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Review

Assessing Climate Change Impacts on Irrigation Water Requirements under Mediterranean Conditions—A Review of the Methodological Approaches Focusing on Maize Crop

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Abstract: Climate change is a challenging fact influencing diverse sectors in society including the agricultural one, which is heavily dependent on natural resources and climate. In the Mediterranean region, climate change-related increases in air temperature, and in the frequency and intensity of extreme weather events, such as droughts, boost the pressure on the agricultural systems and affect crop yield potential. The growth of the world population implies that production needs to increase in a sustainable manner. Therefore, this study focuses on the maize crop due to its importance for food security and because it is a crop with significant water consumption that occupies a large worldwide area. In order to study climate change impacts on crop production, plant water requirements, and provide farmers guidelines helping them to adapt, it is necessary to simultaneously evaluate a large number of factors. For this reason, modelling tools are normally used to measure the future impact of climate change on crop yield by using historical and future climate data. This review focuses on climate change impacts on maize crop irrigation requirements and compares—by means of critical analysis—existing approaches that allow for the building a set of mitigation and adaptation measures throughout the study of climate.

Keywords: crop water productivity; irrigation requirements; mitigation and adaptation measures on agriculture; crop yield; modelling

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1. Introduction

Natural phenomena and human activities modify the global atmosphere composition, increasing greenhouse gas (GHGs) concentration [1]. Due to that fact, some changes occur in the average values of climatic elements, such as temperature and precipitation, leading to changes in climate. These changes lead to some impacts on agriculture affecting productivity, water resources, and nutritional quality, and induce fluctuation in food production, leading to variability in food availability, and, consequently in the prices [2]. Climate change (CC) is one of the biggest concerns for current agricultural and livestock systems. Agriculture, as the major sustainable source of food, is strongly affected by climate changes and weather extreme events such as changes in temperature, irregular rain patterns, and increases in the level of floods and droughts [3,4]. According to Anwar [5], agricultural systems are continuously responding to biophysical changes, such as pests and diseases, as well as market fluctuations and changes in agricultural policies, including subsidies, credit facilities, and incentives. Due to climate change, farmers will have to adapt to the coming environmental changes through, for instance, climate-smart agriculture [6], i.e., taking more effective care of the soil and its capacity to retain water, carbon, and nutrients. This farmers' adaptation is also essential due to the combination between climate change and the increase in the world's population. In this background, producing more food for more people, in a sustainable manner, while guaranteeing food security becomes paramount. In addition, combining climate change and the very significant upward trend in maize grain prices on international markets [7] shows the need to increase the production of this crop.

This paper presents a review of climate change impacts on the agricultural sector, with a focus on maize crop irrigation water requirements, as well as mitigation strategies, including the reduction in, or removal of, current and future emissions, and adaptation measures to build resilience against emerging and long-term climate impacts.

This literature review was carried out according to the following criteria (Figure 1): (i) were selected Scopus/Elsevier/Wiley peer-reviewed articles that are listed in Scholar Google, Web of Science and in Science Direct; (ii) the articles cited focus mainly on the impacts of climate change on maize crop namely on the irrigation water requirements; (iii) articles for different regions were selected but most of them focus on the Mediterranean region.

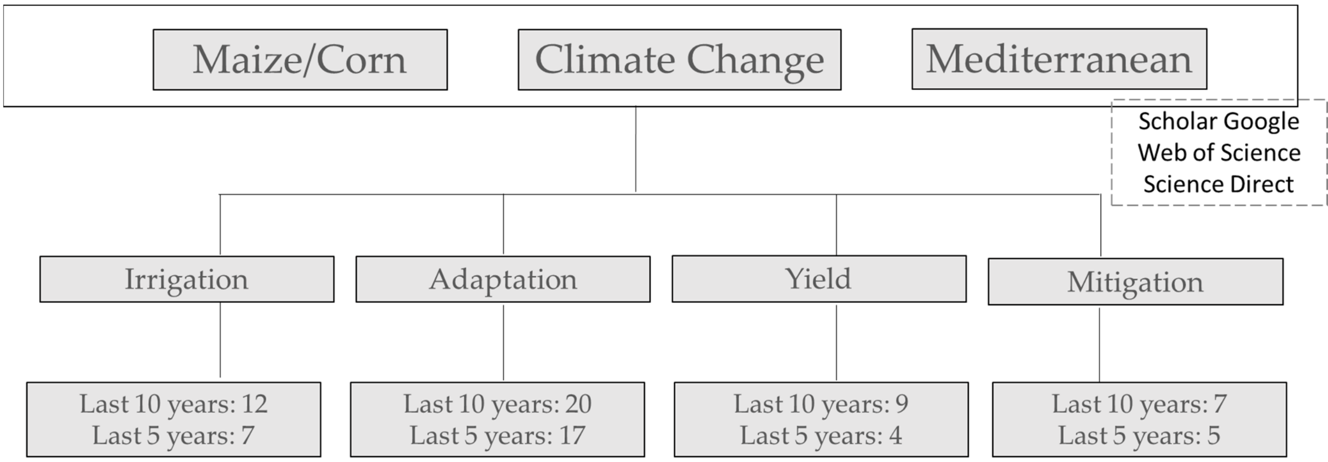

Figure 1. The keywords used in the present study to select peer-reviewed papers, and the number of the selected papers according to the selection criteria.

