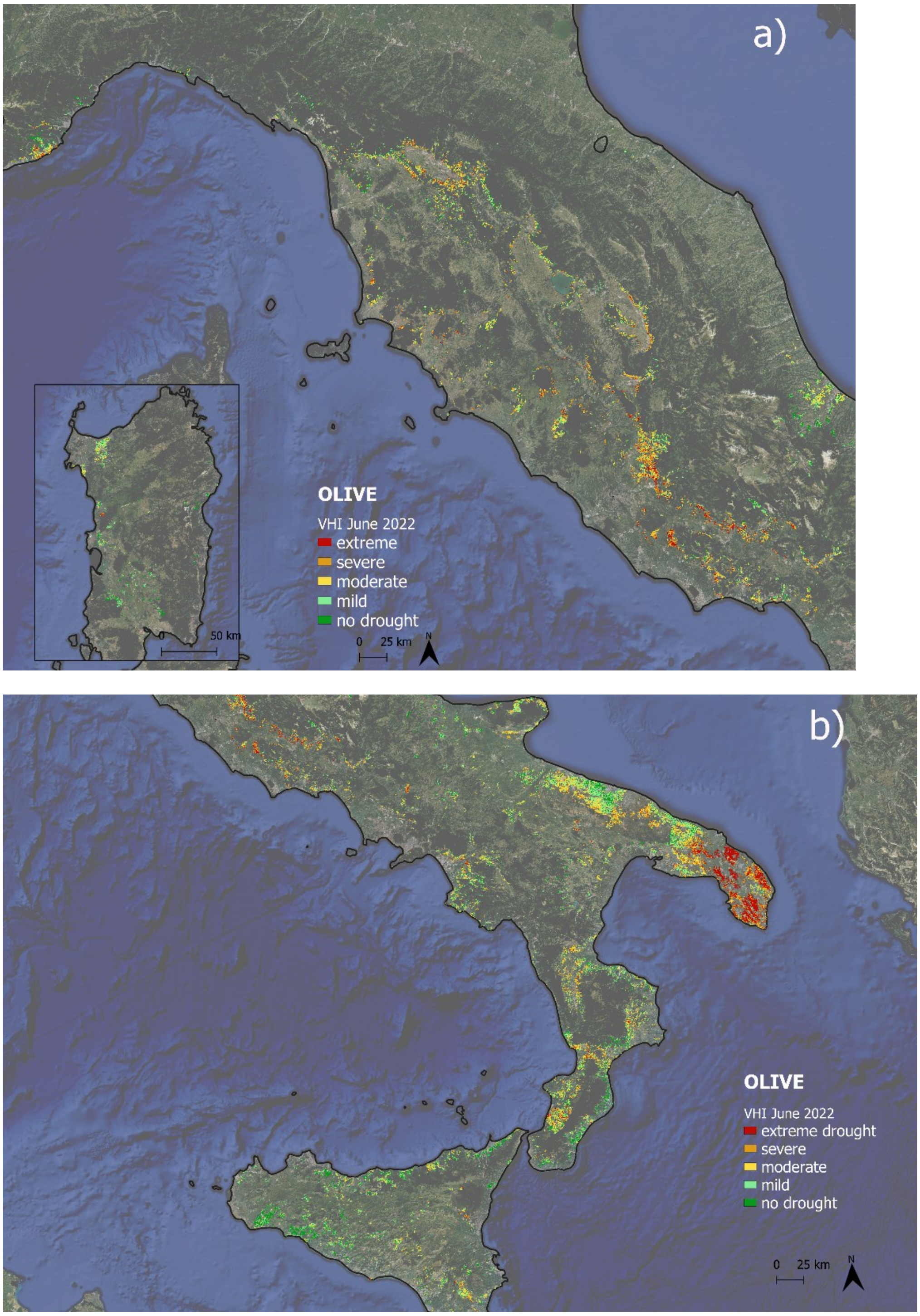


Fig. 2.2e Olive trees distribution in Central (a) and Southern (b) regions and Sardinia (a) differentiated by VHI intensity level of June 2022. *The geographical position of Sardinia doesn't respect the real coordinates for convenience.*

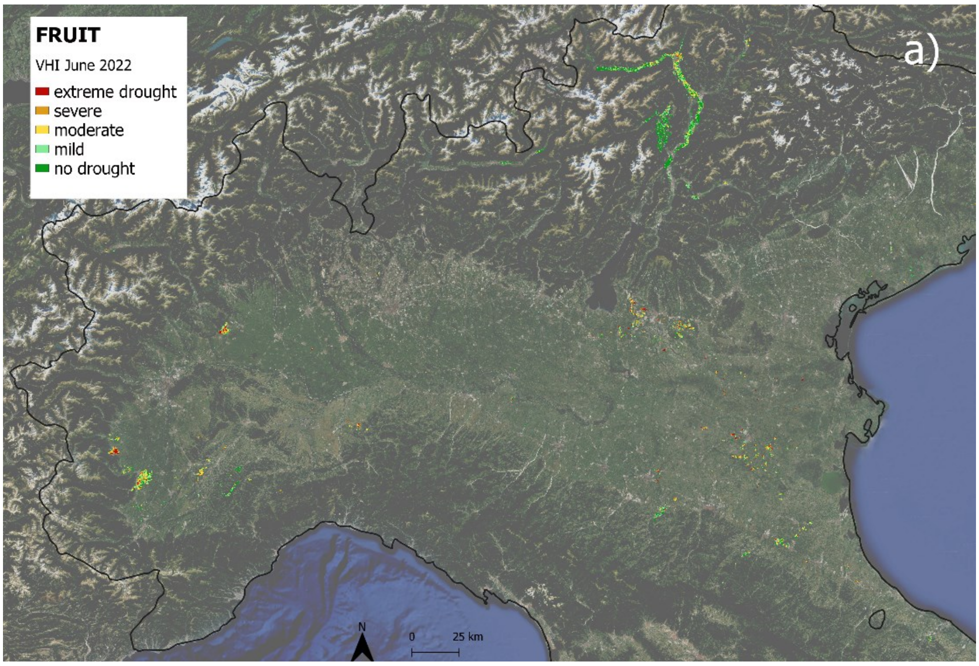
f. Fruits

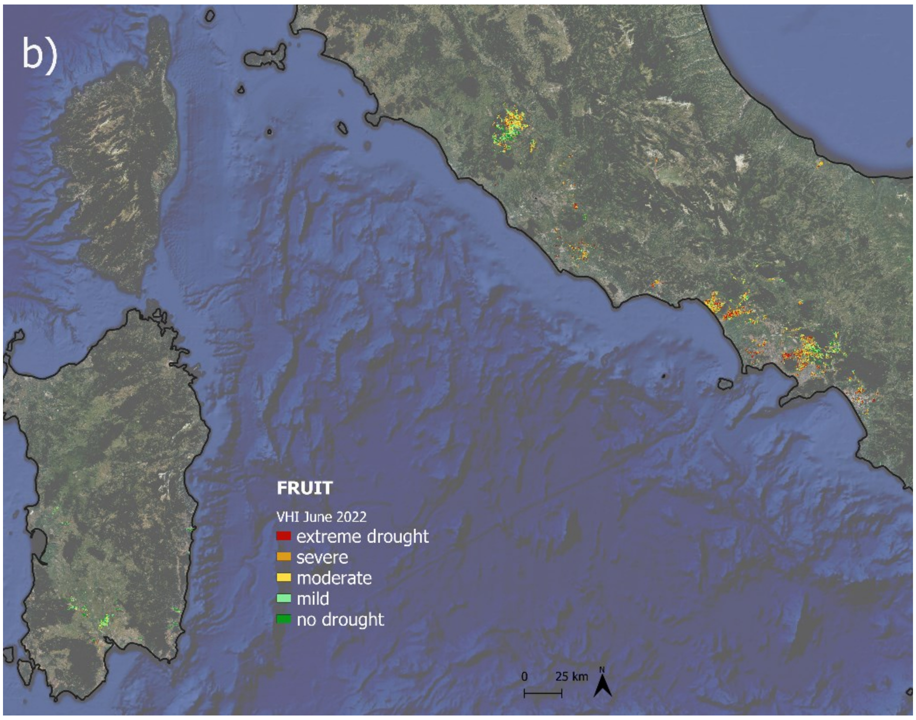
Fruit orchards resulted in a worse condition than olive trees since 55.78% of fields were subjected to extreme (18.92%), severe (11.64%) and moderate (25.22%) levels of drought. The most depleted dedicated areas can be identified in Piedmont, around Saluzzo and Santhià, in Trentino Alto Adige, around Merano, in Veneto, near Verona, in Emilia-Romagna around Ferrara, in Lazio, near Viterbo, in Campania in the area between Napoli and Caserta, in Apulia, near Monopoli, in Basilicata along the Ionian coast, in Calabria near Rosarno, and in Sicily, in the provinces of Catania and Siracusa and near Nolo **(tab.F) (fig. 2.2f).**

In contrast, the cultivations mildly and unaffected, which covered 23.9% and 20.3% apiece, were found in Trentino Alto Adige, around Bolzano, and scattered in central regions, in the area of Avellino, in Campania, in Calabria near Vibo Valentia and along the Ionian coast, in Sicily near Rubano, in the south, and around Palermo, in the north, and in southern Sardinia, near Cagliari. **(Tab. F) (Fig. 2.2f)**

VHI	*extreme*	*severe*	*moderate*	*mild*	*No drought*
Fruit	11.64%	18.92%	25.22%	23.89%	20.32%

Tab. F Fruit detailed results from tab 2.2





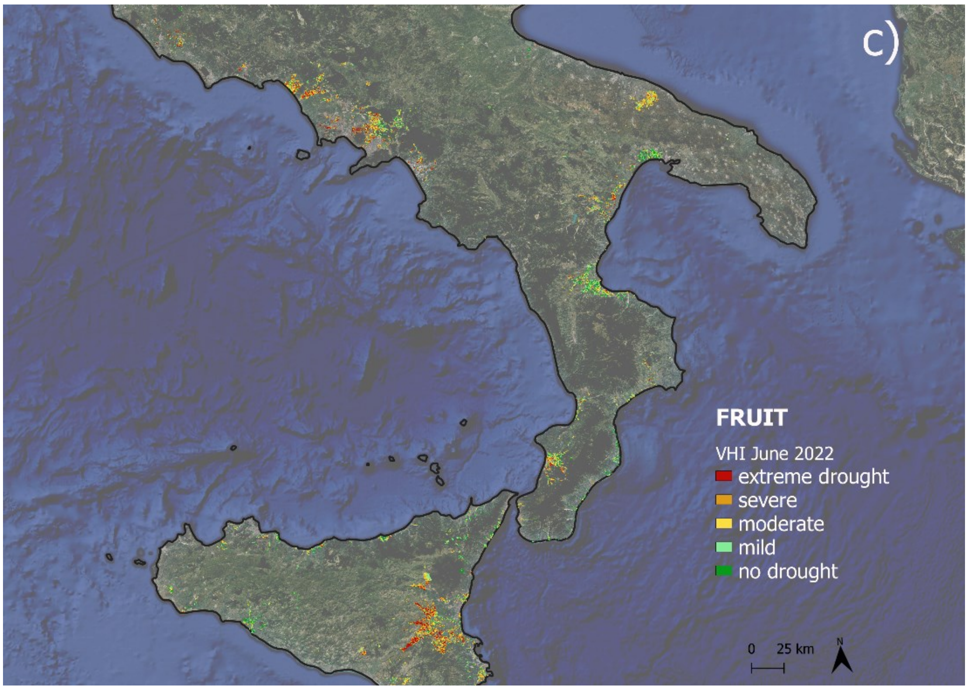


Fig. 2.2f Fruit trees distribution in northern (a), Central, including Sardinia, (b),and southern (c) Italy differentiated by VHI intensity level of June 2022.

g. <u>Pulses & vegetables</u>

Despite pulses and vegetables cultivated areas being less extensive compared to the previous crops, they can be considered as the third most damaged crop by the gravity of drought: 9% and 22.15% of their fields were undermined by extreme and severe intensity respectively. Moreover, more than half were under moderate (27.68%) and mild (22.94%) classes, thus less than 20% were not affected. **(Tab. G)**

As seen in the previous chapter, pulses and vegetable cultivations are widespread and scattered throughout the country, thus their location is not precise. However, underlying maps **(Fig. 2.2g)** show that, principally, moderate, severe and extreme situations were grouped near the Delta of the Po river, which isn't reported in the figure due to unclear visibility, near Grosseto and Montepulciano in Tuscany, in Apulia, in the Murgia plain up to Altamura and Matera and in southern areas, near Caserta, in Campania, around Crotone in Calabria, north and south-western coast of Sicily, and southern Sardinia around Sanluri.

VHI	*extreme*	*severe*	*moderate*	*mild*	*No drought*
Pulses & vegetables	8.99%	22.15%	27.68%	22.94%	18.25%

Tab. G Pulses & vegetables detailed results from the tab. 2.2

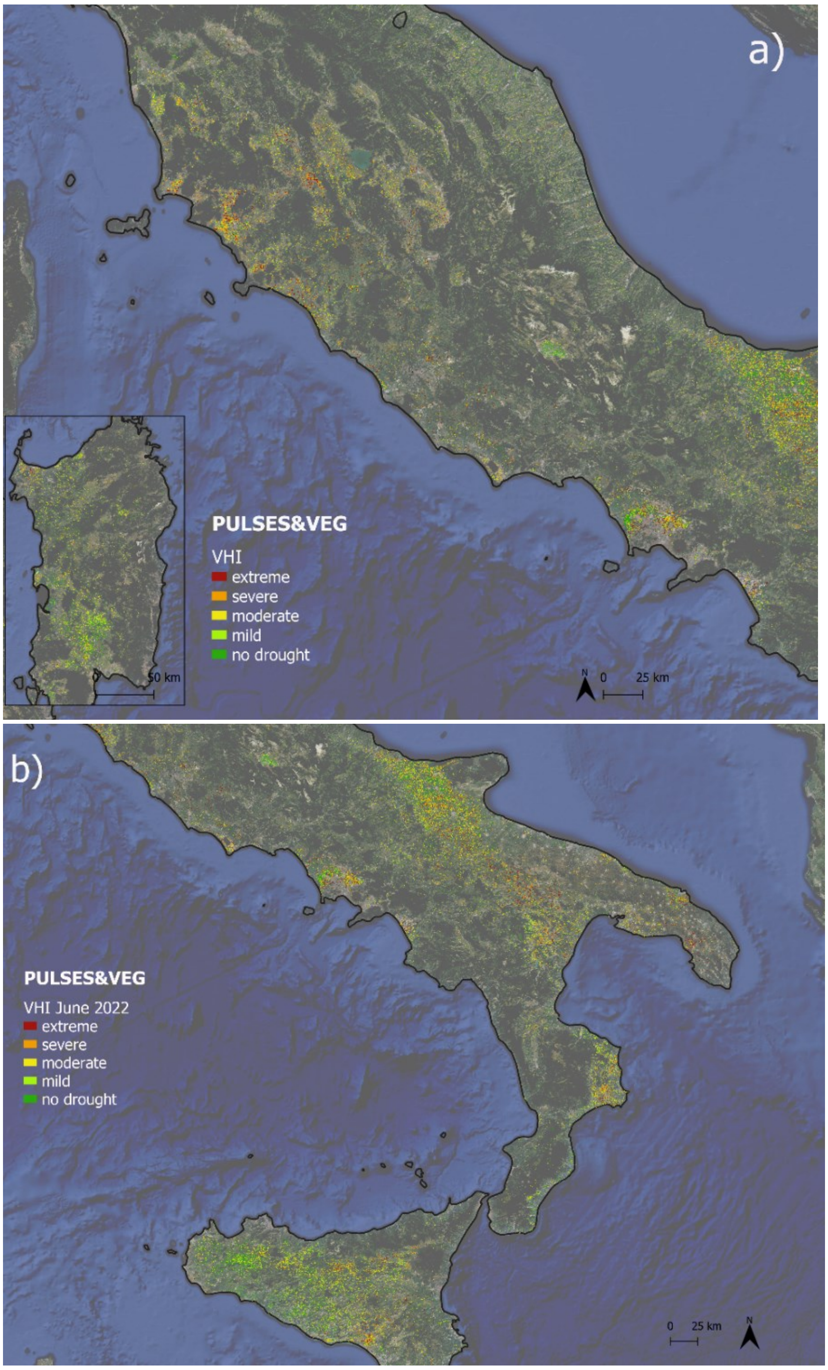


Fig. 2.3g Central (a), including Sardinia, and southern (b) distribution of pulses & vegetables distinguished by VHI intensity level of June 2022. *The geographical position of Sardinia doesn't respect the real coordinates for convenience.*

2.3 Climate zone mapping

Likewise the earlier sections, in this last part we provide the area extension of selected crops distinguished by different climate zones to which they are subjected, following the modified Köppen-Geiger classification extracted from Beck H.E et al. **(Beck, H.E. *et al*. 2018).** Bearing in mind that Beck and colleagues indicated "present" the period between 1980-2016 and "future" the period 2017-2100 under the worse scenario (8.5 RCP). Both their maps have1 km resolution. Our results, first regarding the present and shown in the table **2.3.1,** depict 7 main climatic zones out of 27: arid, steppe, hot (BSh); arid, steppe, cold (BSk); temperate dry summer, hot summer (Csa); temperate, dry summer, warm summer (Csb); temperate, no dry season, hot summer (Cfa); temperate, no dry season warm summer (Cfb); cold, no dry season, warm summer (Dfb). Secondly, **table 2.3.2** points out 4 future climate zones which should characterize cultivated areas: arid, steppe, hot (BSh); arid, steppe, cold (BSk); temperate, dry summer, hot summer (Csa); temperate, no dry season, hot summer (Cfa).

PRESENT CLIMATE	*Arid, steppe, hot (BSh)*	*Arid, steppe, cold (BSk)*	*Temperate, dry summer, hot summer (Csa)*	*Temperate, dry summer, warm summer (Csb)*	*Temperate, no dry season, hot summer (Cfa)*	*Temperate, no dry season, warm summer (Cfb)*	*Cold, no dry season, warm summer (Dfb)*
Common wheat	0.00%	2.20%	8.30%		86.60%		
Durum wheat	0.26%	31.49%	56.35%		9.11%		
Maize			3.40%		94.33%	1.07%	
Rice			2.44%		97.56%		
Olive		18.83%	68.88%		11.71%		
Fruit	0.12%	5.53%	72.25%		15%	1.4%	4.86%
Pulses & vegetables	0.43%	22%	57.36%	1.13%	18.56%		

Tab. 2.3.1 Summary of area extension (in percentage) of specific crops distinguished by different climate zones over the period 1980-2016. The colours used to fill the cell are the same as the following maps' legend.