The present study aims to present different approaches for studying the impact of climate change on irrigation water requirements of maize, which, depending on assumptions made, can lead to varied results.

2. Climate Changes

The increase in the average air temperature has been seen over the years due to the greenhouse effect. This is caused by greenhouse gases that accumulate in the Earth's atmosphere, leading to increased concentration over time. Examples of GHGs are water vapour (H_2O), methane (CH_4), carbon dioxide (CO_2), ozone (O_3), nitrous oxide (N_2O), and chlorofluorocarbons (CFCs) among others [8]. The concentration of GHGs such as CH_4, CO_2, and N_2O has increased by 150%, 40%, and 20%, respectively, since 1750 [8]. According to Lal [9], the agriculture sector contributes to GHGs emissions directly (by developing activities such as livestock, irrigation, grain drying, fertilizer, and pesticides) and indirectly (via soil erosion, land conversion, and biomass burning). According to IPCC [10], the global surface temperature increase by the end of the 21st century is expected to exceed 1.5 °C relative to the 1850–1900 period for most scenarios and is likely to exceed 2.0 °C for many scenarios, making it necessary to intensify measures of mitigation and adaptation to CC impacts. At the global scale, the precipitation will increase with the increases in the global mean surface temperature and could increase by 1–3% $°C^{-1}$; however, there will be significant spatial variation in these changes [11].

To obtain projections of the future climate, consistent from a physical point of view, models of the Earth's climate system are built [10,12]. Thus, the study of CC impacts can be carried out using climate models that simulate future climate scenarios based on emission scenarios [10].

Climate models can be classified into two groups: General Circulation Models (GCM) and Regional Climate Models (RCM), depending on the spatial resolution used and the size of the area considered for simulation.

2.1. General Circulation Models (GCM)

GCM are mathematical representations of the climate system that are developed from equations representing the physical processes that occur in the atmosphere and oceans, and their interactions with the lithosphere, biosphere, and cryosphere. The equations are discretized in space and time through a three-dimensional grid that covers the entire globe, typically having a horizontal resolution of between 250 and 600 km [13]. For each model grid cell, the values of meteorological variables (e.g., temperature, pressure, etc.) are determined by resolving equations describing the conservation of mass, energy, and linear momentum [12,14]. The most commonly used climate models are the general circulation models coupled to the ocean atmosphere and are currently the best way to simulate climate change scenarios (CCS) [10].

2.2. Regional Climate Models (RCM)

RCM models simulate the climate for limited regions of the Earth's surface with a spatial resolution that typically varies between a few kilometers to 50 km [15]. RCM models are complementary to global climate analyses or simulations, or to study climate processes in more detail than global models allow for [16], the boundary conditions of these models are generated by the GCM models [12,14,17]. Miranda [12] reports that regional climate models (RCMs) are more advantageous than statistical regionalization techniques. These models are currently becoming the main way to carry out CC impact studies. However, these models still have important sources of uncertainty. Their spatial resolution does not allow for, for instance, explicitly representing cloud formation processes and other small-scale processes, which continue to have to be parameterized [18]. Parameterizations of precipitation-related processes still need to be improved and can be a source of errors for regional models, as is the case for GCM models [12].

Due to their complexity and future unawareness, these models have associated uncertainty since it is difficult to model the climate system. Uncertainties stand out at various levels, particularly at the level (i) of climate base data due to the small number of weather stations and unequal distribution over the globe, (ii) knowledge of the physical and chemical processes of the climate system, and (iii) the simplifications necessary to simulate a system as complex as the climate system through mathematical models [19,20].

Added to this is the uncertainty of future emission scenarios, which depend on possible future economic development scenarios (Section 5).

2.3. Emission Scenarios

The history of IPCC assessment reports covers several generations of emissions scenarios [21]. These include the "1990 IPCC First Scientific Assessment" (SA90), the "1992 IPCC Scenarios" (IS92) [22], and the 2000 "Special Report on Emissions Scenarios" (SRES) [23]. SRES contemplates four possible scenarios: A1, A2, B1, and B2. In these scenarios, with A and B denoting an economic and environmental emphasis, respectively, 1 and 2 represent a global and regional focus, respectively [24]. IPCC also reports more recently developed scenarios, i.e., the "Representative Concentration Pathways" (RCPs) [25] and the "Shared Socioeconomic Pathways" [26,27].

In contrast to the SRES scenarios that include only the forcing by GHGs and aerosol from artificial climate change factors [28], RCPs (Table 1) are characterized by the increase in radiation expressed in W m^{-2}, a set of greenhouse gas concentration and emissions pathways designed to support research on the impacts of, and potential policy responses to climate change [25]. The first scenario, RCP2.6, constitutes a rigorous mitigation scenario with a peak radiative forcing of around 3 W m^{-2}. RCP4.5 and RCP6.0 are intermediate scenarios that indicate a medium forcing level, where society controls the increase in GHGs emissions (with peaks of radiative forcing of around 4.5 and 6 W m^{-2}). Finally, RCP8.5 represents a rising radiative forcing pathway leading to 8.5 W m^{-2} until the end of the 21st century. RCP8.5 is a so-called "baseline" scenario that does not include any specific climate mitigation target [29]. The RCP scenarios commonly used in the study of climate change impacts are RCP4.5 and RCP8.5.

Table 1. Future climate change projections. Source: IPCC, 2014.

		2046–2065		**2081–2100**	
Temperature increase compared to the 1986–2005 period (°C)	Scenario	Mean	Probable variation	Mean	Probable variation
	RCP2.6	1	0.4 to 1.6	1	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2	1.4 to 2.6	3.7	2.6 to 4.8

3. Impacts on Agriculture

Climate change is a major challenge to global food security, as it threatens the agricultural sector's ability to produce adequate food for the growing population while also being environmentally sustainable [30]. Agriculture is a very climate-dependent economic activity, so efforts to propose CC adaptation measures need to be stepped up. The increase in air temperature caused by GHGs has a huge impact on the pace of soil salinity development [31,32] and the crop cycle, namely phenology, productivity, and water requirements [33–37]. This complex scenario requires the urgent implementation of sustainable measures, which are capable of improving crop yield and quality [38,39] fostering the robustness and resilience of cropping systems [40].

3.1. Soil

The rise in atmospheric GHGs concentrations and the subsequent increase in air temperatures, together with extreme events of rainfall, are predicted to have a huge impact on soil erosion, declining rangeland quality (mainly organic matter content), and salinization [32,41]. In particular, in the Mediterranean region, precipitation tends to decrease, increasing the concentration of salts in the soil (due to reducing soil drainage). This accumulation of salts can result in reduced plant growth, reduced yields, and in severe cases, crop failure. Salinity limits water uptake by plants by reducing the osmotic potential, making it more difficult for the plant to extract water [31]. On the other hand, in Mediterranean regions, this precipitation will tend to be more concentrated in winter, increasing flooding episodes and, consequently, soil erosion.

3.2. Phenology and Productivity

3.2.1. Temperature

Air temperature affects the development and phenology of crops. There are three photosynthetic pathways: C3, C4 and crassulacean acid metabolism (CAM). In C3 plants (which include cotton, rice, wheat, barley, soybeans, sunflower, potatoes, and legumes), the first product of photosynthesis is a three-carbon molecule. In C4 photosynthesis (such as maize, sorghum, sugarcane, and millet) plants, the initial photosynthetic product is a four-carbon molecule [42]. For the average air temperature increase, C4 cultures are more tolerant than C3 crops [43]. C3 crops, in the face of the increase in temperature, have an increase in photorespiration, resulting in a decrease in the net photosynthetic rate. More-over, it is important to note that there are biological limits associated with maximum temperatures; as a result, there are threshold values from which there is no accumulation of growing degree-day (GDD) [43,44].

The increase in the average air temperature accelerates crop phenological development rates and shortens the lengths of the crop growing stages, along with intensified transpiration rates, compared to the reference period. However, the impacts on the phenology of the crop (shortening of the cycle) should not be confused with the alteration of the growing season (with suitable temperatures), which will tend to increase at higher latitude—an earlier spring allows for taking advantage of a longer growing season [45,46]. Thus, the higher the average air temperature, the shorter the cycle and, consequently, the lower its productivity (since when temperatures are high, the metabolic activity of plants increases, reducing their yield) [47]. Hussain and Bangash [48] report that for the maize crop, a 1 °C increase in mean temperature could reduce yield by around 7%, in the Northern irrigated plain regions in Pujab, India. These studies prove that maize yields normally decrease with increasing temperature due to the shorter phenological phases; according to Maitah [49], there is a low negative correlation between grain maize yield (C4) and the average temperature. A study developed by Lizaso [50] shows that maize grain yield is reduced under heat waves mainly via pollen viability that in turn determines kernel number, although a smaller but significant effect of the female component has been detected. This occurs due to the fact that the cell division in the grain endosperm decreases above 35 °C and 30 °C, respectively [51].

For annual crops, the shortening of the cycle and the anticipating of sowing dates (e.g., for maize) can vary between −30 and −10 days, depending on the region [45,52], reducing the crop exposure to periods of excessive temperatures and, consequently, the consumption of water intended for irrigation [33]. For permanent crops, the number of chill hours plays a key role when it comes to breaking dormancy. Therefore, under CCS, where the increase in temperature is predominant, it will be more difficult to meet the chilling requirements of these crops (e.g., olives require a certain period of low temperatures for normal flowering [53]), which can lead to increased crop cycle duration and consequently, higher irrigation requirements.

It is predicted that the spring-summer season will have higher air temperatures, which would be beneficial for crop production in the Nordic countries where the length of the growing season is currently a limiting factor [54,55]. Thus, it would probably be required to move some crop production into other areas with lower temperatures [56] because production conditions are enhanced. Accordingly, the northern locations can be considered winners of CC [57]. Other indirect effects of temperature rise include increased frequency of heatwaves and the impacts on pests, weeds, and plant diseases, as depicted in [58], which compromise food security.