FUTURE CLIMATE	*Arid, steppe, hot (BSh)*	*Arid, steppe, cold (BSk)*	*Temperate, dry summer, hot summer (Csa)*	*Temperate, dry summer warm summer (Csb)*	*Temperate, no dry season, hot summer (Cfa)*	*Temperate, no dry season, warm summer (Cfb)*	*Cold, no dry season, warm summer (Dfb)*
Common wheat	16.60%	2.20%	27.40%		53.20%		
Durum wheat	49.21%	11.21%	37.47%		1.60%		
Maize	8.50%	1.20%	15.10%		74.80%		
Rice	5.40%		17%		77.57%		
Olive	27.36%	2%	70.35%		0.29%		
Fruit	32.54%	0.90%	52.48%		13.70%		
Pulses & vegetables	43.45%	5%	43.88%		7.58%		

Tab. 2.3.2 Summary of area extension (in percentage) of specific crops distinguished by different climate zones over the period 2017-2100. The colours used to fill the cell are the same as the following maps' legend.

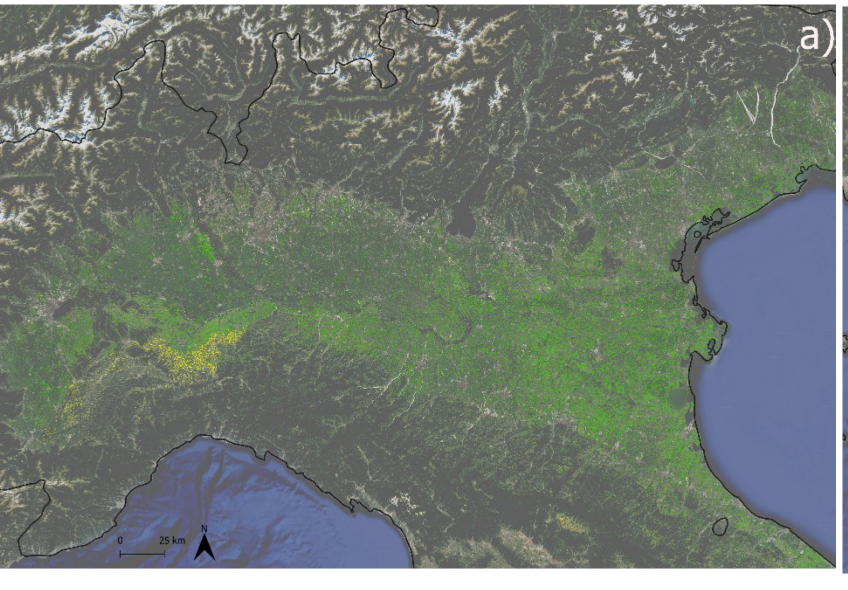
a. Common wheat

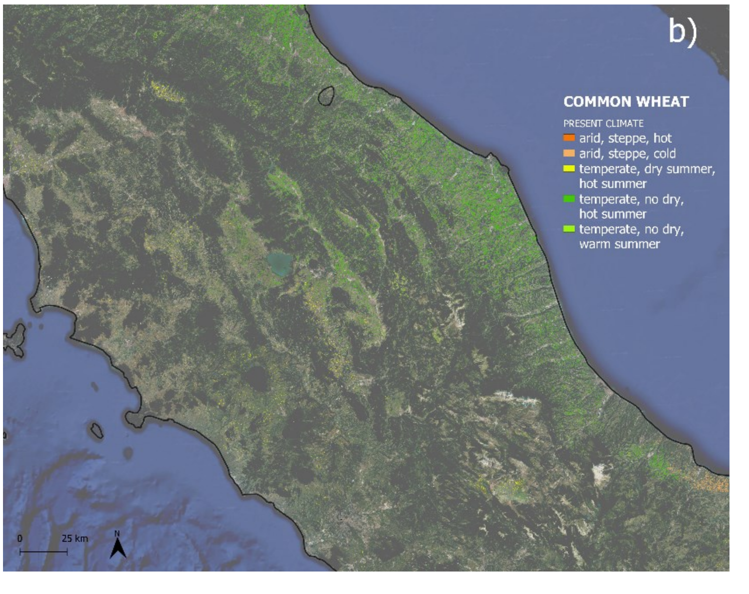
Common wheat fields are largely characterized by temperate climate, specifically 86.6% is in temperate, no-dry season, hot summer (Cfa) and 8.30% temperate, dry summer, hot summer (Csa) **(tab. A.)**. The former corresponds to cultivations located throughout the entire Po valley from Cuneo, in Piedmont, across Lombardy, southern Veneto around the provinces of Verona, Venezia Mestre and Rovigo, up to Palmanova in Friuli Venezia-Giulia, then also those found in Emilia-Romagna and along the Adriatic coast; the latter characterizes only the fields around Alessandria, in Piedmont. Only 2.20% experience an arid, steppe, cold climate (BSk) specifically, in Molise, around Termoli. **(fig. 2.3a)**

Over the period 2017-2100, considering the RCP 8.5 scenario, huge changes are expected: arid, steppe, hot (BSh) would appear in 16.6% of fields, specifically in the Po Delta, along the Adriatic coast up to Termoli, in Molise; whereas, the area affected by arid, steppe, cold (BSk) may remain identical in extent but not in location, since in this case it would involve Alba's territory, in Piedmont. The temperate, dry summer, hot summer (Csa) should dramatically increase to 27.40% (+19.1%) by enlarging into the Po valley along the flow of the river, from Alessandria, in Piedmont, through Piacenza up to Rimini, in Emilia-Romagna and internally, reaching Fabriano and Orvieto, in Umbria; whilst, the temperate, no dry season, hot summer (Cfa) climate could decrease by 33.40% remaining in the Mantova province in Lombardy, as far as southern Friuli Venezia Giulia and Marche, near Pesaro and Macerata. **(tab. A) (fig. 2.3a)**

COMMON WHEAT	*Present climate*	*Future climate*	Δ
Arid, steppe, hot (BSh)	0.00%	16.60%	16.6%
Arid, steppe, cold (BSk)	2.20%	2.20%	0%
Temperate, dry summer, hot summer (Csa)	8.30%	27.40%	19.1%
Temperate, no dry season, hot summer (Cfa)	86.6%	53.20%	-33.4%

Tab. A Detailed climate zone for common wheat from tabs. 2.3.1 and 2.3.2





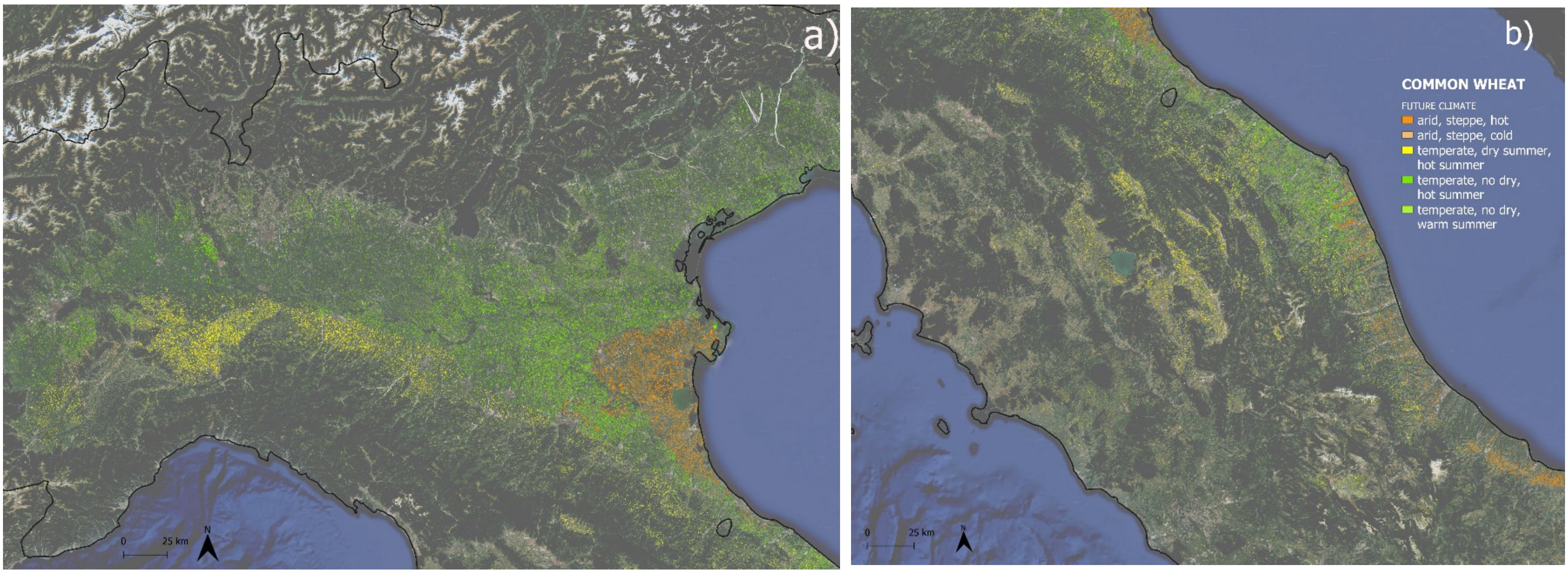


Fig. 2.3a Distribution of common wheat in Northern (a) and Central regions (b) under present climate (on the top) and future climate zones (on the bottom)

b. Durum wheat

More than half (56.53%) of durum wheat cultivations in central and inland areas of Tuscany, around Volterra and Siena provinces, in south of Sardinia near Cagliari, in Sicily, in Apulia from Altamura to the Molise border, and also in Calabria near Crotone and Castrovillari, are defined by temperate, dry summer, hot summer (Csa) climate; whereas only 9.11% are distinguished by temperate, no dry season, hot summer (Cfa). The latter characterizes the central regions around Trasimeno lake, in Umbria, and Molise in the province of Campobasso on the boundary with Apulia. **(Tab. B) (Fig. 2.3b)** Nevertheless, conversely to common wheat, a significant part of cultivation (31.49%) already experiences arid, steppe, cold climate (BSk) **(Tab.B)** involving in particular the north of Apulia from the Murgia plain to the entire Foggia province, Basilicata, around Matera, and Tuscany, at Grosseto province. **(fig. 2.3b)**

The framework will dramatically change in the future with a doubling of arid, steppe, hot climate (BSh) (from 0.29% to 49.21%) appearing from Termoli, in Molise, across the Murgia plain, up to the Ionian coast in Basilicata, in the Caltanissetta province, in Sicily, and in Cagliari, in southern Sardinia. All other types are then forecasted to decrease: the arid, steppe, cold (BSk) may reduce by 20.28% (from 31.49% to 11.21%) remaining only in the fields aligned from Campobasso, in Molise, to the boundaries with Basilicata; temperate, dry summer, hot summer (Csa) may drop by 18.88% (from 56.35% to 37.47%) characterizing the central regions, mainly in northern and internal Tuscany around the provinces of Livorno and Siena, Lazio, around Civitavecchia and Rome, and Umbria, around Perugia, but also Apulia, around Altamura, Calabria, around Crotone and Vibo Valentia, northern Sicily and southern Sardinia, in the south; temperate, no dry season, hot summer (Cfa) should decline almost completely reaching 1.6%. **(tab. B) (fig. 2.3b)**

DURUM WHEAT	*Present climate*	*Future climate*	Δ
Arid, steppe, hot (Bsh)	0.26%	49.21%	48.95%
Arid, steppe, cold (Bsk)	31.49%	11.21%	-20.28%
Temperate, dry summer, hot summer (Csa)	56.35%	37.47%	-18.88%
Temperate, no dry season, hot summer (Cfa)	9.11%	1.60%	-7.51%

Tab B. Durum wheat detailed results from tabs. 2.3.1 and 2.3.2

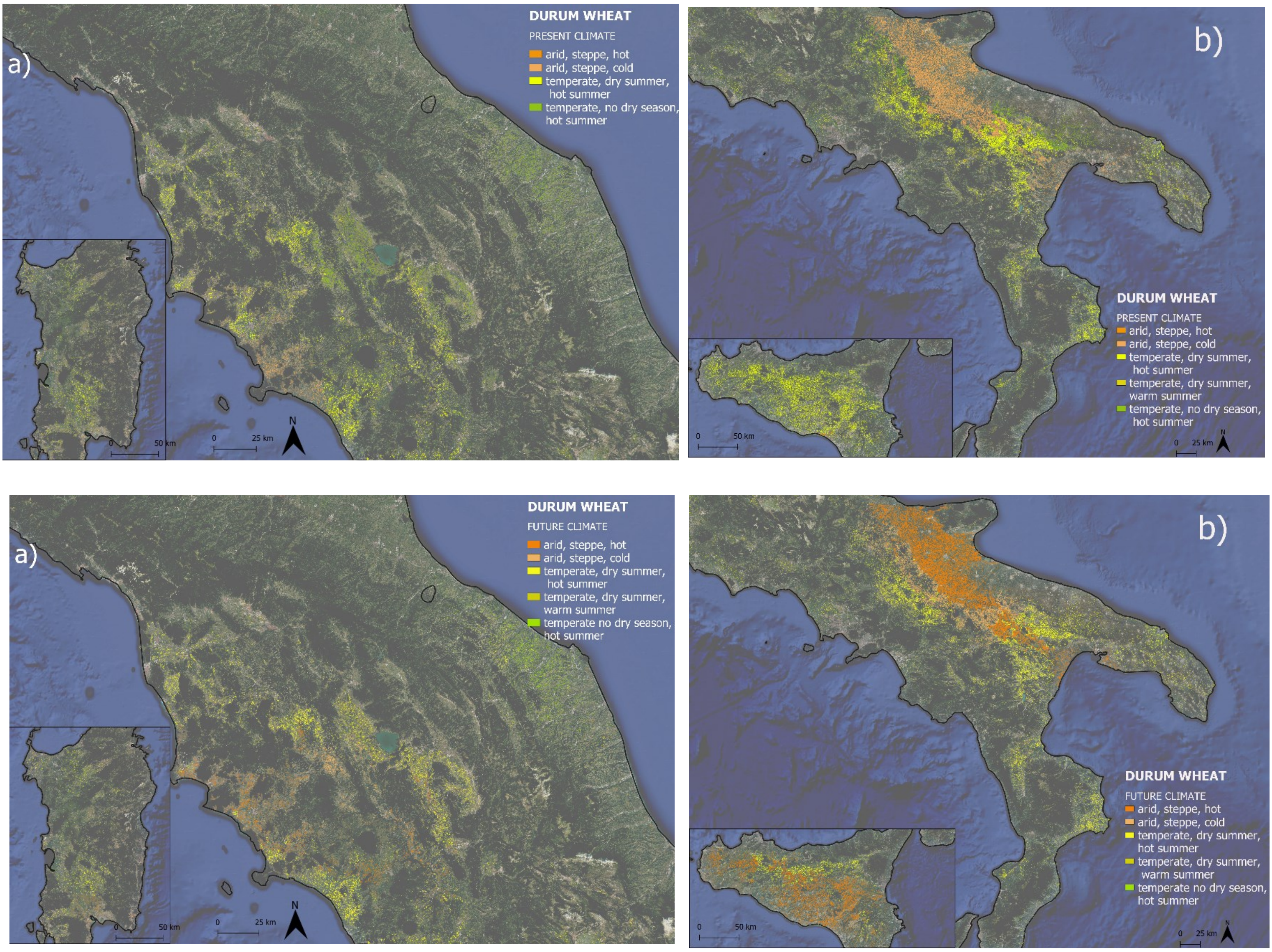


Fig. 2.3b Central, including Sardinia, (a) and southern (b) distribution of durum wheat distinguished by present climate (on the top) and future climate (on the bottom). *The geographical position of Sicily and Sardinia doesn't respect the real coordinates for convenience.*

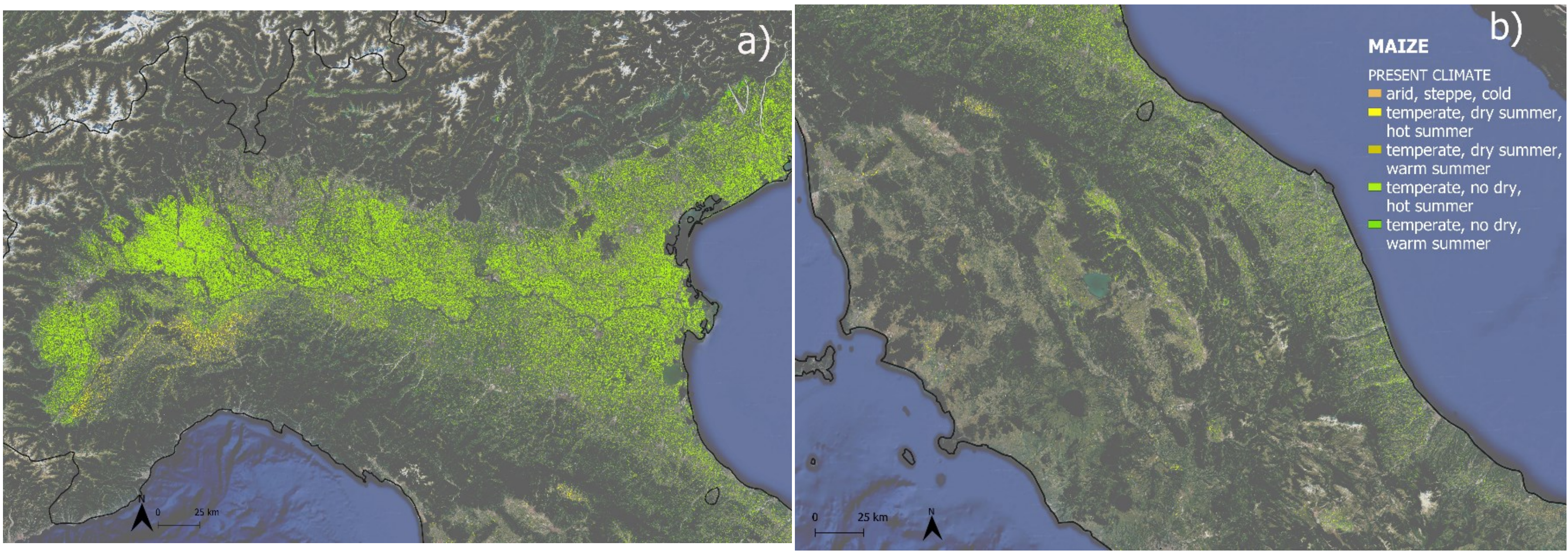
c. <u>Maize</u>

Almost all maize cultivations (94.33%) are characterized by temperate, no dry season, hot summer (Cfa) in particular those placed all over the Adriatic coast from Forlì, in Emilia-Romagna, to Chieti, in Abruzzo, and through the Po Valley from Piedmont to Friuli Venezia Giulia; only 3.4% is defined by temperate, dry summer, hot summer (Csa) corresponding to the areas in Campania, around Caserta; and 1.07% by temperate, no dry season, warm summer (Cfb). **(tab. C) (Fig. 2.3c).**