3.2.2. Carbon Dioxide

The main effects of elevated CO_2 concentration ([CO_2]) on plants include a reduction in transpiration and stomatal conductance, improved water and light-use efficiency, and thus an increase in photosynthetic rate [59,60]. Due to its fertilizer effects on photosynthesis, the increase in [CO_2] leads to an increase in productivity, and it is more relevant in C3 plants (with an increase of 10 to 20%) than in C4 plants (with an increase of 0 to 10%) [54,61]. This occurs because C3 plants are offered a higher quantity of CO_2 in relation to reference conditions, C4 plants reach their limit of CO_2 absorption faster. As a C4 crop, maize might have less advantage in photosynthetic accumulation for final biomass production than a C3 crop under elevated CO_2 conditions. However, the impact of [CO_2] on plant production also depends on external factors, such as water and nutrient availability, or the presence of pests, diseases, and weeds, that affect the duration of the cycle and the efficiency of the photosynthetic rate.

3.3. Water Requirements

In the context of CC in the Mediterranean region, precipitation will tend to decrease (with fewer events but with greater intensity), especially in the spring. Plant transpiration and soil evaporation increase with increasing temperatures. Thus, the balance between the water received by plants through precipitation and that lost by evapotranspiration (ET) will result in the variation of water storage in the soil [62], which in turn leads to increased pressure on water resources [63,64], mainly in regions already water-stressed [2,63,65]. In regions with more moderate climate conditions, and without a marked dry period during summer, the effects of climate on crops are not so straightforward, as referred by Maitah et al. [49] in a study developed in the Czech Republic. These authors mention that the effect of precipitation might be either negative or positive on maize crops. A negative correlation occurs because of the intensified nitrogen leaching by the excessive precipitation, and a positive correlation may occur if precipitation reduces the existing water stress.

According to Lickley and Solomon [66], a drying tendency is emerging in Southern and Northern Africa, parts of Latin America, Australia, and Southern Europe. Furthermore, the GCM models predict significant drying for these regions as well as for the southern parts of North America. Giorgi [67] refers to the Mediterranean region as a "Hot-Spot" in future CC projections. Thus, in Mediterranean countries, annual crop yields such as cereals are limited by heat stress, water scarcity, and short-grain filling duration. Therefore, permanent crops such as olives, grapevine, and citrus are gaining importance in this region.

The impact of CC on crop water requirements depends on the methodology adopted in the evaluation (Figure 2). There are two main approaches: (i) Crop focus—adjusting the crop cycle, CO_2 fertilizer effect on crop productivity, and stomatal conductance effect on ET are also considered, or (ii) Growing season period focus—evaluating the effects of higher climatic demands considering the maintenance of the current growing season dates (constant phenological dates). In the first approach (i), irrigation requirements decrease due to earlier maturity dates and stomatal closure caused by [CO_2] increase. Gabaldón-Leal et al. [68], for example, present a study for maize where a decrease of up to 25% in irrigation water requirements and an increase in irrigation water productivity of up to 22% were found [33]. However, for the second approach (ii), irrigation requirements generally increase as suggested by studies developed for maize crops [33,47,69–71]. According to Yetik et al. [72], in Mediterranean conditions, irrigation water requirements will increase 7.4% on average, when compared to the 1961–1990 period. In addition, according to Dono et al. [73], irrigation requirements will increase around 11.3% for the business-as-usual scenario.

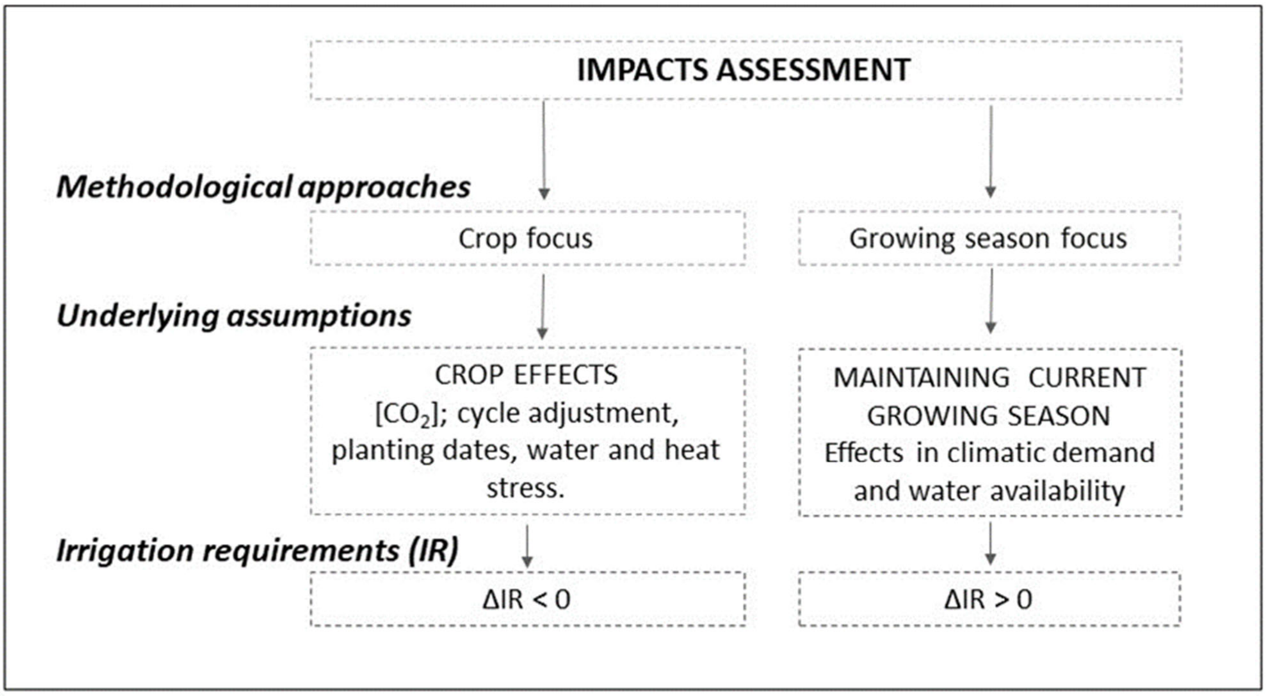

Figure 2. The most common methodological approaches to obtain CC impacts on irrigation requirements.

Table 2 presents some values for the proposed approaches. However, several authors [35,36,74] have already found that the increase in irrigation requirements is linked to the type of adaptation measure adopted and therefore the increases in net irrigation requirements may be more or less significant depending on the perspective of the farmer and the crop concerned. Therefore, long-term planning of agricultural systems should address climate change to ensure that farmers can respond efficiently and sustainably.

Table 2. Variation of irrigation water requirements in the context of CC.

	Approaches	Variation (%)
Impacts	Crop focus	−25% [68]
	Growing season period focus	+2-14% [47]

Therefore, the first approach leads to a decrease in irrigation requirements that could be further accentuated according to the adaptation measures chosen. In contrast, the second approach results in an increase in irrigation requirements, which, in turn, is in line with the projected evolution towards a hotter and drier climate. Therefore, both should be considered due to the fact that the approaches described previously provide complementary results regarding CC impacts evaluation; defining the lower and upper limits of variation in irrigation needs and, when combined, allow us to support more crop-focused adaptation measures and irrigation management throughout the growing season period.

3.4. Water Use Efficiency

Climate change and increasing population do impose additional pressure on resources—namely on water resources and food production [75,76]. Hemathilake et al. [77] reported that the yields of major grain crops roughly increased by only 1% globally in a year, which is much lower than the world's population growth rate. In this context, global maize yield demands in the world could increase by 66% in 2050 compared to current maize yields [78]. Thus, it is necessary to increase production in order to supply the growing population's needs. However, the yield losses could be controlled by an adequate irrigation management [79].

In this regard, FAO [80] estimates a more than 50% increase in irrigated food production by 2050, which will require a 10% increase in water used for agriculture, provided water productivity improves under sustainable agriculture. In this context, water use efficiency (WUE) should be one of the main aspects to be considered when adaptation measures are defined.

WUE translates the relationship between water use and plant growth and is defined as the amount of biomass or grain produced per unit of water used by a plant [75]. This parameter is limited by many factors such as (i) CO_2 concentration [81], (ii) water deficit stress and heat waves. Hatfield et al. [75] report that (i) at the leaf level, increasing CO_2 concentration increases WUE until the leaf is exposed to temperatures exceeding the optimum for growth—heat waves—and then, WUE begins to decrease. However, this event is more prominent in C3 than in C4 crops; (ii) WUE increases under water-deficit stressed conditions due to the lower reduction in net photosynthesis. Thus, understanding the mechanisms that can improve WUE and result in significant water savings and higher yields is therefore essential.

On the other hand, WUE is also dependent on the irrigation system applied. In most maize-producing regions of the world, the most common method for the irrigation is surface irrigation systems, mainly furrow irrigation, which have low-efficiency values. Therefore, replacing irrigation systems for sprinkler or drip irrigation could be a measure that increases WUE [82].

4. Impact Assessment

To assess the impacts of CC in agriculture, it is generally necessary to follow a methodology comprising a series of steps, to obtain reliable CC projections, which are presented in Figure 3.