According to the future projection, slight but important changes are expected: indeed, the temperate, no dry season, warm summer (Cfb) climate may disappear and the temperate, no dry season, hot summer (Cfa) may reduce by 19.53% involving only fields in Piedmont, near Pinerolo, in Lombardy, in Veneto, in the provinces of Verona, Padova and Rovigo, and in Friuli Venezia Giulia, near Udine. These decreases will be replaced by the appearance of arid, steppe, hot (Bsh) and cold (Bsk) climates covering 8.5% in the Po Delta and along the Adriatic coast, and 1.2% in Piedmont, around Alba, respectively. Temperate, dry summer, hot summer (Csa) would also reach 15.10% (+11.10%) marking fields located in the south of Piedmont around the Alessandria and Cuneo provinces, along the Po river flow crossing Piacenza, in Emilia-Romagna, and some inland areas surrounding Arezzo and Trasimeno lake, in Tuscany and Umbria. **(Tab. C) (fig. 2.3c).**

MAIZE	*Present climate*	*Future climate*	Δ
Arid, steppe, hot (Bsh)	0%	8.5%	8.5%
Arid, steppe, cold (Bsk)	0%	1.2%	1.2%
Temperate, dry summer, hot summer (Csa)	3.4%	15.10%	11.10%
Temperate, no dry season, hot summer (Cfa)	94.33%	74.8%	-19.53%
Temperate, no dry season, warm summer (Cfb)	1.07%	0%	-1.07%

Tab.C Maize detailed results from tabs 2.3.1 and 2.3.2



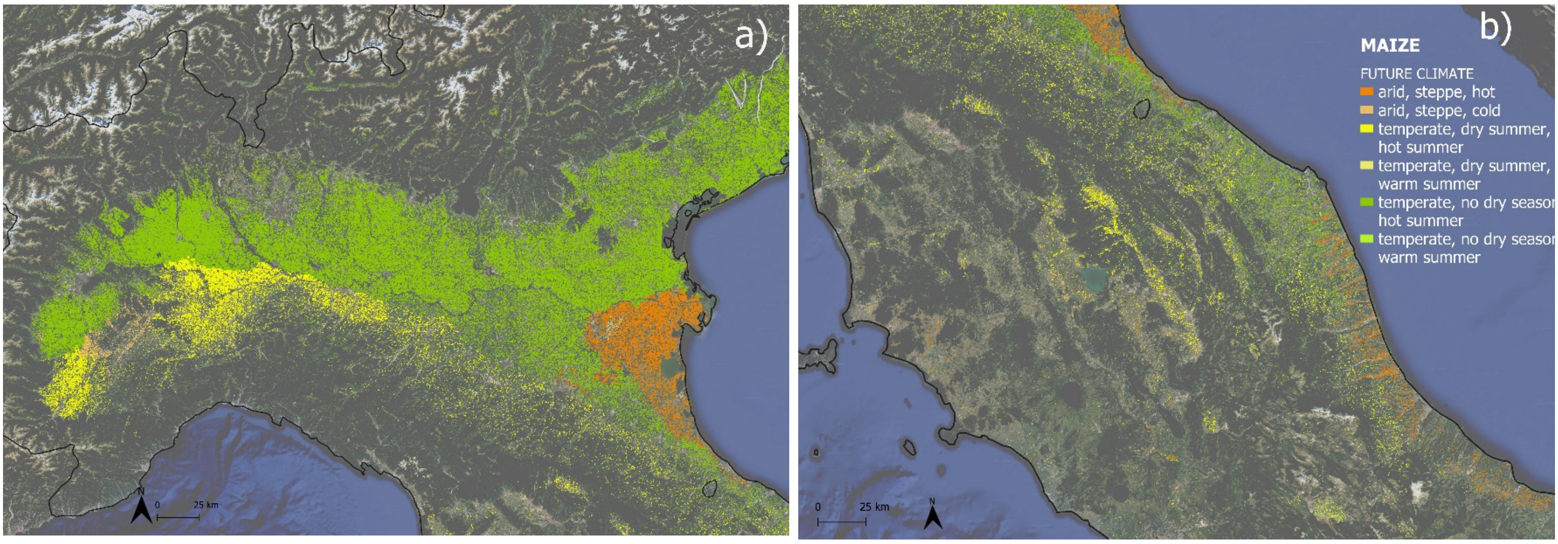


Fig. 2.3c Northern (a) and central (b) distribution of maize distinguished by present climate (on the top) and future climate (on the bottom)

d. <u>Rice</u>

The Italian rice fields are mainly located in temperate climatic territories: 97.56% are in temperate, no-dry season, hot summer (Cfa) and 2.44% in temperate, dry summer, hot summer (Csa). **(Tab. D)** The former distinguishes paddies set in Piedmont and Lombardy from Vercelli and Novara to Pavia and those near the Po Delta; the latter involves only fields in northern Sardinia. **(Fig. 2.3d).** This framework is supposed to change from 2017 to 2100 resulting in the conversion to arid, steppe, hot climate (Bsh) of all fields located at the Po delta, between the south of Veneto and the Ferrara province, as estimated also in the Straffelini and Tarolli's study. **(Straffelini and Tarolli, 2023)**. Moreover, paddies should experience a lesser extent of temperate, dry summer, hot summer (Csa) which would cover only 17% (+14.56%) corresponding to cultivations located around Casale Monferrato, in Piedmont, in the Lomellina valley, in Lombardy, and in Oristano, in eastern Sardinia, and a greater extent of temperate, no dry season, hot summer (Cfa) which would characterize 77.57%, albeit the 19.99% decrease. **(tab. D)** The latter is clear in the area of Biella, in northern Piedmont, and in the Mantova and Pavia provinces in Lombardy. **(fig. 2.3d)**

RICE	*Present climate*	*Future climate*	Δ
Arid, steppe, hot (Bsh)	0%	5.4%	5.40%
Arid, steppe, cold (Bsk)	0%	0%	0%
Temperate, dry summer, hot summer (Csa)	2.44%	17%	14.56%
Temperate, no dry season, hot summer (Cfa)	97.56%	77.57%	-19.99%

Tab. D Rice detailed results from tabs 2.3.1 and 2.3.2

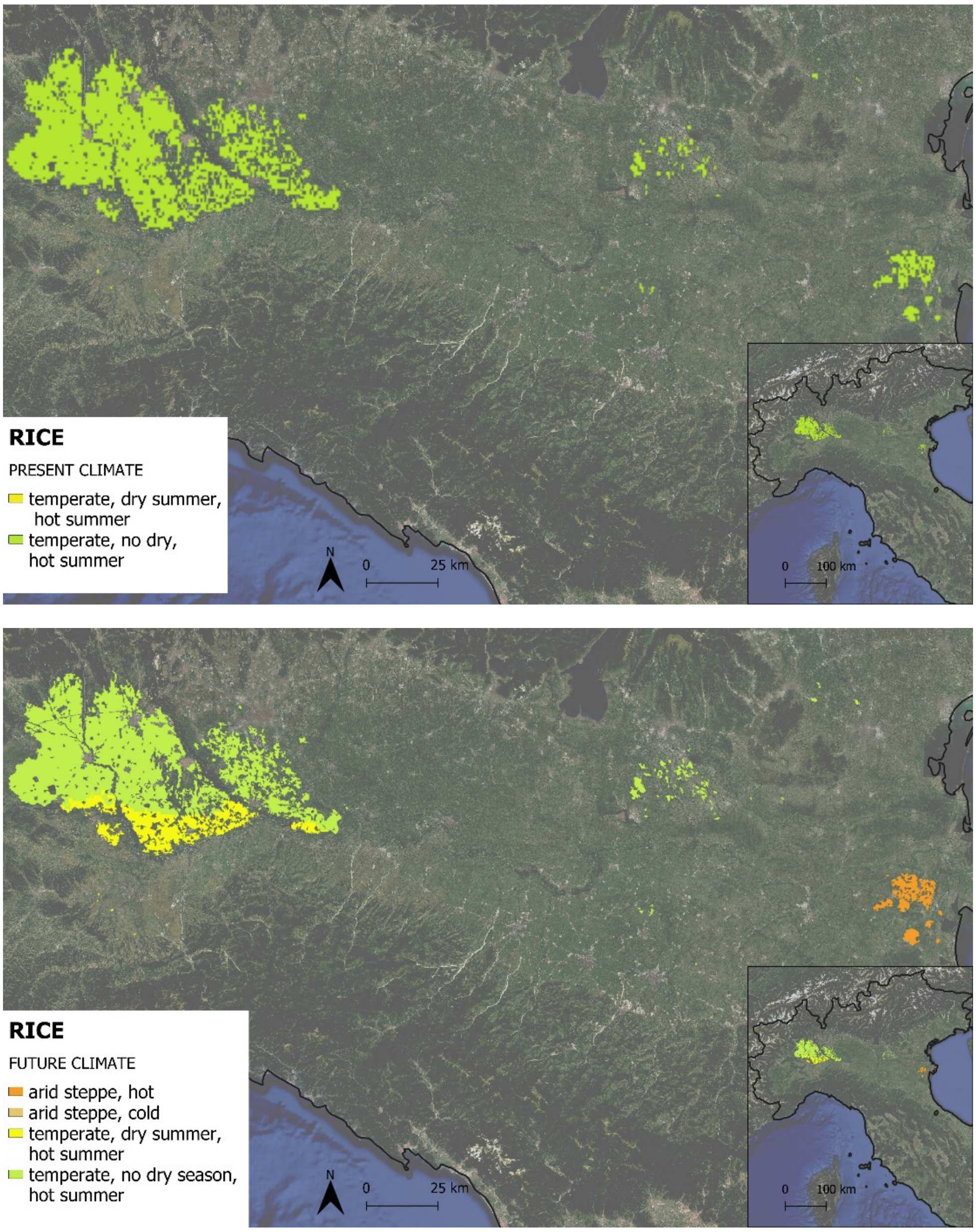


Fig. 2.3d Northern distribution of rice distinguished by present climate (on the top) and future climate (on the bottom)

e. <u>Olives</u>

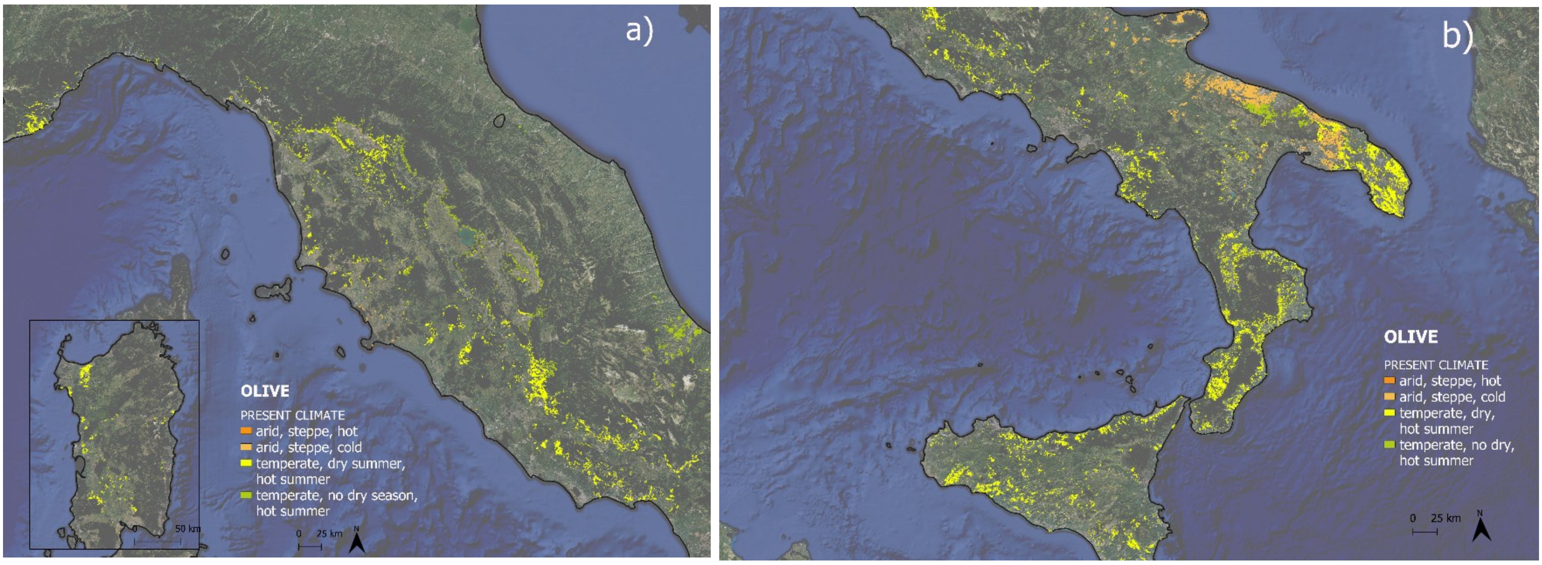
Similarly to durum wheat, olive trees, are largely characterized by arid, steppe, cold (Bsk) (18.83%) and temperate, dry summer, hot summer (68.88%) (Csa) climates. The former turns out to be specific to those placed in the north of Apulia, in the Gargano plain, around Bari and in the province of Taranto; the latter, instead, characterizes groves located in Liguria, in the province of Imperia, in Lazio near Frosinone and Rieti, in northern Tuscany from Lucca to Pistoia, in the south of Apulia around Lecce, in Calabria along both coasts and overspread in Sicily. So, the remaining 11.71% is defined by temperate, no dry season, hot summer (Cfa), corresponding to fields surrounding the Garda lake, from Florence and Arezzo, in Tuscany, to Terni, in Umbria, in Abruzzo, in the Pescara province, and Apulia in the Murgia plain and around Barletta. **(Tab. E) (Fig. 2.3e)**

In the future, this crop would show a conversion from arid, steppe, cold (Bsk), which would drop to 2%, remaining only in the inland areas of Tuscany and around Viterbo, in Lazio, to arid, steppe, hot

(Bsh) which may suddenly cover 27.36%, especially from Pescara, in Abruzzo, through the Adriatic coast, up to the Gargano plain and the Bari province, in Apulia, and around the provinces of Agrigento, Ragusa and Palermo in Sicily. Regarding temperate zones, the temperate, dry summer, hot summer (Csa) would increase by 1.47% reaching 70.35% of olives involving those previously identified with the addition of those in the province of Florence and Arezzo, in Tuscany, Terni and around Trasimeno lake in Umbria, in the province of Brindisi and in the Murgia plain, in southern Apulia, in both sides of Calabria, in the Messina's territory in Sicily and northern Sardinia, near Sassari; whereas temperate, no dry season, hot summer (Cfa) would plummet to 0.29% by losing 11.42%.**(tab. E) (Fig. 2.3e)**

OLIVE	*Present climate*	*Future climate*	Δ
Arid, steppe, hot (Bsh)	0%	27.36%	27.36%
Arid, steppe, cold (Bsk)	18.83%	2%	-16.83%
Temperate, dry summer, hot summer (Csa)	68.88%	70.35%	1.47%
Temperate, no dry season, hot summer (Cfa)	11.71%	0.29%	-11.42%

Tab E. Olive detailed results from tabs 2.3.1 and 2.3.2



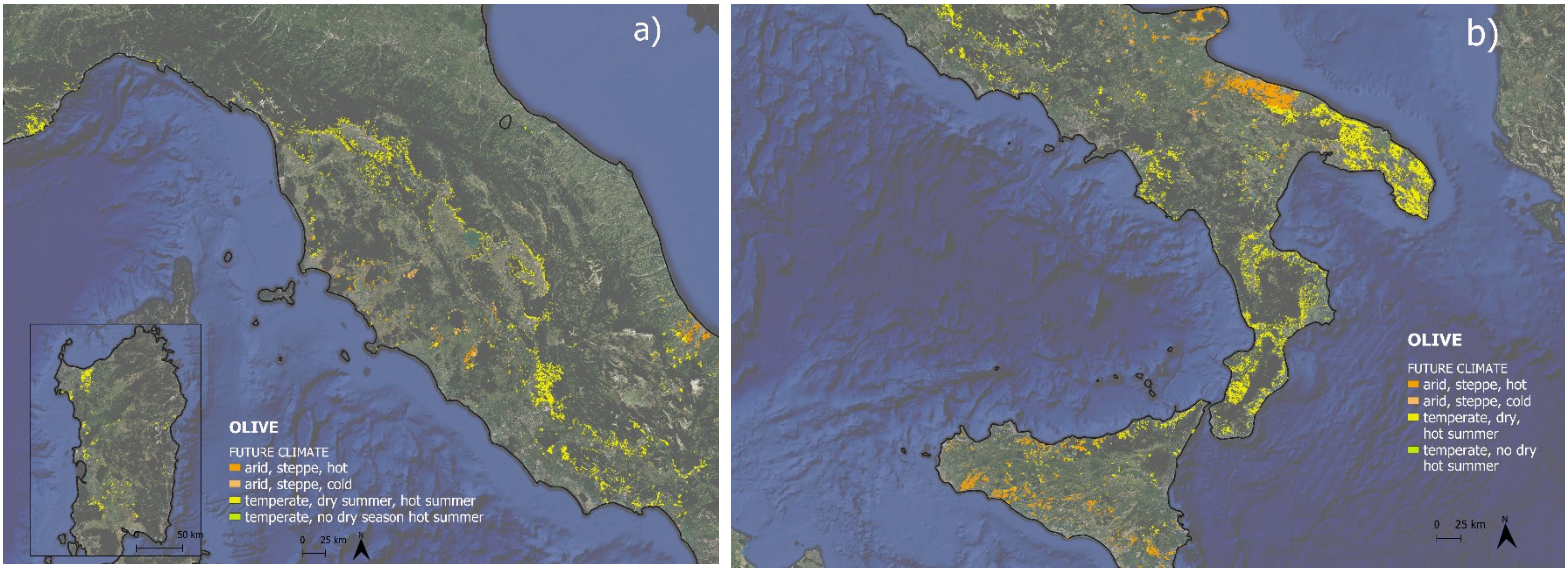


Fig. 2.3e Central, including Sardinia, (a) and Southern (b) distribution of olive distinguished by present climate (on the top) and future climate (on the bottom). *The geographical position of Sardinia (a) is reported without respecting the real coordinates for convenience.*

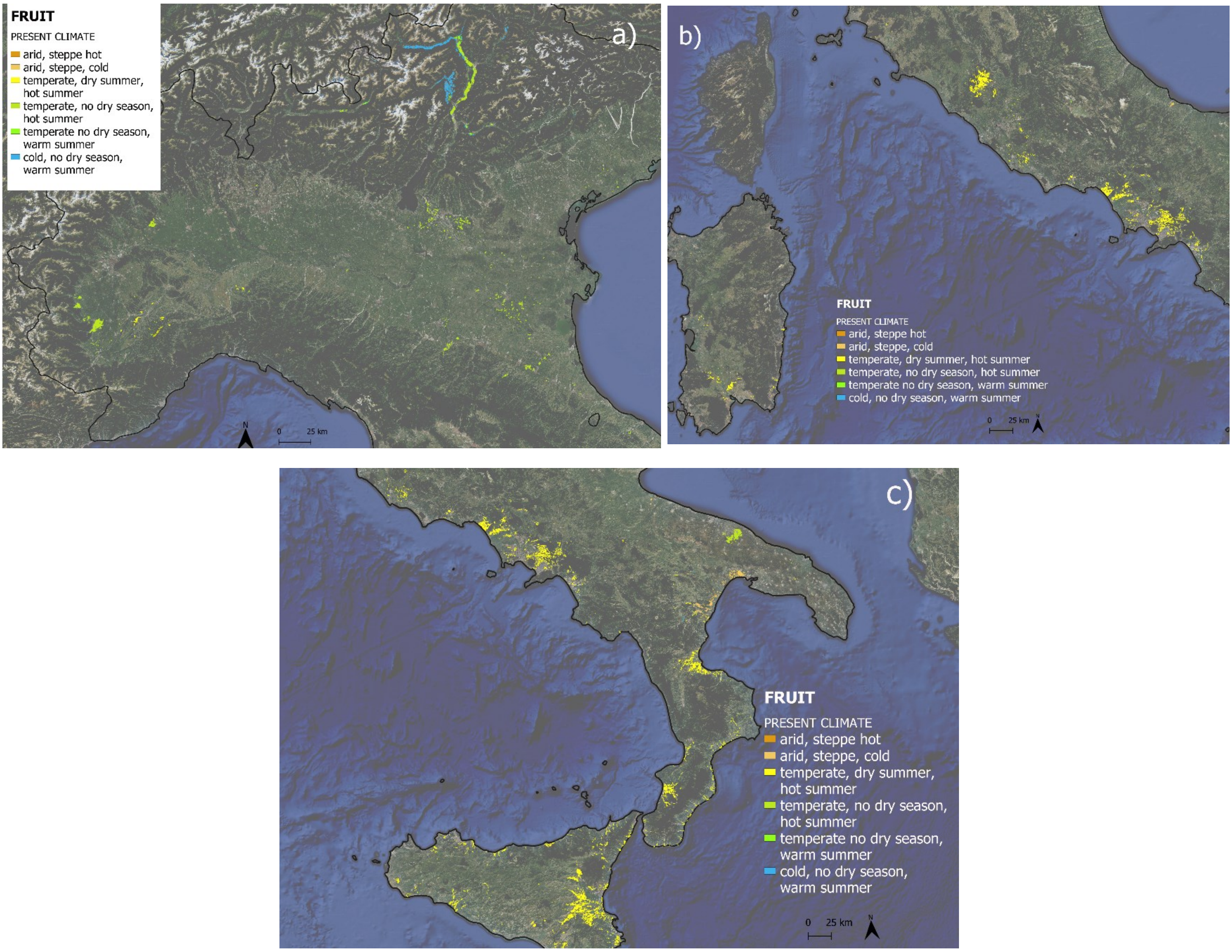
f. <u>Fruit</u>

In contrast to previous crops, 4.86% of fruit trees are characterized by a cold, no dry season, warm summer climate (Dfb), corresponding to part of those set in Trentino Alto Adige, near Bolzano. The temperate, no dry season, hot summer (Cfa) climate involves 15% of cultivations, particularly the other part of those located in Bolzano, those in Lombardy around Garda lake, in Piedmont, in Emilia-Romagna around Ferrara and Imola, in Veneto, in the Verona province, and Apulia, near the Bari province; whilst the temperate no dry season, warm summer (Cfb) covers only 1.4%. The majority of cultivation (72.25%), then, depends on a temperate, dry summer, hot summer (Csa) that characterizes the internal areas of Piedmont corresponding to Alba, Lazio near Viterbo and Latina, Campania around Capua and the province of Avellino, northern Calabria around Rosarno and inland areas of Sicily. A meagre portion, specifically 5.53% and 0.12% are respectively located in arid, steppe cold (Bsk) and hot (Bsh)climatic conditions, both placed in Basilicata, along the Ionian coast. **(Tab. F.) (Fig. 2.3f)**

The arid, steppe, hot zones are expected to increase to 32.54% comprising the fields around Ferrara, in Emilia-Romagna, in southern Basilicata, in Sicily around Catania, Agrigento and Palermo, and Sardinia, in the province of Cagliari. Consequently, a drop of all others is expected: the arid, steppe, cold (Bsk) should decline to less than 1%; the temperate, dry summer, hot summer (Csa) may decrease to 52.48% (-19.77%) covering only the fields in Piedmont, near Saluzzo, in Lazio, near Viterbo, in Campania around Capua and Caserta, in Apulia, in Polignano, in Calabria along both coasts, and Sicily around Messina and northern Catania; the temperate, no dry season, hot summer (Cfa) could reduce to 13.70% (-12.61%) involving orchards placed in Trentino Alto Adige, near Bolzano, in Piedmont near Santhià, and to a lesser extent in Emilia-Romagna, around Faenza. Lastly, cold, no dry season, warm summer (Dfb), would disappear completely and the temperate, no dry season, warm summer (Cfb) would drop to 0.37% (-0.77%). **(tab. F) (fig. 2.3f)**

FRUITS	*Present climate*	*Future climate*	Δ
Arid, steppe, hot (Bsh)	0.12%	32.54%	32.42%
Arid, steppe, cold (Bsk)	5.53%	0.90%	-4.63%
Temperate, dry summer, hot summer (Csa)	72.25%	52.48%	-19.77%
Temperate, no dry season, hot summer (Cfa)	15%	13.7%	-12.61%
Temperate, no dry season, warm summer (Cfb)	1.14%	0.37%	-0.77%
Cold, no dry season, warm summer (Dfb)	4.86%		-4.86%

Tab. F Fruits detailed results from tabs 2.3.1 and 2.3.2



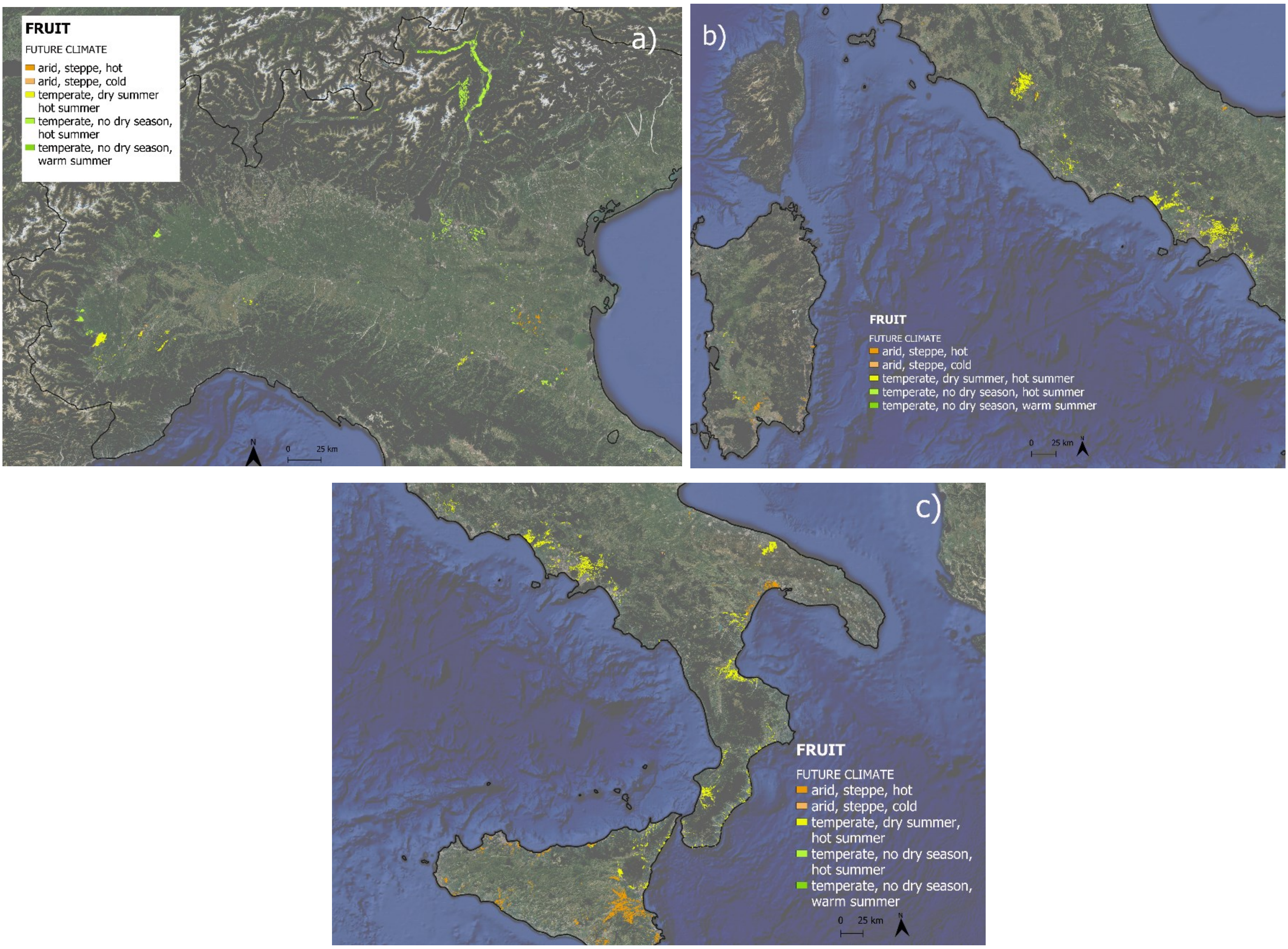


Fig. 2.3f Northern (a) Central, including Sardinia (b) and southern (c) distribution of fruit trees distinguished by present climate zones (on the top) and future climate zones (on the bottom)

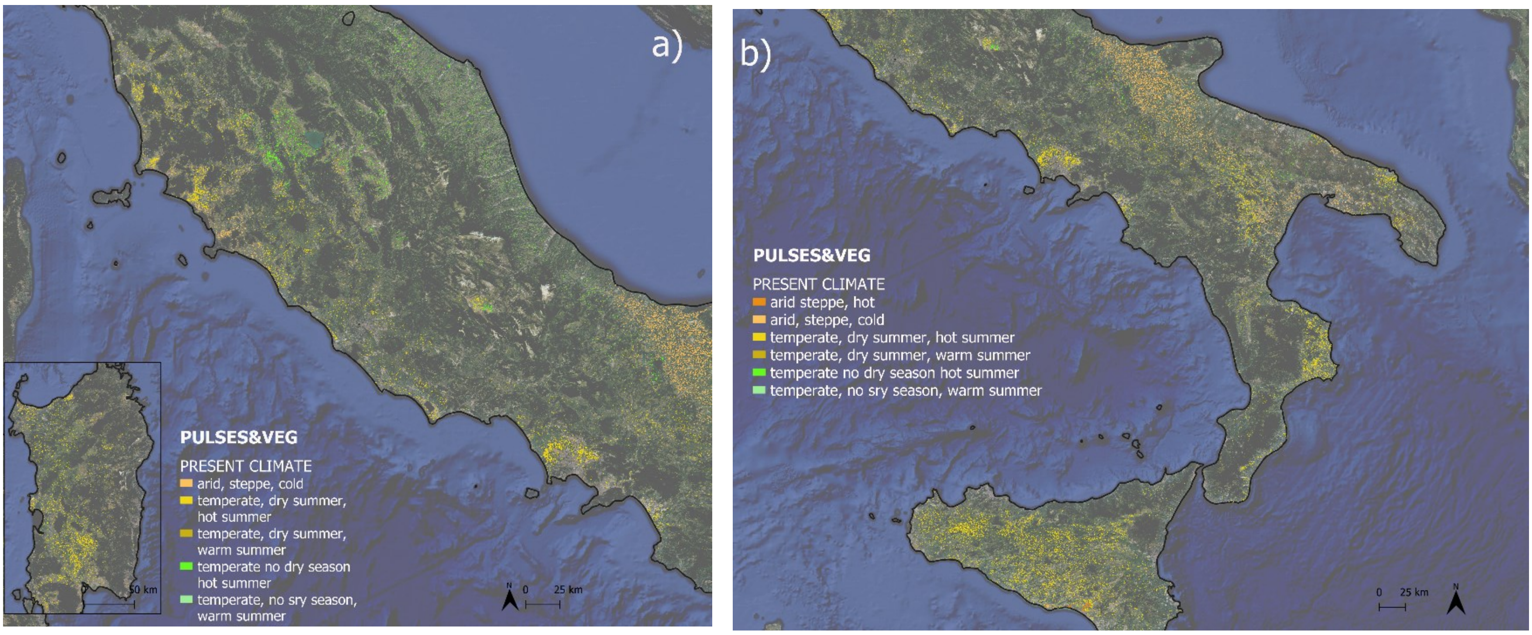
g. <u>Pulses & vegetables</u>

Similarly to durum wheat, a discrete percentage (22%) of pulses and vegetables cultivated area is affected by arid, steppe, cold climate (Bsk), specifically in eastern Molise along Adriatic coast, in Apulia, in the Foggia province and Francavilla areas, and southern Basilicata; 18.56% is characterized by temperate, no dry season, hot summer (Cfa) distinguished in Emilia-Romagna, in the Piacenza province, in the Po Delta and Marche along the Adriatic coast. The greatest extension (57.36%) is marked, instead, by temperate, dry summer, hot summer (Csa) found in Apulia, in the Brindisi province, in Calabria, from Crotone along the Ionian sea, in Campania, near Capua, in northern Basilicata and around Matera, and in internal areas of Sicily. Lastly, the least present climates are arid, steppe, hot (Bsh) and temperate, dry summer, warm summer (Csb) which cover 0.43% and 1.13% apiece. **(tab. G) (fig. 2.3g).**

Once more, the future projection records an evident increase in arid, steppe, hot climate (Bsh) which should cover 43.02% of pulses & vegetable fields, specifically those in the Po Delta, in the south, from Molise, near Termoli, across Apulia, in the Foggia province, as far as Matera in Basilicata, in Sicily and Sardinia, in the Cagliari province. Consequently, there would be a decrease in arid, steppe, cold (Bsk) which should lose 17%, interesting only 5% of orchards particularly those placed around Montepulciano, in Tuscany. Then, whereas the temperate, dry summer, warm summer (Csb) would disappear completely, the temperate dry summer, hot summer (Csa) could reach 43.88% (-13.48%) characterizing eastern and southern Sardinia, the coast of the Po river, the north of Tuscany near Lucca and Volterra, Umbria, around Trasimeno lake, Abruzzo, near Avezzano, Campania, in the Caserta province, southern Basilicata and Calabria, near Crotone. Finally, temperate, no dry season, hot summer (Cfa) would remain only in 7.58% of fields scattered in northern regions. **(tab.G) (Fig. 2.3g)**

PULSES & VEGETABLES	*Present climate*	*Future climate*	Δ
Arid, steppe, hot (Bsh)	0.43%	43.45%	43.02%
Arid, steppe, cold (Bsk)	22%	5%	-17%
Temperate, dry summer, hot summer (Csa)	57.36%	43.88%	-13.48%
Temperate, dry summer, warm summer (Csb)	1.13%	0%	-1.13%
Temperate, no dry season, hot summer (Cfa)	18.56%	7.58%	-10.98%

Tab. G Pulses & vegetables detailed results from tabs 2.3.1 and 2.3.2



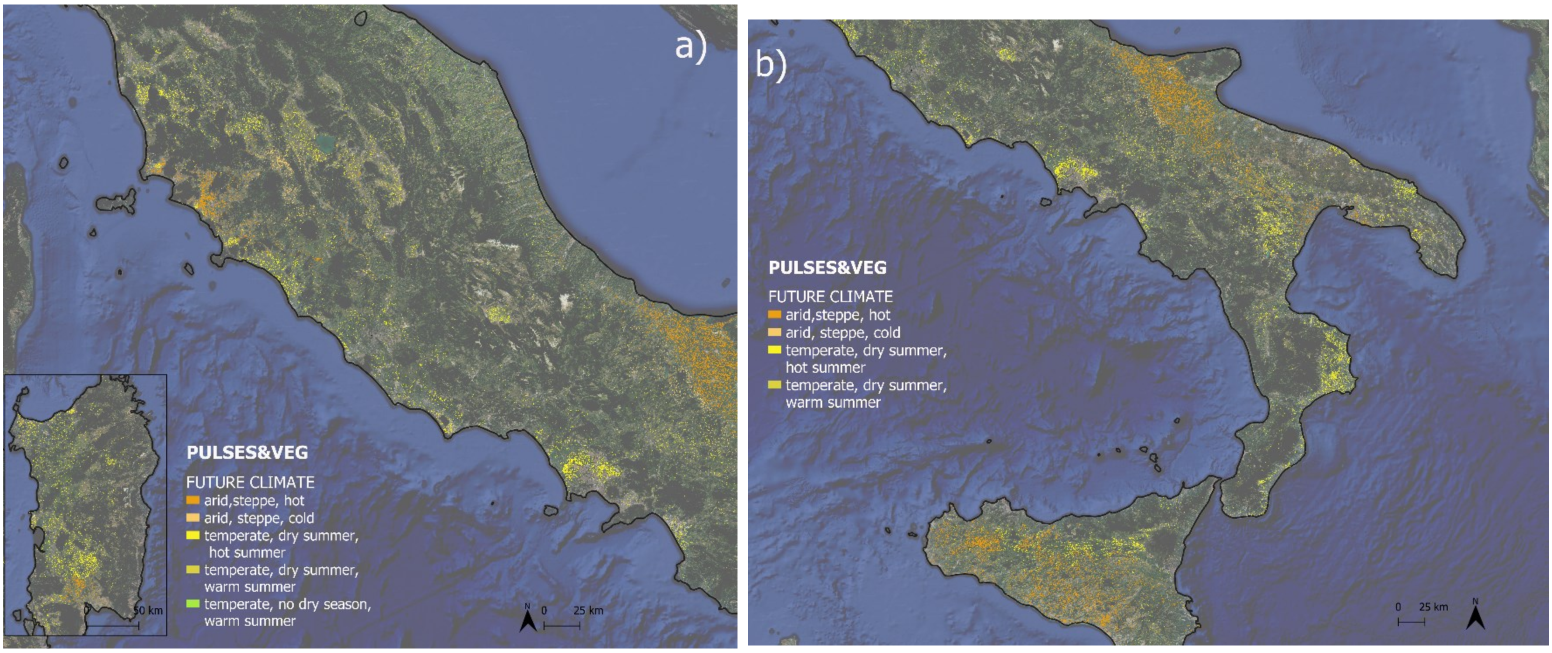


Fig. 2.3g Central, including Sardinia (a) and southern (b)distribution of pulses& vegetables trees distinguished by present climate zones (on the top) and future climate zones (on the bottom). *The geographical position of Sardinia (a) is reported without respecting the real coordinates for convenience.*