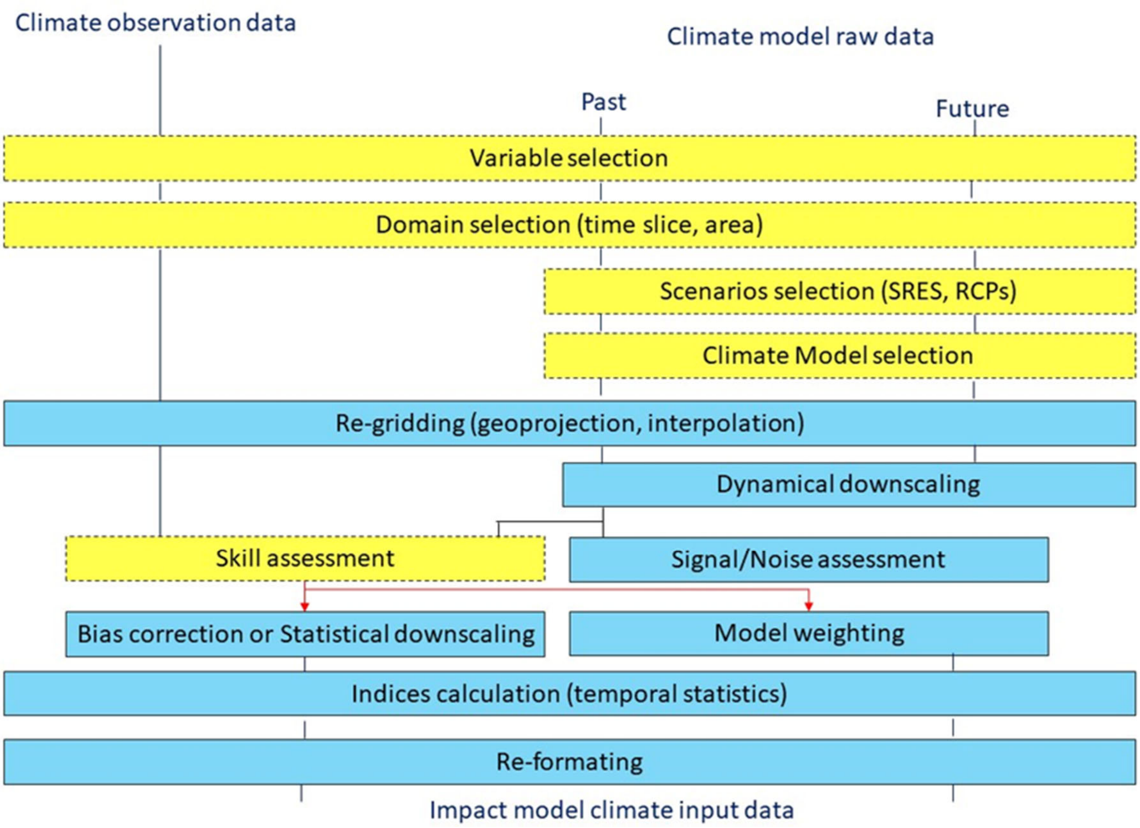

Figure 3. Steps required to assess CC impacts (adapted IS-ENES, 2019). Legend. Yellow boxes—crucial steps; blue boxes—optional steps.

4.1. Build Future CCS

To build the future CCS, information from weather stations for the reference period considered, usually 1971–2000 [10,36], must be collected and, these values, with the anomalies for each CCS, when considering a bias correction methodology, should be affected.

One common approach for the construction of future climate series is to perform a bias correction, which can be carried out by using the Delta Change method (DCM) [83]. The DCM is the method suggested to generate future climatic series because DCM is a method that allows for maintaining temperature variance and precipitation variation coefficient and not changing the number of precipitation days, thus upholding the current climate variability [84]. The monthly correction factors of the deviations used in the DCM take the form of multiplicative factors for precipitation and additives for the other climatic variables (such as temperature).

To produce air temperature correction series two kinds of data are necessary: i) the temperature observed in the reference period for the region under study and ii) the anomaly that corresponds to the difference between the temperature simulated by the model relative to the CCS and the temperature simulated by the model for the reference period. The disturbance of the temperature series is performed by adding the observed temperature to the anomalies, as presented by Lenderink [84] and Maraun [85]. The same authors also propose constructing future precipitation series with three types of data: (i) precipitation observed in the reference period for the region under study; (ii) precipitation from RCM scenarios, that correspond to average monthly precipitation simulated by the RCM model related to the CCS considered, and (iii) precipitation from RCM control, that corresponds to average monthly precipitation simulated by the RCM model for the reference period. In the case of precipitation, the future series is obtained through multiplicative factors, so that the number of days with rain is maintained in a given year. Thus, the future precipitation series are constructed through multiplicative factors between precipitation observed and a ratio between precipitation RCM scenarios and precipitation RCM control.

4.2. Climate Change Impacts Assessments Methodologies in Agriculture

The CC impact assessment studies can be carried out using several approaches, with the following being the most common: (i) deterministic models, (ii) temporal or spatial analogies, and (iii) a statistical approach:

(i). Soil water balance (SWB) and crop growth models are commonly used. A schematic representation of the modeling approach is presented in Figure 4. Examples of SWB models include: ISAREG [86], SWAT [87], HYPE [88], HEC-HMS [89], HSPF [90], SWIM [91] and SIMDualKc [92]. Dynamic crop growth models, such as AquaCrop [93,94], STICS [95]; AdaptaOlive [34], and WEAP-PGM [96], simulate crop responses to management practices (e.g., irrigation) and soil properties (e.g., depth, texture), as well as crop physiological responses to atmospheric conditions (e.g., precipitation, temperature, and carbon dioxide) [47];

(ii). The temporal analogy consists of referring to an earlier period as an image of a future CCS to respond to climatic variability. For example, studying the behavior of a crop in a particularly hot year as an indicator of the impact of future CC. The spatial analogy involves conducting research in one region and identifying parallels to how another region might be affected by climate change [97]. However, the characteristics of the chosen region may not be the same as those of the area under study, namely referring to the latitude (solar radiation);

(iii). Some functions based on multiple regression analysis [98,99] allow for the estimation of yields. These types of studies allow us to define a set of adaptation measures and to evaluate them by simulating the crop behavior for different CCS and management practices, in order to assess the most appropriate to reduce the negative impacts of CC on crop yield [33,74,100].