CHAPTER 3. DISCUSSION

Numerous scholars have been more and more driven by the urgency to deepen and forecast the economic, social, political, and agricultural impact of climate issues, and this study, in line with the literature, further confirms the worrying long-term emergency of climate change concerning Italian agricultural production and development. Whereas unique biodiversity, which derives from climate heterogeneity characterizing the country, enables the cultivation of several crop species, the same exacerbates the national vulnerability to extreme events from north to south. Additionally, large differences in soil and topographic features are involved explaining the great variable sensitivity to soil erosion, drought and water scarcity throughout the territory. (**Coderoni, S. *et al.* 2023; Ali E., Cramer W., *et al.* 2022; European Commission 2020b).** Indeed, changes in temperature and precipitation regimens are surely unquestionable and differently distributed from region to region and over seasons. Any repeated anomalies could cause an environmental disaster to areas that normally aren't affected and can take several forms depending on the season, as in the case of erosive rainfall which seems to be more present in autumn as cumulative precipitation and summer as short and heavy storms. **(Padulano, R *et al.* 2023; Salvati, L. *et al.* 2012).** The extent of the damage, then, depends on the current soil conditions: as an example for all, the lower the soil organic carbon held in the soil, the less the soil water retention capacity and the higher the impact of drought and soil erosion by water runoff. **(Salvati, L. *et al.* 2012; Coderoni, S. *et al.* 2023)**

Our findings, dealing with soil erosion in 2016, relied on the pan-European Panagos' study and highlighted northern Alps, southern Piedmont, western Liguria, near the province of Imperia, the Padana plain, the entire Adriatic coast, Tuscany, mainly Grosseto and the Arezzo province, Lazio, around Viterbo, and southern regions like Basilicata, Calabria, Sicily and eastern Sardinia as the most critical areas. Although we didn't provide a precise gauge of erosion in these areas, a good correspondence with existing papers can be found. Grimm *et al.,* applying the RUSLE equation in Italy, similarly, pinpointed the abovementioned areas as the most affected (**Grimm, M. *et al.* 2003**). Furthermore, the advancement in remote sensing analysis has encouraged experts to develop research monitoring the erosion process in several Italian cultivated areas, a great number of which deal with those located in mountainous and hilly landscapes. **(Brandolini, P. *et al.* 2018b and references therein)** Heavy mechanization on one side and land abandonment on the other are recognised as the main erosive impacting factors worsening the sensitivity of lands to erosion, as demonstrated in Liguria, Tuscany, Sicily and Basilicata **(Straffelini, E. *et al.* 2022; Brandolini, P. *et al.* 2018a, 2018b; Capolongo, D. *et al.* 2008).** Tuscany and Central Apennines were also extensively examined as dangerous sites through the detection of increasing frequency and intensity of storms **(Vallebona, C. *et al.* 2016; Borrelli, P. *et al.* 2014):** 59% of arable lands in those zones resulted to suffer from moderate to severe soil erosion **(Vallebona, C. *et al.* 2016).** Undoubtedly, specific geomorphological and climate conditions can predispose a region to high soil water erosion rates, as in the case of Calabria (**Terranova, O. *et al.* 2009**). Lastly, the Murgia plain crossing Basilicata and Apulia is known to experience moderate to extreme soil erosion **(Aiello, A. *et al* 2015)**

The second issue concerning the country is the intensification of drought episodes that arise from the combination of global warming with an extreme decrease in precipitation. It's not by chance that Italy, as well as the entire Mediterranean basin, has been acknowledged as a critical hotspot due to its high risk of drought and water scarcity which can lead to desertification. (**Coderoni, S.*et al.* 2023; Ali E., Cramer W., *et al.* 2022)** According to an European estimation, Italy is among the countries losing the highest amount of money from drought, about 1.4 billion €/year **(European Commission, 2020a)** up to 3 billion in exceptional events like those in 2017 and 2022 **(Rossi, L. *et al.* 2023; Paoloni, M. 2022).** This problem has recently become a point of interest, despite analyses demonstrated a growth in its incidence since 1950 and a doubling of this trend in the last fifty years **(Sofia, G. *et al,* 2023)**. Consequences are different according to the area in which it occurs: whereas northern regions would experience a drier climate, southern ones would be further damaged by an exacerbation of their water scarcity. (**Salvati, L. *et al.* 2012).**

Our elaboration explores the intensive and persistent drought of summer 2022 which was promoted by an extensive lack of rainfall and higher-than-average temperatures that occurred from the beginning of the year. This event emblematically undermined the whole country forcing farmers to increase the demand for water irrigation (**European Commission, Joint Research Centre 2022)**. A persistent dipole of sea level pressure anomalies over northwestern and southeastern Europe, which should have contrasted the transit of Atlantic perturbations, is considered the most worthy explanation of the negative rainfall, and also snowfall, during winter. Instead, from spring and over the summer, a persistent thermal north-African anticyclone enhanced the temperature rise until +2 and +3.5 °C and the precipitation depletion. **(Bonaldo, D. *et al.* (2022).** Immediately, in the northern, this resulted in a significant decrease in Po river discharge causing also the infiltration of salt from the sea into the Delta and 40 km upstream (**Tarolli, P. *et al.* 2023; ADBPO, 2022)**. The exceptionality of this event, hence, lies in its spatial and temporal extension which has no precedents **(Bonaldo, D. *et al.* (2022).** Specifically, our analysis of the Vegetation Health Index (VHI) of June 2022, which is considered a reliable instrument to monitor the drought-derived agricultural stress, revealed critical conditions roughly in the same areas previously underlined for their high erosion rate: some areas in northern Alps chain, which is also consistent with the Global Drought Observatory's report **(European Commission, Joint Research Centre 2022),** western Piedmont around Torino, Alessandria, Biella and Novara, in northern Padana plain through Monza and Garda lake up to Friuli-Venezia Giulia, along the Adriatic coast, in Tuscany, in the province of Grosseto, around Trasimeno lake in Umbria, as far as the south with a particular interest in Lazio, Campania, Basilicata, around Matera, southern Apulia, northern Calabria, southeastern coast of Sicily and northwestern in Sardinia.

The Vegetation Indices are scarcely explored among European articles (**Bachmair, S. *et al.* 2018),** even less in Italian ones: indeed, many prefer to provide meteorological or hydrological drought-risk monitoring based upon the control of Standardized Precipitation Index (SPI) and Standardized Deficit Index -which is obtained from the difference between Evapotranspiration and precipitation measures- as in case of Todisco and Vergni who distinguished a drought risk in Umbria region that would have destined to worsen in the following 30 years. (**Vergni, L. and Todisco, F. 2011).** Nonetheless, among few exceptions, Villani and colleagues, combined VHI with other past and future indices and produced a thorough drought-risk assessment in central and southern Tuscany over 2022, highlighting the province of Grosseto and the cities of Albegna and Ombrone as the most at risk. (**Villani, L. *et al.* 2022).**

Thereafter, knowing the undeniable role of climate change in plants' development and growth, we carried out an analysis estimating the extension (in percentage) of erosion updated to 2016 and drought to 2022 on the cultivated areas dedicated to seven key Italian crops: common and durum wheat, maize, rice, olives, fruits, pulses and vegetables. Any changes in temperature and precipitation have different consequences depending on the region in which they take place, the season and the type of crop growing there, and even, whether it is an irrigated or rain-fed one. For instance, observing at the local level, an increase in annual rainfall would be more beneficial in the south and, conversely, potentially harmful in the north. On the contrary, a depletion in cumulative precipitation in those regions already concerned about water scarcity could exacerbate the pressure on the irrigation system. (**Bozzola, M. *et al.* 2018**; **Casolani, N. *et al.* 2020; Zampieri, M. *et al.* 2017).** Likewise, warmer temperatures in winter or spring seem to benefit rain-fed crops more than irrigated ones, vice versa in the case of warmer autumn. **(Salvati, L. *et al* 2012; Van Passel, S. *et al.* 2017)** The season and the growing phase during which anomalies happen, then, are equally crucial because the higher the temperature deviations in early phases, cold or summer season or the higher the cumulative precipitation over spring, the lower the land productivity. In particular perennial crops require a proper chilling time in order to overcome flower bud endodormancy, otherwise, their yield may be compromised. **(Coderoni, S. *et al.* 2023).**

Our outcomes pinpointed durum wheat and olive trees as the most affected by soil erosion in 2016 since 34.32% and 43.9% of their fields underwent severe soil loss rates, where "severe" means all the classified levels over 10 t/ha/y as suggested by Panagos **(Panagos, P. *et al* 2020)**; fruit and pulses & vegetables are the second by erosion gravity with 23.4% and 29.8%. Specifically, the most involved areas devoted to these cultivations are those in Trentino Alto Adige, near Bolzano, Liguria, northern and central Tuscany, Umbria, around Trasimeno lake and Perugia, from Molise to Basilicata, in Campania, around Caserta, Calabria, northern Sicily and Sardinia, near Sassari.

Whereas the extended erosion process in Italian durum wheat cultivations has been already acknowledged, especially in southern regions where the production is concentrated, lesser attention is oriented toward Italian olive groves about which many uncertainties persist regarding the estimation of their actual soil loss. Notwithstanding, international literature agrees on the assessment of olive trees as those having the highest erosion rates in the Mediterranean basin. **(Gómez, J.A. *et al.* 2014; Fleskens, L. and Stroosnijder, L. 2007).** In both cases, the reason could lie in the more frequent erosive rainfall as shorter and heavy storms or cumulative precipitation which usually took place in soil already degraded by tillage operations: the compaction deriving from heavy mechanization, coupled with the massive exploitation of natural resources, brought to a decrease in soil infiltration and retention capacities. (**De Vita, P. *et al.* 2007; Baiamonte, G. *et al.* 2019; Gómez, J.A. *et al.* 1999**; **Padulano, R. *et al.* 2023).**

As concern the drought in 2022, common and durum wheat stand out as the most overwhelmed as more than half of their fields (56.1% for the former and 67.12% for the latter) were damaged by "moderate," "severe" and "extreme" drought. The other investigated crops were compromised at a similar extension: 38.1% of maize; 53.7% of olives; 55.8% of fruits; and 58.8% of pulses & vegetables. On the contrary, rice emerged as the least affected since 68.3% of paddies weren't found to be in drought conditions. This result is matched with that we extracted for erosion and further confirms the correlation between these two environmental issues: wherever severe erosion takes place, the soil may be more prone to drought. (**Masroor, M. *et al.* 2022).** Indeed, flat lands where rice is usually cultivated are less affected by erosion process compared to steep slopes, therefore they could be also less exposed to drought risk **(Straffelini et al., 2022).** Furthermore, it is worth noting that many of the areas most devoted to these crops and threatened by drought roughly correspond to those aforementioned for erosion: only differences are the Po Delta and Apulia (mainly around

Brindisi, Taranto, and Lecce), which weren't mentioned for erosion but resulted in being jeopardized by a severe and extreme drought.

The criticality of this worrisome frameworks is strengthened by heavy production anomalies recorded at the end of 2022 seasonal harvesting by ISTAT (national statistic institution) and ISMEA (Institute of Services for the Agricultural and Food Market-Istituto di Servizi per il Mercato Agricolo e Alimentare, in Italian). Bearing in mind the direct and indirect impact of climate on the plant development, crop yield losses due to unfavourable conditions have been consolidated by now. (**Lesk, C. *et al.* 2016; Zampieri, M. *et al.* 2020; Lobell, D. B. *et al.*, 2011; De Vita *et al.* 2007).** Certainly, statistical uncertainties remain since, on the one hand, farmers could limit the damages of by managing fields properly and more sustainably, and, on the other, an unanticipated climatic variability could always occur under several forms. **(Bozzola, M. and Swanson, T. 2014).** Furthermore, as regards 2022, the war in Ukraine should not be overlooked since it caused an increase in energy costs by hindering the farming activity, mainly of maize and common wheat. **(ISMEA, 2023a).**

However, the national drop of all cereals (maize, rice, durum and common wheat) are largely explained by rainfall limitations that occurred over 2022, indeed, as was investigated by Santini et al, a contingency in precipitation up to 8 months before the harvesting of maize, 3 months that of rice and from 5 to 7 months for spring wheat would have a significant correspondence with lower-than-normal yield. Moreover, they demonstrated that the shorter the drought conditions (1-2 months) around the growing season, the more detrimental the impact on production (**Santini, M. *et al.* 2022).** According to national statistics, the country has lost 10% of durum and common wheat, the distribution of which is convenient with our results following the areas that we have defined as most impoverished by drought: the northern regions, such as Piedmont and Emilia-Romagna were more affected by common wheat decline and recorded -15% and -25% respectively, while southern by that of durum wheat, like the north of Apulia which reached -18%. Maize lessened overall by 23% more noticeable in the northeast, where Veneto recorded -32% of production, and northwest, in which Lombardy declined by 25%. Lastly, rice was the most jeopardized with a global drop of 60% which in Piedmont achieves 90%. Therefore, probably, that 16.5% of the fields we estimated affected by intense drought (from moderate to extreme level) burdened heavily on the entire production. **(ISTAT, 2022b).**

Despite the well-known high resistance of olive trees to environmental stress, the difficult climate conditions over the last year damaged the olive blooming and fruit setting as well: during summer, farmers were obliged to resort to extraordinary irrigation overloading the capacity of wells and water reservoirs. Simultaneously, the modest rainfall of August worsened the situation favouring the development of pests, mainly that of fruit fly. **(ISMEA, 2022).** Southern regions, indeed, had to cope with poor yields: Apulia was the most weakened losing 52% of its production also due to the occurrence of *Xylella fastidiosa* infection, a famous bacterium that causes the complete dryness of stems and leaves up to the plant death (**Gentile, A. 2022)**; as regards the others, Calabria dropped by 42%, Sicily by 25%, Sardinia by 13%, Basilicata and Abruzzo by 40%. **(ISMEA, 2022)** Once more, the regions aforementioned are the same already highlighted as being involved in severe drought.

Fruit and pulses & vegetable sectors didn't fare better during 2022 since they had dealt with the sequential onset of an earlier frost in January, which undermined new buds, followed by a sudden record-breaking May when temperature shot up to 40°C burning fruits. The oranges' campaign decreased by 20%, mainly in Calabria where was recorded a decline of 46%; apples dropped by 11% in the northwest, whose Trentino counted for 5%, and 20% in the south, in which Calabria was again the most depleted with a drop of 70%. The fruit category, in our case, embraces also nut trees (see chapter 1.3 of this section) among which hazelnuts were the most compromised by climate: as a whole, northwestern regions reported a reduction of 15%, in particular Veneto lost 30%, and southern ones of 9%. **(ISTAT, 2022b)** The economic relevance of these losses became clear if it is considered that Italy stands out also as the second country by the highest shares of citrus fruits, nuts, apples and oranges. **(Eurostat, 2019).** In addition, it is the second worldwide producer of hazelnuts of which the country can boast 3 IGP (Protected Geographic Identification) denominations **(National Conference, 2002).**

As for vegetables, the country lost as a whole 8% of tomatoes (considering those destined for fresh consumption) recording the highest decreases in the northwest, which gets to -25%, and in the south where Apulia reached -37%. **(ISTAT, 2022b).** Dry pulses, also, are comprised of this group and despite the leading global production being owned to America and India, in Europe they cover 13% of the area dedicated to fresh vegetables, and, furthermore, they have utmost relevance in the Mediterranean pyramid. **(Eurostat, 2019).** Legumes' yield is largely unstable since they are highly sensitive to soil erosion, drought, waterlogging and warming, however, the root system development and the relationship between above and belowground traits are not completely understood by now **(Wacker, T.S. *et al* 2023)**. The only well-known characteristics that differ them from other crops are that flowering is the most critical stage, they are potentially able to produce new pods until environmental conditions are good enough and, thirdly, they can benefit from the symbiotic nitrogen fixation. Among all varieties, lentils seem to be the most resistant to drought and better adaptable to low rainfall, however, whether water stress occurs during the reproductive phase, their yield would be damaged by the accelerated senescence and maturity (**Amassaghrou, A. *et al.* 2023).** As well as an exposure of chickpea to heat during pod development could alter pod fertility and seed yield (**Wang, J. *et al.*, 2006).** Therefore, it is not surprising that Italian lentils underwent a decline owing to the drought of 2022 recording a drop of 15% throughout the entire territory, with specific concentration in central regions which reached a loss of 21%. **(ISTAT, 2022b).**

After the ensued evaluation of drought and erosion extension, as a novelty, we further quantified the different climate zones on the cultivated areas of the same crops. To do this, we adapted to the study area the Beck's present climate map, in which the Köppen-Geiger's climate classification is reported. **(Beck, H.E. *et al.* 2018).** We are aware that the term "present" is referred to the period 1980-2016 which doesn't reflect our present, but actually our past, nevertheless, we preferred to exploit it anymore aiming at a better monitoring of climate shifts.

The elaboration showed three main climate types: temperate, dry summer, hot summer (Csa) which characterizes the majority of durum wheat, olive trees, fruit and pulses and vegetable orchards, mainly located in Liguria and southern Piedmont in the north, Tuscany, Umbria and Lazio in central regions, in Campania, entire Calabria, northern Sicily and northern and southern Sardinia, in the south; temperate, no dry season, hot summer (Cfb) which involves almost the totality of common wheat, maize, and rice fields, mainly those placed throughout the Po valley, from Piedmont as far as Friuli Venezia Giulia and along the entire Adriatic coast; arid, steppe, cold (Bsk) that marks evidently durum wheat and olive trees set in Tuscany, northern Apulia comprising Molise. Then, other climate types emerge in the minority: arid, steppe, hot (Bsh) was identified in 0.3% of durum wheat, 0.12% of fruit orchards and 0.43% of pulses & vegetables; temperate, dry summer, warm summer (Csb) was found only in the 1.13% of pulses & vegetables; temperate, no dry season, warm summer (Cfb) in 1.07% of maize and 1.4% of fruits; cold, no dry season, warm summer (Dfb) characterizes only 4.86% of fruits, placed in the Trentino Alto Adige region.

Evaluations regarding arid climate are consistent with Salvati's analysis which carried out an estimation of the Aridity Index (AI) between the 1980-2010 period in individual regions outlining southern regions as those with the lowest AI values which correspond to the highest degree of aridity**. (Salvati, L. *et al.* 2012).**

3.1 The impact on crop yields in future

The last step of this study entails a look ahead in terms of soil erosion by 2050 and future climate in the period 2017-2100 that could impact the development of selected crops. As assessed by the Euro-Mediterranean Centre for Climate Change, the temperature rise could reach 5°C if greenhouse gas emissions remain unchecked. This increase would be uniform over seasons with small differences between spring and summer: during the first, the warming could move from +1 to 1.5°C, while in the second, it can achieve +1.5 or +2°C. (**Spano, D. *et al.* 2020).** Similar results were obtained by Tomozeiu whose projection highlights an upward trend in temperature in northern Italy, in all seasons, which may worsen during the 2070-2099 period when the rise could reach 2.5°C, greatly affecting the Po Valley (**Tomozeiu, R. *et al.* 2014)**. Some other warming forecasts are stronger, ranging from a minimum of +4°C in autumn to +7.5°C in summer **(Bucchignani *et al.*, 2016)**. Consequently, precipitation regimens should also be altered, bearing in mind that any variations depend on local climatic processes. **(Faggian, P. 2021).** The literature agrees with the prediction of an increase in precipitation in winter over northern and central Italy (from 5% to 30%) and a heavy reduction in summer (up to 50% under 8.5 RCP scenario), particularly critical in the Alpine area and in the south. **(Spano *et al.*, 2020; Bucchignani *et al.*, 2016; Faggian, P. 2021).** Similarly, coastal areas will be also affected by an extreme rainfall rise, especially during the winter and autumn, as estimated along the Tyrrhenian coast by Dettori. (**Dettori *et al.*, 2011; Faggian, P. 2021)**. Given this evidence, a decrease in river discharge is also worryingly expected, indeed, considering the 8.5 RCP scenario, a decline of 33%, 38% and 26% respectively in June, July and August have been detected in 2100. **(Bonaldo *et al.*, 2022)**. Convenient to these conclusions, our results describe an enlargement of areas affected by arid, steppe, hot (Bsh) and temperate, dry summer hot summer (Csa) climates. Interestingly, the former should be localized in the Delta of the Po river, between southern Veneto and the Ferrara province, central zones of Tuscany around Grosseto and Arezzo, along the Adriatic coast from Abruzzo to Apulia, comprising also Matera, in Basilicata, almost the whole Sicily and southwest of Sardinia. Despite aridity isn't a synonym for drought as the former is a persistent characteristic of the local climate, whereas the latter is referred to as temporal meteorological variability, a correlation between them could be found: for instance, southern Italy should experience an increase in drought frequency as well as a conversion towards arid climate. (**PNACC, 2023; Faggian, P. 2021)**

As regards cultivations, the analysis figures out four climate types: almost half of durum wheat (49.21%), pulses & vegetables (43.45%), fruit (32.54%) and olive (27.36%) fields should undergo an arid, steppe, hot climate (Bsh) mainly placed in the northern areas earlier listed and more specifically in the Gargano plain and the Bari province, in Apulia, and in the provinces of Agrigento, Ragusa and

Catania, in Sicily; temperate, dry summer, hot summer (Csa) would cover the majority of olive (70.35%) and fruit (52.48%) trees and a great part of common wheat (27.4%), durum wheat (37.47%) and pulses & vegetables (43.88%) geographically set in southern Piedmont, in Liguria, in northern and central Tuscany, in Umbria, Lazio, Campania, Calabria, southern Apulia, northern Sicily and northern Sardinia; temperate, no dry season, hot summer (Cfa) will remain largely in common wheat (53.20%), maize (74.80%) and rice (77.57%) spread throughout the Po valley, from Piedmont to Friuli Venezia Giulia. Finally, the least present would be arid, steppe, cold (Bsk) that should characterize only 2% of common wheat and olives and 11.21% of durum wheat cultivated in the Alba's territory in Piedmont, around Montepulciano, in Tuscany, and in Lazio, around Viterbo.

These forecasted climate shifts certainly would undermine future crop yields. **(Spano, D. *et al.* 2020; Mereu, V. *et al.* 2021).** As an example, a steady warming and decrease of precipitation in summer would be detrimental for cereals production by causing a progressive advancement of maturity date and a damage on plants which require abundant water during their vegetative or growing phase, which occur in summer months. **(Accetturo and Alpino, 2023).** As a matter of fact, if any strategies will not be applied to counter the worrisome predictions, the production of wheat may decline by 50% in central and southern regions, and that of maize may drop by 20-30% in the Po Valley by 2030 and by 30% in Lazio, Umbria and Sardinia by 2080. **(Spano, D. *et al.* 2020; Mereu, V. *et al.* 2021).** Similarly, rice may reduce by 8% in 2030 and by 12% in 2070, in the Lomellina Valley, in Lombardy, as well as in the Po Delta, aridity is forecasted to cover 70% of rice fields, as evaluated by Straffelini and Tarolli. **(Bregaglio S *et al*, 2017; Straffelini, E. and Tarolli, P. 2023).** Nevertheless, Coldiretti has already registered a shrinkage of rice paddies extension of 8 thousand hectares (**Paoloni, M., 2023)**

The earlier occurrence of some phenological stages, owing to global warming, would cause also a shortening of the olive trees life cycle: indeed, the proper development of flowering could occur only after sufficient time at low temperatures. Other supposed consequences of the temperature rise are the increase in evapotranspiration joined with an uptrend in net irrigation requirements. The latter is more concerning because it threatens regions already weakened by water scarcity. **(Tanasijevic, L. *et al.* 2014)** Undoubtedly, climate conditions at specific latitude and altitudes and farming operations play a pivotal role: as for the first, farmers are trying to move their cultivations to higher altitudes (**European Environment Agency, 2019)**; for the second, the tillage operations are identified to be more impacting by modifying the soil structure making it more or less resilient. The absence of tillage seems to ease water infiltration compared to conventional operations, aiding soil to better withstand drought episodes preserving high yields. (**Gómez, J.A. *et al.* 1999)**

Ultimately, fruits and vegetables are also destined to be depleted by temperature and precipitation changes owing to their narrow dependence on irrigation systems and the resulting difficulty to complete blooming. On the contrary, a drier climate could be in somehow beneficial by hindering the development of some pests by reducing their infections, at the same time this advantage isn't uniform as, for instance, a new syndrome among kiwifruit trees has risen from high-temperature peaks during summer. **(Bevacqua, D. *et al.* 2023; CREA, 2023a and 2023b).** Unlike other crops, literature has so far not quantified a prediction for fruit yield anomalies in Italy.

The same crops investigated so far would also remain jeopardized by water soil erosion: indeed, the Mediterranean basin may show an increase in the extent of soil erosion by 2050, albeit minimal. This would be related to the expected conversion of precipitation into more intense and short-lived concentrated storms, particularly on steep slopes. **(Panagos *et al.*, 2021)(Vallebona *et al.*, 2015).**

According to our findings, olives, durum wheat, fruits, pulses and vegetables would be persistently marked by severe erosion, particularly in the earlier listed areas characterized by arid, steppe, hot and temperate, dry summer, hot summer climates.

In summary, future prospects would show further threats incoming for the Mediterranean diet: the worsening of climate conditions earlier analysed and the expected decline in yields of the investigated crops could result in greater difficulty in adhering to the traditional Mediterranean model. As discussed in the previous section, the expected negative frameworks would not only concern dietary patterns but rather all other aspects related to them: indeed, the term diet also embraces a country's culture, society, history and economy. **(UNESCO, 2010).** The UNESCO acknowledgment of the Mediterranean diet as an Cultural Intangible Heritage is intended to emphasize precisely this concept since, in fact, the title refers to a heritage that contributes to social cohesion and encourages a sense of identity. **(UNESCO, 2011).** Therefore, the areas we have stressed as most undermined by all environmental issues we have explored must also be considered in light of this troubling view that could inexorably lose Italy's cultural history and tradition.

3.2 Limits of the study and future perspectives

Limits of this study mainly concern temporal discrepancies among all sources that reduce the accuracy of our estimate: Corine Land Cover and Eucrop maps, used to locate cultivated areas on the national territory, are dated to 2018, whereas Panagos' erosion survey is referred to 2016 and the VHI measurement to 2022. These differences result in a less accurate geographic assessment of the intersection among maps, albeit in terms of pixel differences. Another limitation, then, may derive from the adoption of future climate maps, which are built on simulation algorithms and, so, naturally suffer from biases, and from their application on current agricultural systems that we are aware may evolve. Lastly, not to mention, all the limits inherent in the maps and already pointed out by the authors themselves.

However, to the best of our knowledge, these are the most up-to-date references that can be found in the literature, thus their reliability makes our estimate equally valid. For instance, the combined use of Corine Land Cover and Eucrop maps allowed us to fill in missing data and improve the accuracy of our research, since the former is based on 2 satellite images, while the latter relies on LUCAS survey and Sentil-1 images which are more precise. **(d'Andrimont *et al.*, 2021a, 2021b).** Likewise, despite the well-known limitations of the RUSLE equation, the Panagos' processing remains the best assessment of pan-European erosion, even for the future simulation that is based on the CMIP5 model, the same one applied by Beck. The latter has been only recently updated with a new phase (the CMIP6), that, according to some authors, records distinct estimations of agricultural global production not appearing to be the best choice (**Bourdeau-Goulet, S., Hassanzadeh, E., 2021).**

Finally, the application of future climate model on present cropland areas allowed us to show the areas currently most at risk and to indirectly emphasize the close relationship between climate agriculture and society by evaluating the impact of extreme weather events on crops that form the basis of individual diets. The novelty matter of this study can inspire stakeholders and policy makers to provide appropriate defence measures and new in-depth research on this topic. In particular, the latter may include the development of a drought-monitoring model, scientific investigation on techniques to improve plant adaptability and resistance, advancement in irrigation technology to waste as little water as possible, the publication of sustainable water resource management programs geared toward the areas most affected by aridity and drought and the spread of educative projects to strengthen the importance of adhering to the Mediterranean diet for human health, well-being of the environment, and cultural national identity.

CHAPTER 4. CONCLUSIONS

This study contributes to bridging a gap in the literature by addressing the impact of climatic events on Italian agricultural areas cultivated with crops at the basis of the Mediterranean diet. In doing so, it aims to focus attention on the danger of climate change to individual lifestyle and to the Italian economy and society. Indeed, it is worth stressing that future climate scenarios will also involve people who can suffer from extreme weather events, as they can damage homes, cities and cultivated fields and threaten human health by reducing watersheds, food production and its security and enhancing pressure on natural resources**. (FAO, 2018).** Drought, is an example of complex hazard which can trigger physical harm to the elderly and vulnerable people by heatwaves or by crop failures that can lead to malnutrition and disease outbreaks. This concerns particularly countries lying in poverty conditions where population could be forced to migrate. **(United Nations, 2021).** The prolonged drought episode of 2022 was a prime instance of the relationship between climate change and society also in Italy, where the extreme high temperatures combined with a shrinkage of precipitation exacerbated water scarcity and deeply burdened on the agribusiness sector that experienced substantial declines in production. Our findings highlighted that more than half of durum wheat (67.1%) and pulses & vegetables (58.8%) croplands were jeopardized by intense drought (from moderate to extreme levels) in June 2022, immediately followed by common wheat (56.1%), fruits (55.8%) and olives (53.7%).

Another worrying issue that deeply marks national territory is erosion: it mainly arises from erosive activity of water, both as surface runoff and as short and intense storms. **(Vallebona *et al.*, 2015; Straffelini *et al.*, 2022)**. This is related to the soil water retention capacity which can be eventually further reduced by drought: the two events are intertwined by each other. **(Masroor *et al.*, 2022)**. As a matter of fact, almost half of fields dedicated to olive trees (44%), durum wheat (34.3%), fruits (23.4%), and pulses and vegetables (29.8%) were also found in our research to be threatened by severe erosion (i.e. a soil loss rate over than 10 t/ha/y). Additionally, rice and maize, coherently, resulted to not suffer too much from both conditions. The worthy explanation of this difference lies in the fact that rice and maize are normally planted in flat lands which are well-known to be less prone to erosion than steep slopes where olive and fruit trees can be normally found. **(Straffelini *et al.*, 2022).**

A steady upward trend in erosive rainfall coupled with an increasing frequency of drought could negatively impact men and environment leading to desertification. Furthermore, this process, that would bring to a soil completely unfertile, can be exacerbated by aridity**. (Salvati, L. *et al.*, 2012)**. Once again, olives, durum wheat, pulses and vegetables are largely involved: 18.8% of fields cultivated with olives, 31.5% with durum wheat, and 22% pulses and vegetables are currently distinguished by arid, steppe, cold climate (Bsk) as obtained by the analysis of Beck's present map.

Geographically, the above mentioned crops are, as a whole, located in the northern Alps, in Trentino Alto Adige, in southern Piedmont around Alba and the province of Alessandria, in the Imperia province in Liguria, the Delta of the Po river, in the province of Grosseto, in Tuscany, the entire Adriatic coast, Viterbo, in Lazio, in the province of Caserta in Campania, in the Foggia province in northern Apulia, in Matera and along the Ionic coast in Basilicata and both coasts in Calabria, in the provinces of Agrigento, Catania, Palermo and Messina in Sicily and those of Cagliari and Sassari in Sardinia. These same zones will additionally experience, in the future, a dramatic transition towards arid, steppe, hot (Bsh) or an extension of a temperate, dry summer, hot summer (Csa) climates. As for crops, durum wheat, fruits, olives and pulses and vegetables remain the most vulnerable cultivations, even exploring changed frameworks. On the contrary, likewise present situation, maize, rice and common wheat may endure to be largely marked by temperate, no dry season hot summer (Cfa) with a little increase in arid, steppe, hot (Bsh).

These worrisome scenarios directly overload the adherence to the Mediterranean diet since durum wheat is the main ingredient of bakery products, maize is fundamental for animal feed **(ISMEA, 2023a)** rice, fruit, pulses and vegetables should be present at each meal, and olives are the component of extra virgin olive oil, which is a milestone of the Mediterranean cuisine. Consequently, several reactions could derive: on the one hand, the farmers' attempt to move cultivations to different latitudes and altitudes in the hope of finding better conditions, and, on the other hand, a change in the entire agricultural system. Actually, both are already taking place: olive trees are undergoing a northward shifting toward northern regions (Piedmont and Friuli-Venezia Giulia) and Apennine chains **(CREA, 2023c);** at the same time mangoes and avocados are beginning to be planted in Sicily. **(Edagricole, 2022)** Whether these two options are economically sound in that they enable farmers to earn sufficient income, they are not well suited to withstand this long-term emergency. Undoubtedly, the linkage between climate and agriculture moves in both directions: indeed, farming operations can influence and exacerbate climate change manifestations. For instance, irrigation normally exploits 90% of groundwater reservoirs undermining the soil **(Sofia, G. *et al.* 2023)** and exposing it to a high risk of erosion, as well as the use of heavy mechanization causes the compaction of the terrain hindering its water retention capacity. **(Straffelini, E. *et al.,* 2022; European Environment Agency, 2012).**

In light of this evidence, the modern food system is no longer suitable and there is an urgent need to rethink it aiming to develop sustainable practices to mitigate climate change and, simultaneously, to improve plant resistance and adaptability. In recent years, scholars have followed one another to estimate beneficial impacts of specific agricultural techniques on sustainability: careful selection of crop varieties and tillage operations, reduced application of fertilizers, and exploitation of a more efficient irrigation system are those most involved in the lessening of GHG concentrations, especially NH_2 and CH_4, and in the rise of soil organic carbon stocks. The latter, in particular, has been demonstrated as one of the most reliable factors to ease climate change as soil carbon accumulation could uphold crop growth under drought conditions, increase water infiltration and retention, reduce soil evaporation and soil losses by water runoff, and stimulate biodiversity aiding the pest defeat. **(Aguilera, E. *et al.* 2020).** Additionally, cover crops are another important contributor to contrasting soil erosion by improving the infiltration and protecting bare soil from intense storms: this practice alone can reduce the risk by 20% and even more when combined with no-tillage operations**. (Panagos *et al.*, 2021)**. On the contrary, despite monoculture having been proven to be associated with ecosystem depletion, crop rotation has received divergent opinions in the literature. It has been emphasized as enabling to promote biodiversity (**FAO, 2018**), while Panagos defined it as a forthcoming risk factor for soil erosion **(Panagos *et al.*, 2021)**

Certainly, irrigation is the most critical point, particularly for fruits, pulses and vegetables that rely on it, but it is also becoming crucial for olive trees. Efficient water management is paramount to address all environmental challenges discussed so far and to cope with increasingly unpredictable weather. **(Bozzola and Swanson, 2014**). First, it's important to perform it when phenological moments are more convenient for fruit setting than for wood growth in order to maintain 70-80% of humidity. **(CREA, 2023a)**. Then, avoiding water waste is of utmost relevance and the precise irrigation developed as sub-irrigation or sub-surface drip irrigation can be helpful. Indeed, these techniques ensure the water and nutrients entrance directly into the roots through a capillary structure, and afterwards, the amount of water or fertilizer absorbed would be proportional to the actual need of the plant based on its dryness. However, in case of excess, the surplus is collected and reused for the next irrigation. This prevents nutrient and water leaching. (**Ferrarezi, R. S. *et al.* 2015).** Advances in technology has also provided plant breeding of drought-resistance crop species which contribute to reducing the vulnerability of an agricultural system, albeit site-specific management should be considered. **(Daryanto, S., Wang, L. and Jacinthe, P.-A., 2017)**

Despite all possible adjustments and modifications, a complete revolution are needed for some crops, such as rice. Its cultivation, indeed, is based on flooding that causes an increase in CH_4 emissions due to the anaerobic condition it is in. **(Sanz-Cobena *et al.*, 2017).** The most prominent new practice is dry-seeding: local experiments in northern Italy have shown its advantage in saving water in the early stages of crop growth and yields compatible with those obtained by continuous flooding. Notwithstanding, a complete conversion doesn't seem to be achievable as this method would require more water in the later stages of the season, when water accessibility may be less. Therefore, a balanced application of traditional and innovative farming methods may be more sustainable. **(Zampieri *et al.*, 2019)**

Besides the innovation, which is undoubtedly essential in the discussion about relationship between agriculture and sustainability and can strengthen the food system resilience, improve resource efficiency and secure social equity, the tradition should not be overlooked. Many scholars have considered their integration to better gear toward climate change challenges. Their combination in the agribusiness sector could lead to a real valorisation of typical and traditional agri-food products. Reaching climate-neutral economic model is, also, more attainable through more sustainable agriculture. In this regard, individual eating choices assume a central role in this conversion: companies could begin to pay more attention to taking care of the environment by proposing more sustainable alternatives in their production cycle in order to meet marketing requirements. Therefore, a revival of the Mediterranean diet, which values biodiversity, encourages the respect for seasonality and high consumption of plant-based foods at the expense of meat and animal-derived ones, and emphasizes conviviality, can reinforce the evolution of the food system, can be promptly helpful in mitigation of climate change and can strengthen community belonging. **(Capone *et al.*, 2021)** As estimated by Zhang and Chai, the recovery of the traditional Mediterranean diet could alone halve the GHG emissions currently derived from the modern lifestyle, which deals mainly with the Western prototype **(Zhang and Chai, 2022)**. Not to mention that greater adherence to original model also ensures positive effects on human health.