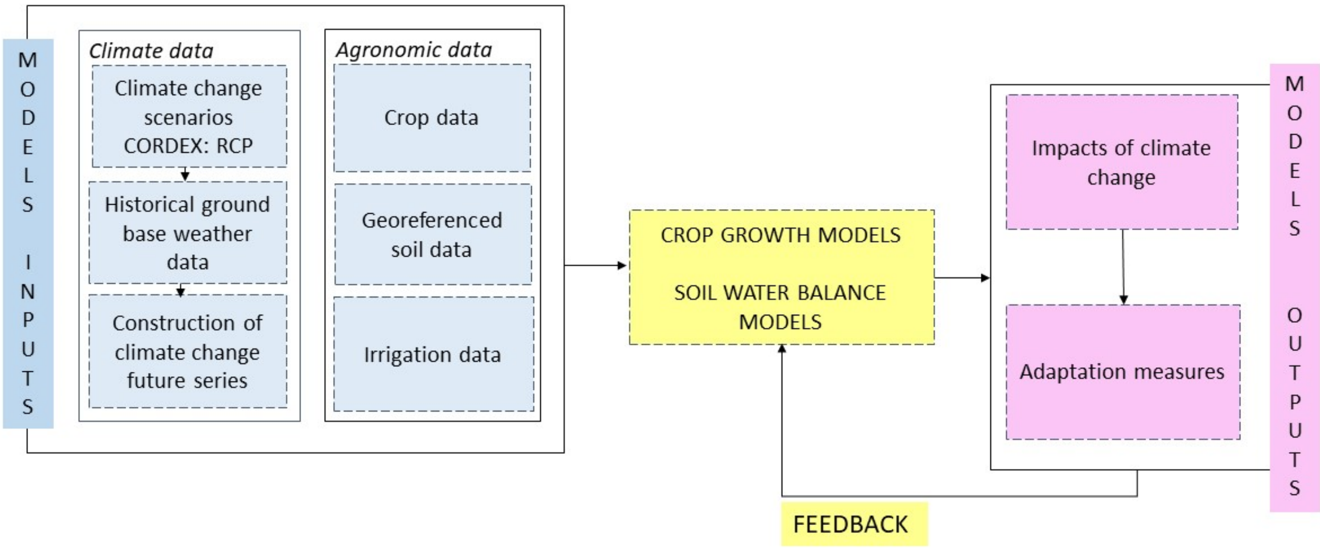

Figure 4. Schematic representation of the most common conceptual approaches applied to assess the impacts of climate change on Agriculture using crop growth and SWB models.

The commonly performed approach for maize crop is that of deterministic models as presented in studies by the following authors: Gabaldón-Leal et al. [68] in Andalusia region; Gabaldón-Leal et al. [44] for maize yield under heat stress conditions; Yang et al. [47] for maize yield in Portugal; Baum et al. [101] for different maize planting dates in Central US; Uretra et al. [102] for maize yield in Mexico; Amnuaylojaroen et al. [103] for maize production in Northern Thailand.

5. Uncertainties

As mentioned above, model simulation is an effective way to study the effects of CC on agriculture, as it allows for projections into the future. Although it is difficult to foresee future CC evolution and eliminate uncertainties in assessing its effects. Thus, the uncertainty can be minimized through greater awareness of sources of uncertainty and greater efforts to develop more sophisticated assessment tools [20].

Uncertainties have two different backgrounds. On the hand, the use of RCP scenarios inputs uncertainties because they depend on economic development scenarios. This occurs due to a high level of uncertainty that exists relative to the evolution of future anthropogenic GHG emissions, in the conversion of these emissions into future concentrations of GHG in the atmosphere, and in the corresponding radiative forcing [10,19,104]. On the other hand, there is also uncertainty associated with crop modelling because the models correspond to simplifications of very complex systems. As Kamali et al. [100] note, at the crop level, uncertainties can be verified for the (i) CO_2 effect on the evapotranspiration; (ii) the effect on the crop cycle; (iii) varieties; (iv) sowing dates and (v) irrigation systems, for example.

6. Mitigation and Adaptation Measures

As climate change has been felt in agricultural production systems, adaptation and mitigation measures need to be developed to adjust crop requirements to the new climate reality, reducing the risks of CC [10,105]. Thus, if policy makers and farmers develop adequate adaptations plans, it is possible for the agriculture sector to withstand changes in temperature and precipitation and maybe take advantage of CC [106]. However, as already mentioned above, the high level of uncertainty associated with CC and emission scenarios, and the economic effects on the crop production systems, makes it difficult to define these measures.

Mitigation strategies can prevent the impacts caused by CC, and improve the effectiveness of adaptive, transformative, and coping strategies [107]. According to Maione et al. [108] and Meissner et al. [109], some mitigation options enable economic gains while simultaneously contributing to climate change mitigation or adaptation (win-win policy options) and can be adopted in a short period. Nevertheless, there are also mitigation options that may provide benefits to one aspect, while worsening the situation in the other (win-lose policy options). Mitigation measures involve reducing GHGs emissions in agriculture, such as reducing carbon intensity (e.g., by energy efficiency or renewable energy), optimizing nutrient use (e.g., precise dosing and timing of fertilizers, substituting synthetic fertilizers by organic fertilizers), or reducing CH_4 emissions by manure digestion [110–112].