In conclusion, our findings innovatively show the crops and areas most affected by current and future climate change and related extreme events. Such information can promote greater awareness of the worrying climate effects that are hampering Italian farming activities and could shift individual diets away from adherence to the Mediterranean diet with primary effects on the national economy, society, culture and population health. We hope, therefore, to inspire further more localized studies on the most vulnerable areas that analyse sustainable water management strategies and to stress the urgency of prompt actions by governments to economically incentivize farmers to convert their agricultural systems to more sustainable ones and to disseminate to the population the Mediterranean dietary guidelines that guarantee human and environmental well-being.

BIBLIOGRAPHY

[1] Abar, L. *et al.* (2016) '*Blood concentrations of carotenoids and retinol and lung cancer risk: an update of the WCRF–AICR systematic review of published prospective studies'*, Cancer Medicine, 5(8), pp. 2069–2083;

[2] Abbass, K. *et al.* (2022) *'A review of the global climate change impacts, adaptation, and sustainable mitigation measures'*, Environmental Science and Pollution Research, 29(28), pp. 42539–42559. Available at: https://doi.org/10.1007/s11356-022-19718-6.

[3] Accetturo, A. and Alpino, M. (2023) *'Climate Change and Italian Agriculture: Evidence from Weather Shocks',* SSRN Electronic Journal [Preprint]. Available at: https://doi.org/10.2139/ssrn.4464128.

[4] Aguilera, E. *et al.* (2020) *'Agroecology for adaptation to climate change and resource depletion in the Mediterranean region. A review'*, Agricultural Systems, 181, p. 102809. Available at: https://doi.org/10.1016/j.agsy.2020.102809.

[5] Aiello, A., Adamo, M. and Canora, F. (2015*) 'Remote sensing and GIS to assess soil erosion with RUSLE3D and USPED at river basin scale in southern Italy',* CATENA, 131, pp. 174–185. Available at: https://doi.org/10.1016/j.catena.2015.04.003

[6] Ali, E., W. Cramer, J. Carnicer, E. Georgopoulou, N.J.M. Hilmi, G. Le Cozannet, and P. Lionello, (2022): *Cross-Chapter Paper 4: Mediterranean Region. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*.Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2233–2272, doi:10.1017/9781009325844.021.

[7] Amalo, L.F., Hidayat, R., and Haris (2017) '*Comparison between remote-sensing-based drought indices in East Java',* IOP Conference Series: Earth and Environmental Science, 54, p. 012009. Available at: https://doi.org/10.1088/1755-1315/54/1/012009.

[8] Amassaghrou, A. *et al.* (2023) *'Yield and related traits of three legume crops grown in olive-based agroforestry under an intense drought in the South Mediterranean'*, Saudi Journal of Biological Sciences, 30(4), p. 103597. Available at: https://doi.org/10.1016/j.sjbs.2023.103597

[9] Anderson, R., Bayer, P.E. and Edwards, D. (2020) *'Climate change and the need for agricultural adaptation'*, Current Opinion in Plant Biology, 56, pp. 197–202. Available at: https://doi.org/10.1016/j.pbi.2019.12.006.

[10] Aune, D. *et al*. (2016) *'Whole grain consumption and risk of cardiovascular disease, cancer, and all cause and cause specific mortality: systematic review and dose-response meta-analysis of prospective studies'*, BMJ, 353, p. i2716

[11] Autorità Bacino Distrettuale del Fiume Po (ADBPO), Bullettin of July 2022 Available at: https://www.adbpo.it/wp-content/uploads/2022/07/12_Bollettino_22luglio22_Osservatorio.pdf

[12] Bachmair, S. *et al.* (2018) *'How well do meteorological indicators represent agricultural and forest drought across Europe?',* Environmental Research Letters, 13(3), p. 034042. Available at: https://doi.org/10.1088/1748-9326/aaafda.

[13] Bach-Faig, A. *et al.* (2011) *'Mediterranean diet pyramid today. Science and cultural updates',* Public Health Nutrition, 14(12A), pp. 2274–2284. Available at: https://doi.org/10.1017/S1368980011002515.

[14] Baiamonte, G. *et al.* (2019) *'Durum wheat yield uncertainty under different tillage management practices and climatic conditions',* Soil and Tillage Research, 194, p. 104346. Available at: https://doi.org/10.1016/j.still.2019.104346.

[15] Baruth, B. *et al.* (2022) *JRC MARS Bulletin - Crop monitoring in Europe* - August 2022 - Vol. 30 No 8, JRC Publications Repository. Available at: https://doi.org/10.2760/31930.

[16] Beck, H.E. *et al*. (2018*) 'Present and future Köppen-Geiger climate classification maps at 1-km resolution'*, Scientific Data, 5(1), p. 180214. Available at: https://doi.org/10.1038/sdata.2018.214

[17] Bednar-Friedl, B., R. Biesbroek, D.N. Schmidt, et al. 2022: Europe. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1817–1927, doi:10.1017/9781009325844.015

[18] Belal, A.-A. *et al.* (2014) '*Drought risk assessment using remote sensing and GIS techniques', Arabian Journal of Geosciences*, 7(1), pp. 35–53. Available at: https://doi.org/10.1007/s12517-012-0707-2.

[19] Bento, V.A. *et al.* (2018) '*A climatological assessment of drought impact on vegetation health index'*, Agricultural and Forest Meteorology, 259, pp. 286–295. Available at: https://doi.org/10.1016/j.agrformet.2018.05.014.

[20] Bevacqua, D. *et al.* (2023) '*A climate-driven compartmental model for fungal diseases in fruit orchards: The impacts of climate change on a brown rot-peach system'*, Agricultural and Forest Meteorology, 332, p. 109293. Available at: https://doi.org/10.1016/j.agrformet.2022.109293

[21] Bhushan, A. *et al.* (2018) '*Adherence to Mediterranean diet and subjective cognitive function in men',* European Journal of Epidemiology, 33(2), pp. 223–234. Available at: https://doi.org/10.1007/s10654-017-0330-3.

[22] Bitok, E. and Sabaté, J. (2018) *'Nuts and Cardiovascular Disease'*, Progress in Cardiovascular Diseases, 61(1), pp. 33–37.)

[23] Bonaldo, D. *et al.* (2022) '*The summer 2022 drought: a taste of future climate for the Po valley (Italy)?*', Regional Environmental Change, 23(1), p. 1. Available at: https://doi.org/10.1007/s10113-022-02004-z

[24] Borrelli, P. *et al.* (2014) *'Modeling soil erosion and river sediment yield for an intermountain drainage basin of the Central Apennines, Italy'*, CATENA, 114, pp. 45–58. Available at: https://doi.org/10.1016/j.catena.2013.10.007

[25] Bourdeau-Goulet, S., Hassanzadeh, E., 2021. *Comparisons between CMIP5 and CMIP6 models: simulations of climate indices influencing food security, infrastructure resilience, and human health in Canada*. Earth's Future 9 (5). https://doi.org/ 10.1029/2021EF001995

[26] Bozzola, M. and Swanson, T. (2014) *'Policy implications of climate variability on agriculture: Water management in the Po river basin, Italy',* Environmental Science & Policy, 43, pp. 26–38. Available at: https://doi.org/10.1016/j.envsci.2013.12.002.

[27] Bozzola, M. et al. (2018) '*A Ricardian analysis of the impact of climate change on Italian agriculture'*, European Review of Agricultural Economics, 45(1), pp. 57–79. Available at: https://doi.org/10.1093/erae/jbx023.

[28] Brandolini, P. *et al.* (2018a) *'Response of Terraced Slopes to a Very Intense Rainfall Event and Relationships with Land Abandonment: A Case Study from Cinque Terre (Italy)*', Land Degradation & Development, 29(3), pp. 630–642. Available at: https://doi.org/10.1002/ldr.2672.

[29] Brandolini, P. *et al.* (2018b) '*Hillslope degradation in representative Italian areas: Just soil erosion risk or opportunity for development?*', Land Degradation & Development, 29(9), pp. 3050–3068. Available at: https://doi.org/10.1002/ldr.2999

[30] Bregaglio, S. *et al.* (2017) *'Identifying trends and associated uncertainties in potential rice production under climate change in Mediterranean areas*', Agricultural and Forest Meteorology, 237–238, pp. 219–232. Available at: https://doi.org/10.1016/j.agrformet.2017.02.015.

[31] Bucchignani, E. *et al.* (2016) '*High-resolution climate simulations with COSMO-CLM over Italy: performance evaluation and climate projections for the 21st century',* International Journal of Climatology, 36(2), pp. 735–756. Available at: https://doi.org/10.1002/joc.4379.

[32] Burlingame B, Dernini S. (2010) *Sustainable diets and biodiversity directions and solutions for policy, research and action.* Food and Agriculture Organization (FAO). Available from: https://www.fao.org/3/i3004e/i3004e00.htm

[33] Burlingame, B. *et al*. (2015) *Mediterranean food consumption patterns. Diet, environment, society, economy and health: White Paper*. Rome, Italy: FAO. Available at: https://www.fao.org/documents/card/es/c/9104aa92-4561-4375-abb2-2651260fdaca/

[34] Capolongo, D. *et al.* (2008) '*Spatial and temporal variations in soil erosion and deposition due to land-levelling in a semi-arid area of Basilicata (Southern Italy)*', Earth Surface Processes and Landforms, 33(3), pp. 364–379. Available at: https://doi.org/10.1002/esp.1560

[35] Capone, R. *et al.* (2021) *'Sustainability of Food Systems in the Mediterranean Region'*, New Medit, 20, pp. 131–143. Available at: https://doi.org/10.30682/nmsi21i.

[36] Caretta, M.A., A. Mukherji, M. Arfanuzzaman, *et al,* (2022): *Water. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 551–712, doi:10.1017/9781009325844.006.)

[37] Casolani, N. *et al.* (2020) '*Climate variability in agriculture and crop water requirement: Spatial analysis of Italian provinces'*, Journal of Cleaner Production, 262, p. 121331. Available at: https://doi.org/10.1016/j.jclepro.2020.121331

[38] CBRE, Agribusiness In Italy Report (2022). Available at: https://www.cbre.it/insights/reports/agribusiness-in-italy-report

[39] Chatzopoulos, T. *et al.* (2021) *'Potential impacts of concurrent and recurrent climate extremes on the global food system by 2030'*, Environmental Research Letters, 16(12), p. 124021. Available at: https://doi.org/10.1088/1748-9326/ac343b.)

[40] CoastAdapt, How to understand climate change scenarios (2017). Available at: https://www.coastadapt.com.au/how-to-pages/how-to-understand-climate-change-scenarios

[41] Coderoni, S. and Pagliacci, F. (2023) *'The impact of climate change on land productivity. A micro-level assessment for Italian farms',* Agricultural Systems, 205, p. 103565. Available at: https://doi.org/10.1016/j.agsy.2022.103565.

[42] Coldiretti, (2022) '*Al via la raccolta del riso italiano, -30% produzione'*, Il punto Coldiretti, 17 September. Available at: https://www.ilpuntocoldiretti.it/attualita/economia/al-via-la-raccolta-del-riso-italiano-30-produzione/;

[43] Convegno Nazionale sul Nocciolo, Giffoni V. P., ottobre Available at: http://www.agricoltura.regione.campania.it/pubblicazioni/pdf/atti_nocciolo.pdf

[44] Copernicus Climate, *European State of the Climate* (2022). Available at: https://climate.copernicus.eu/esotc/2022

[45] Copernicus Land Monitoring Service (2018). Available at: https://land.copernicus.eu/pan-european/corine-land-cover/clc2018

[46] Copernicus Land Monitoring Service (2018), *Technical Guidelines*. Available at: https://land.copernicus.eu/user-corner/technical-library/corine-land-cover-nomenclature-guidelines/html/

[47] CREA. (2023a), *Colture arboree e siccità/2: verso una nuova frutticoltura*. Available at: https://creafuturo.crea.gov.it/7685/

[48] CREA. (2023b) '*Moria del kiwi: colpa anche della siccità | CREA futuro'* Available at: https://creafuturo.crea.gov.it/7693/

[49] CREA. (2023c), *Colture arboree e siccità: verso una nuova olivicoltura* Available at: https://creafuturo.crea.gov.it/8376/

[50] d'Andrimont, R. et al. (2021a) '*From parcel to continental scale – A first European crop type map based on Sentinel-1 and LUCAS Copernicus in-situ observations',* Remote Sensing of Environment, 266, p. 112708. Available at: https://doi.org/10.1016/j.rse.2021.112708.

[51] d'Andrimont, R. et al. (2021b) *'LUCAS Copernicus 2018: Earth-observation-relevant in situ data on land cover and use throughout the European Union'*, Earth System Science Data, 13(3), pp. 1119–1133. Available at: https://doi.org/10.5194/essd-13-1119-2021.

[52] Daryanto, S., Wang, L. and Jacinthe, P.-A. (2017) 'Global synthesis of drought effects on cereal, legume, tuber and root crops production: A review', *Agricultural Water Management*, 179, pp. 18–33. Available at: https://doi.org/10.1016/j.agwat.2016.04.022.

[53] de Lorgeril, M. et al. (1994) '*Mediterranean alpha-linolenic acid-rich diet in secondary prevention of coronary heart disease',* The Lancet, 343(8911), pp. 1454–1459. Available at: https://doi.org/10.1016/S0140-6736(94)92580-1.

[54] Dernini, S. and Berry, E.M. (2015) '*Mediterranean Diet: From a Healthy Diet to a Sustainable Dietary Pattern', Frontiers in Nutrition,* 2. Available at: https://doi.org/10.3389/fnut.2015.00015.

[55] Dettori, M. et al. (2011) *'Using CERES-Wheat to simulate durum wheat production and phenology in Southern Sardinia, Italy'*, Field Crops Research, 120(1), pp. 179–188. Available at: https://doi.org/10.1016/j.fcr.2010.09.008.

[56] De Vita, P. et al. (2007) *'No-tillage and conventional tillage effects on durum wheat yield, grain quality and soil moisture content in southern Italy'*, Soil and Tillage Research, 92(1), pp. 69–78. Available at: https://doi.org/10.1016/j.still.2006.01.012

[57] Di Maso, M. et al. (2020) '*Adherence to the Mediterranean Diet and Mortality after Breast Cancer',* Nutrients, 12(12), p. E3649. Available at: https://doi.org/10.3390/nu12123649

[58] Edagricole, (2022) "*Mango e papaia danno soddisfazione anche al Sud Italia - Frutticoltura*. Rivista di Frutticoltura e Ortofloricoltura.URL https://rivistafrutticoltura.edagricole.it/colture/frutta-mediterranea/mango-papaia-sud-italia/

[59] Estruch R, Ros E, Salas-Salvadó J, Covas MI, Corell D, Arós F, *et al.* (2013*) Primary prevention of cardiovascular disease with a Mediterranean diet.* N Engl J Med 368:1279–90. doi:10.1056/NEJMoa1200303

[60] European Agriculture and Rural Development, (2023). *Short-term outlook* Available at: https://agriculture.ec.europa.eu/data-and-analysis/markets/outlook/short-term_en

[61] European Commission. (2022) *Directorate General for Agriculture and Rural Development. EU agricultural outlook for markets, income, and environment 2022-2032*. LU: Publications Office. Available at: https://data.europa.eu/doi/10.2762/29222

[62] European Commission. Joint Research Centre. (2022) *Drought in northern Italy March 2022: GDO analytical report*. LU: Publications Office. Available at: https://data.europa.eu/doi/10.2760/781876

[63] European Commission. Joint Research Centre. (2020a) *Global warming and drought impacts in the EU: JRC PESETA IV project:* Task 7. LU: Publications Office. Available at: https://data.europa.eu/doi/10.2760/597045

[64] European Commission- Joint Research Centre. (2020b*) Climate change impacts and adaptation in Europe: JRC PESETA IV final report*. LU: Publications Office. Available at: https://data.europa.eu/doi/10.2760/171121

[65] European Environment Agency, (2012) "*Water resources in Europe in the context of vulnerability"*. Available at: https://www.eea.europa.eu/publications/water-resources-and-vulnerability

[66] European Environment Agency (2019), *Climate change adaptation in the agriculture sector in Europe* Available at: https://www.eea.europa.eu/publications/cc-adaptation-agriculture

[67] Eurostat.(2019) *The fruit and vegetable sector in the EU - a statistical overview*. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=The_fruit_and_vegetable_sector_in_the_EU_-_a_statistical_overview

[68] Eurostat,(2022a) *Agriculture statistics at regional level*. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agriculture_statistics_at_regional_level

[69] Eurostat.(2022b) *Farms and farmland in the European Union* - statistics. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Farms_and_farmland_in_the_European_Union_-_statistics

[70] Eurostat. (2023a) *Agri-environmental indicator - cropping patterns*. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_cropping_patterns

[71] Eurostat. *Agri-environmental indicator - livestock patterns* (2023b). Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_livestock_patterns

[72] European Agri-Food Data Portal (2023) Available at: https://datam.jrc.ec.europa.eu/datam/mashup/EU_ESTIMATED_AGRICULTURAL_BALANCE_SHEETS/

[73] Faggian, P. (2021) *'Future Precipitation Scenarios over Italy',* Water, 13(10), p. 1335. Available at: https://doi.org/10.3390/w13101335.

[74] Ferrarezi, R.S. et al. (2015) *'Subirrigation: Historical Overview, Challenges, and Future Prospects'*, HortTechnology, 25(3), pp. 262–276. Available at: https://doi.org/10.21273/HORTTECH.25.3.262

[75] Fleskens, L. and Stroosnijder, L. (2007) '*Is soil erosion in olive groves as bad as often claimed?*', Geoderma, 141(3), pp. 260–271. Available at: https://doi.org/10.1016/j.geoderma.2007.06.009

[76] Food and Agriculture Organization, (2018). *"The future of Food and Agriculture: Alternative pathways to 2050 | Knowledge for policy*" Available at: https://knowledge4policy.ec.europa.eu/publication/future-food-agriculture-alternative-pathways-2050_en

[77] Gentile, A. (2022) '*Come la Xylella è arrivata in Puglia'*, Nature Italy [Preprint]. Available at: https://doi.org/10.1038/d43978-022-00009-0

[78] Gómez, J.A. *et al.* (1999) '*Effects of tillage method on soil physical properties, infiltration and yield in an olive orchard',* Soil and Tillage Research, 52(3), pp. 167–175. Available at: https://doi.org/10.1016/S0167-1987(99)00078-1.
[79] Gómez, J.A. *et al.* (2014) *'Olive Cultivation, its Impact on Soil Erosion and its Progression into Yield Impacts in Southern Spain in the Past as a Key to a Future of Increasing Climate Uncertainty'*, Agriculture, 4(2), pp. 170–198. Available at: https://doi.org/10.3390/agriculture4020170ò.
[80] Gratsea, M. *et al.* (2022) *'Assessing the long-term impact of climate change on olive crops and olive fly in Andalusia, Spain, through climate indices and return period analysis'*, Climate Services, 28, p. 100325. Available at: https://doi.org/10.1016/j.cliser.2022.100325
[81] Greven, M. *et al.* (2009) *'The effects of drought on the water use, fruit development and oil yield from young olive trees'*, Agricultural Water Management, 96(11), pp. 1525–1531. Available at: https://doi.org/10.1016/j.agwat.2009.06.002.
[82] Grimm, M. et al. (2003) *'Soil Erosion Risk in Italy: a revised USLE approach'*, European soil bureau - research report no. 11
[83] IPCC website https://www.ipcc.ch/about/history/
[84] IPCC (2012) "*Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation"* Available at: https://www.ipcc.ch/report/managing-the-risks-of-extreme-events-and-disasters-to-advance-climate-change-adaptation/
[85] ISMEA Tiziana Sarnari, (2022) *Report of olive oil productive estimation 2022/2023.* Available at: https://www.ismeamercati.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/12365
[86] ISMEA (2023a) *Seminativi - Cereali - News e analisi - La filiera del mais: struttura, criticità e impatto della PAC 2023-27,* Available at: https://www.ismeamercati.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/12522
[87] ISMEA (2023b) *Ortofrutta - Agrumi - Ultime dal settore - Tendenze Agrumi - Focus arance* Available at: https://www.ismeamercati.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/12513
[88] ISPRIA, (2011) *Publications on the socio-economic context*, Available at: https://www.isprambiente.gov.it/files/pubblicazioni/statoambiente/tematiche2011/II_Contesto_socio_economico_2011.pdf).
[89] ISPRIA, (2022a).*Bulletin on climate*, Available at: http://www.scia.isprambiente.it/wwwrootscia/Documentazione/BOLLETTINO_CLIMA_2022.pdf
[90] ISPRIA, (2022b*). Bulletin on climate*- Available at : https://www.adbpo.it/wp-content/uploads/2022/09/15_Bollettino_07settembre22_Osservatorio-2.pdf
[91] ISPRIA, (2022c). *Bulletin on climate*–Available at : https://www.adbpo.it/wp-content/uploads/2022/07/12_Bollettino_22luglio22_Osservatorio.pdf
[92] ISTAT, (2014). *Principal geostatistical dimensions and degree of urbanization of country.* Available at: https://www.istat.it/it/archivio/137001
[93] ISTAT, (2022a). *7° General census of agriculture: first results.*Available at: https://www.istat.it/it/files//2022/06/REPORT-CENSIAGRI_2021-def.pdf
[94] ISTAT - Istituto Nazionale di Statistica, (2022b). *Yield production factsheet*. Available at: http://dati.istat.it/Index.aspx?QueryId=33702#
[95] ISTAT, (2023) *Census of the population.* Available at: http://dati.istat.it/Index.aspx?QueryId=18460#
[96] Kastorini CM, Milionis HJ, Esposito K, Giugliano D, Goudevenos JA, Panagiotakos DB. (2011) *The effect of Mediterranean diet on metabolic syndrome and its components a meta-*

analysis of 50 studies and 534,906 individuals. J Am Coll Cardiol 57(11):1299–313. doi:10.1016/j.jacc.2010.09.073
[97] Keys, A. et al. (1986) *'The diet and 15-year death rate in the seven countries study'*, American Journal of Epidemiology, 124(6), pp. 903–915.
[98] Kottek, M., Grieser, J., Beck, C., Rudolf, B. & Rubel, F. (2006).*World map of the Köppen-Geiger climate classification updated.* Meteorologische Zeitschrift 15, 259–263
[99] Lăcătușu, C.-M. *et al.* (2019) '*The Mediterranean Diet: From an Environment-Driven Food Culture to an Emerging Medical Prescription'*, International Journal of Environmental Research and Public Health, 16(6), p. 942. Available at: https://doi.org/10.3390/ijerph16060942.
[100] Lesk C, Rowhani P, Ramankutty N (2016) *Influence of extreme weather disasters on global crop production.* Nature 529:84–87
[101] Lobell, D. B., Schlenker, W. & Costa-Roberts, J. (2011).*Climate trends and global crop production since 1980*. Science 333(6042), 616–620
[102] Masroor, M. *et al.* (2022) '*Analysing the relationship between drought and soil erosion using vegetation health index and RUSLE models in Godavari middle sub-basin, India'*, Geoscience Frontiers, 13(2), p. 101312. Available at: https://doi.org/10.1016/j.gsf.2021.101312
[103] Mazzocchi, A. *et al.* (2019) '*The Secrets of the Mediterranean Diet. Does [Only] Olive Oil Matter?'*, Nutrients, 11(12), p. 2941.)
[104] Mereu, V. *et al.* (2021) *'Modeling high-resolution climate change impacts on wheat and maize in Italy',* Climate Risk Management, 33, p. 100339. Available at: https://doi.org/10.1016/j.crm.2021.100339
[105] Ministry of Economy Development,(2022) *Agrifood | Italian Trade Agency*. Available at: https://www.ice.it/en/invest/sectors/agrifood
[106] Natural Resource Defence Council, (2021). *Soil Erosion*. Available at: https://www.nrdc.org/stories/soil-erosion-101
[107] OECD (2009) *OECD Rural Policy Reviews*, Italy 2009. Available at: https://doi.org/10.1787/9789264056237-en
[108] OECD (2018) *Agricultural Policy Monitoring and Evaluation 2018.* Available at: https://doi.org/10.1787/agr_pol-2018-en.).
[109] OECD and Food and Agriculture Organization of the United Nations (2022) *OECD-FAO Agricultural Outlook 2022-2031*. Available at: https://doi.org/10.1787/f1b0b29c-en
[110] Padulano, R. *et al.* (2023) *'Monthly to seasonal rainfall erosivity over Italy: Current assessment by empirical model and future projections by EURO-CORDEX ensemble',* CATENA, 223, p. 106943. Available at: https://doi.org/10.1016/j.catena.2023.106943.
[111] Panagos, P. *et al.* (2015) '*The new assessment of soil loss by water erosion in Europe'*, Environmental Science & Policy, 54, pp. 438–447. Available at: https://doi.org/10.1016/j.envsci.2015.08.012.
[112] Panagos, P. *et al.* (2020) '*A Soil Erosion Indicator for Supporting Agricultural, Environmental and Climate Policies in the European Union'*, Remote Sensing, 12(9), p. 1365. Available at: https://doi.org/10.3390/rs12091365.
[113] Panagos, P. *et al.* (2021) '*Projections of soil loss by water erosion in Europe by 2050'*, Environmental Science & Policy, 124, pp. 380–392. Available at: https://doi.org/10.1016/j.envsci.2021.07.012.
[114] Paoloni, M. (2022) *Siccità: il conto dei danni sale a 3 mld, sos raccolti, Coldiretti*. Available at: https://www.coldiretti.it/economia/siccita-il-conto-dei-danni-sale-a-3-mld-sos-raccolti

[115] Paoloni, M. (2023) *Giornata acqua: a rischio 1/3 del Made in Italy a tavola*, Il Punto Coldiretti. Available at: https://www.coldiretti.it/ambiente-e-sviluppo-sostenibile/giornata-acqua-a-rischio-1-3-del-made-in-italy-a-tavola

[116] Patsios, S.I., Kontogiannopoulos, K.N. and Banias, G.F. (2021) '*Environmental impact assessment in agri-production',* in Bio-Economy and Agri-production. Elsevier, pp. 83–116. Available at: https://doi.org/10.1016/B978-0-12-819774-5.00005-9.

[117] Peel, M. C., Finlayson, B. L. & McMahon, T. A. (2007). *Updated world map of the Köppen-Geiger climate classification.* Hydrology and Earth System Sciences 11, 1633–1644

[118] PNACC (Piano Nazionale di Adattamento ai Cambiamenti Climatici) (2023). *Metadata-Environmental Assessment - VAS - VIA - AIA* Available at: https://va.mite.gov.it/it-IT/Oggetti/MetadatoDocumento/771082

[119] Rossi, L. *et al.* (2023) '*A combined index to characterize agricultural drought in Italy at municipality scale'*, Journal of Hydrology: Regional Studies, 47, p. 101404. Available at: https://doi.org/10.1016/j.ejrh.2023.101404.

[120] Ruini, L.F. *et al.* (2015) *'Working toward Healthy and Sustainable Diets: The "Double Pyramid Model" Developed by the Barilla Center for Food and Nutrition to Raise Awareness about the Environmental and Nutritional Impact of Foods'*, Frontiers in Nutrition, 2, p. 9. Available at: https://doi.org/10.3389/fnut.2015.00009

[121] Salvati, L. *et al.* (2012) *'Climate Aridity under Changing Conditions and Implications for the Agricultural Sector: Italy as a Case Study',* Geography Journal, 2013, p. e923173. Available at: https://doi.org/10.1155/2013/923173.

[122] Sangiorgio, D. *et al. (*2020) *'Facing Climate Change: Application of Microbial Biostimulants to Mitigate Stress in Horticultural Crops'*, Agronomy, 10(6), p. 794. Available at: https://doi.org/10.3390/agronomy10060794.

[123] Santini, M. *et al.* (2022) '*Complex drought patterns robustly explain global yield loss for major crops'*, Scientific Reports, 12(1), p. 5792. Available at: https://doi.org/10.1038/s41598-022-09611-0.

[124] Sanz-Cobena, A. *et al.* (2017) '*Strategies for greenhouse gas emissions mitigation in Mediterranean agriculture: A review*', Agriculture, Ecosystems & Environment, 238, pp. 5–24. Available at: https://doi.org/10.1016/j.agee.2016.09.038.

[125] Serra-Majem, L. *et al.* (2019) '*Benefits of the Mediterranean diet: Epidemiological and molecular aspects'*, Molecular Aspects of Medicine, 67, pp. 1–55.)

[126] Shannon, O.M. *et al.* (2018) '*Nitric Oxide Boosting Effects of the Mediterranean Diet: A Potential Mechanism of Action'*, The Journals of Gerontology: Series A, 73(7), pp. 902–904.)

[127] Singh, B.K. *et al.* (2023) '*Climate change impacts on plant pathogens, food security and paths forward',* Nature Reviews Microbiology, pp. 1–17. Available at: https://doi.org/10.1038/s41579-023-00900-7.

[128] Sofi, F. *et al.* (2008) '*Adherence to Mediterranean diet and health status: meta-analysis'*, The BMJ, 337, p. a1344. Available at: https://doi.org/10.1136/bmj.a1344.

[129] Sofia, G., Zaccone, C. and Tarolli, P.T. (2023) *'Agricultural drought severity in NE Italy: Variability, bias, and future scenarios',* International Soil and Water Conservation Research [Preprint]. Available at: https://doi.org/10.1016/j.iswcr.2023.07.003.

[130] Sofo, A. *et al.* (2008) *'The olive tree: a paradigm for drought tolerance in Mediterranean climates'*, Hydrology and Earth System Sciences, 12(1), pp. 293–301. Available at: https://doi.org/10.5194/hess-12-293-2008

[131] Spano, D. *et al.* (2020) *Analisi del Rischio. I cambiamenti climatici in Italia.* Fondazione CMCC - Centro Euro-Mediterraneo sui Cambiamenti Climatici. Available at: https://doi.org/10.25424/CMCC/ANALISI_DEL_RISCHIO.

[132] Straffelini, E. *et al*. (2022) '*A high-resolution physical modelling approach to assess runoff and soil erosion in vineyards under different soil managements',* Soil and Tillage Research, 222, p. 105418. Available at: https://doi.org/10.1016/j.still.2022.105418.

[133] Straffelini, E. and Tarolli, P. (2023) '*Climate change-induced aridity is affecting agriculture in Northeast Italy',* Agricultural Systems, 208, p. 103647. Available at: https://doi.org/10.1016/j.agsy.2023.103647.

[134] Tanasijevic, L. *et al.* (2014) '*Impacts of climate change on olive crop evapotranspiration and irrigation requirements in the Mediterranean region'*, Agricultural Water Management, 144, pp. 54–68. Available at: https://doi.org/10.1016/j.agwat.2014.05.019

[135] Tarolli P, *et al.* (2023) *Saltwater intrusion and climate change impact on coastal agriculture*. PLOS Water 2(4): e0000121. https://doi.org/10.1371/journal.pwat.0000121

[136] Terranova, O. *et al.* (2009) '*Soil erosion risk scenarios in the Mediterranean environment using RUSLE and GIS: An application model for Calabria (southern Italy)*', Geomorphology, 112(3), pp. 228–245. Available at: https://doi.org/10.1016/j.geomorph.2009.06.009

[137] Tilman, D. and Clark, M. (2014) '*Global diets link environmental sustainability and human health'*, Nature, 515(7528), pp. 518–522. Available at: https://doi.org/10.1038/nature13959.

[138] Tomozeiu, R. *et al.* (2014) *'Statistically downscaled climate change projections of surface temperature over Northern Italy for the periods 2021–2050 and 2070–2099'*, Natural Hazards, 72(1), pp. 143–168. Available at: https://doi.org/10.1007/s11069-013-0552-y.--

[139] Toreti, A., Bavera, D., Acosta Navarro, J., *et al*. (2023) . *Drought in Europe March 2023*, Publications Office of the European Union, Luxembourg, doi:10.2760/998985, JRC133025

[140] UNESCO. 2010*. Representative list of the intangible cultural heritage of humanity*. Paris. Available from: http://www.unesco.org/culture/ich/RL/00884

[141] UNESCO.2011. *What is Intangible Cultural Heritage?*. Available at: https://ich.unesco.org/en/what-is-intangible-heritage-00003

[142] UNFCC (United Nation Framework Conventions on Climate Change) (1992) https://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf

[143] United Nations, (2021) *Special report on drought - Global assessment report on disaster risk reduction.* Available at: https://www.undrr.org/quick/13641

[144] United Nation, (2022). *What Is Climate Change?* Available at: https://www.un.org/en/climatechange/what-is-climate-change

[145] USDA-European Union Production (2014). Available at: https://ipad.fas.usda.gov/countrysummary/Default.aspx?id=E4

[146] Vallebona, C., Pellegrino, E., Frumento, P., Bonari, E., (2015). *Temporal trends in extreme rainfall intensity and erosivity in the Mediterranean region: a case study in southern Tuscany, Italy.* Clim. Change 128, 139–151. https://doi.org/10.1007/s10584-014-128

[147] Vallebona, C., Mantino, A. and Bonari, E. (2016) '*Exploring the potential of perennial crops in reducing soil erosion: A GIS-based scenario analysis in southern Tuscany, Italy'*, Applied Geography, 66, pp. 119–131. Available at: https://doi.org/10.1016/j.apgeog.2015.11.015.

[148] Van Passel, S., Massetti, E. and Mendelsohn, R. (2017) '*A Ricardian Analysis of the Impact of Climate Change on European Agriculture',* Environmental and Resource Economics, 67(4), pp. 725–760. Available at: https://doi.org/10.1007/s10640-016-0001-y.

[149] Vergni, L. and Todisco, F. (2011) '*Spatio-temporal variability of precipitation, temperature and agricultural drought indices in Central Italy'*, Agricultural and Forest Meteorology, 151(3), pp. 301–313. Available at: https://doi.org/10.1016/j.agrformet.2010.11.005

[150] Villani, L. *et al.* (2022) '*Drought risk assessment in Mediterranean agricultural watersheds: A case study in Central Italy*', Agricultural Water Management, 271, p. 107748. Available at: https://doi.org/10.1016/j.agwat.2022.107748

[151] Vitagliano, C. and Sebastiani, L. (2002) *'Physiological and biochemical remarks on environmental stress in olive (olea europaea l.)*', Acta Horticulturae, (586), pp. 435–440. Available at: https://doi.org/10.17660/ActaHortic.2002.586.89.

[152] Wacker, T.S. and Dresbøll, D.B. (2023) *'Checking the pulse: perspectives on grain legume production'*, Trends in Plant Science, 28(9), pp. 991–994. Available at: https://doi.org/10.1016/j.tplants.2023.06.004.

[153] Wang, J. *et al.* (2006) *'Response of Chickpea Yield to High Temperature Stress during Reproductive Developmen*t', Crop Science, 46(5), pp. 2171–2178. Available at: https://doi.org/10.2135/cropsci2006.02.0092

[154] Wikipedia, (2023*). "Geografia dell' Italia*" Available at: https://it.wikipedia.org/w/index.php?title=Geografia_dell%27Italia&oldid=133332257

[155] Willett, W. et al. (2019) *'Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems'*, The Lancet, 393(10170), pp. 447–492. Available at: https://doi.org/10.1016/S0140-6736(18)31788-4.

[156] Zampieri, M. *et al.* (2017) '*Wheat yield loss attributable to heat waves, drought and water excess at the global, national and subnational scales'*, Environmental Research Letters, 12(6), p. 064008. Available at: https://doi.org/10.1088/1748-9326/aa723b

[157] Zampieri, M. *et al.* (2019*) 'Adaptation and sustainability of water management for rice agriculture in temperate regions: The Italian case-study',* Land Degradation & Development, 30(17), pp. 2033–2047. Available at: https://doi.org/10.1002/ldr.3402

[158] Zampieri, M. *et al*. (2020) *'Climate resilience of the top ten wheat producers in the Mediterranean and the Middle East'*, Regional Environmental Change, 20(2), p. 41. Available at: https://doi.org/10.1007/s10113-020-01622-9.

[159] Zhang, J. and Chai, L. (2022) '*Trade-off between human health and environmental health in global diets',* Resources, Conservation and Recycling, 182, p. 106336. Available at: https://doi.org/10.1016/j.resconrec.2022.106336.