According to Iglesias et al. [62], Pathak et al. [113], Dubey et al. [114] and Kogo et al. [30], the common farm-level adaptations strategies to buffer against the impacts of climate change and enhance sustainability are, for example:

i. Crop management practices such as the use of diversified crop cultivars, scheduling of planting dates to spread risk and mitigation against food shortages in case of crop failure, planting of early maturing crops during short rainy seasons, planting of drought-tolerant cultivars, practice crop rotation and use of low planting densities during the dry season [98,115–117];
ii. Adaptation of integral system approaches to improve WUE and water productivity in crops, e.g., precision farming and digitalization, through more efficient soil and irrigation management, the adoption of some water conservation techniques such as regulated deficit irrigation, partial root drying, and supplemental irrigation [34,49,75,118–122] and, for instance, the use of pivot in order to create a cooling effect during heat waves;
iii. Conservation agriculture practices such as on-farm rainwater harvesting for irrigation, soil and water conservation through land contouring and terracing, mulching, conservation tillage practices, and integrated soil fertility management [123];
iv. The use of natural plant biostimulants has been also proposed to improve plant resistance to abiotic environmental stresses [40,121];
v. Adoption of soil conservation measures to conserve soil moisture and prevent conditions, such as salinity [124];
vi. Invest in farmer education to adapt to the new reality and to develop systematic farming strategies [125].

The efficiency of each measure is strongly governed by the local specificities and regional-to-local CC signals. Therefore, the responses proposed need to be implemented at regional/local scales, particularly in the most affected regions, in which the Mediterranean Region is included [51,67].

7. Concluding Remarks

In this manuscript, a review of methodological approaches to evaluate the climate change impacts on maize irrigation requirements under Mediterranean conditions has been presented. The review has been developed around the main effects of CC on the maize crop and in the diverse approaches to evaluate the impacts of CC on agriculture, and the respective adaptation measures. With the aim of feeding more people, while maintaining food security, with reduced resources availability (water, soil and energy) the future research will thus focus on increasing the efficient use of water and developing mitigation and adaptation measures to improve agricultural production under climate change conditions. As a final consideration, the issue of uncertainty in its different dimensions should be explicitly considered in studies of the impacts of CC on agriculture because contradictory results may be obtained depending on the scenarios and approaches considered.

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References

1. Malhi, G.S.; Kaur, M.; Kaushik, P. Impact of climate change on agriculture and its mitigation strategies: A review. *Sustainability* **2021**, *13*, 1318. https://doi.org/10.3390/su13031318.
2. Godde, C.M.; Mason-D'Croz, D.; Mayberry, D.E.; Thornton, P.K.; Herrero, M. Impacts of climate change on the livestock food supply chain; a review of the evidence. *Glob. Food Secur.* **2021**, *28*, 100488. https://doi.org/10.1016/j.gfs.2020.100488.
3. Fawzy, S.; Osman, A.I.; Doran, J.; Rooney, D.W. Strategies for mitigation of climate change: A review. *Environ. Chem. Lett.* **2020**, *18*, 2069–2094. https://doi.org/10.1007/s10311-020-01059-w.
4. Markou, M.; Moraiti, C.A.; Stylianou, A.; Papadavid, G. Addressing climate change impacts on agriculture: Adaptation measures for six crops in Cyprus. *Atmosphere* **2020**, *11*, 483. https://doi.org/10.3390/atmos11050483.
5. Anwar, M.R.; Liu, D.L.; Macadam, I.; Kelly, G. Adapting agriculture to climate change: A review. *Theor. Appl. Climatol.* **2013**, *113*, 225–245. https://doi.org/10.1007/s00704-012-0780-1.
6. Zizinga, A.; Mwanjalolo, J.G.M.; Tietjen, B.; Bedadi, B.; Pathak, H.; Gabiri, G.; Beesigamukama, D. Climate change and maize productivity in Uganda: Simulating the impacts and alleviation with climate smart agriculture practices. *Agric. Syst.* **2022**, *199*, 103407. https://doi.org/10.1016/j.agsy.2022.103407.
7. FAO. FAO Cereal Price Index. 2022. Available online: https://www.fao.org/worldfoodsituation/foodpricesindex/en/ (accessed on 16 July 2022).
8. IPCC. Summary for Policymakers. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2013.
9. Lal, R. Climate change and agriculture. In *Climate Change*; Elsevier: Amsterdam, The Netherlands, 2021; pp. 661–686. https://doi.org/10.1016/B978-0-12-821575-3.00031-1.
10. IPCC. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Core Writing Team, Pachauri, R., Meyer, L., Eds.; IPCC: Geneva, Switzerland, 2014.
11. Collins, M.; Knutti, R.; Arblaster, J.; Dufresne, J.-L.; Fichefet, T.; Friedlingstein, P.; Gao, X.; Gutowski, W.J.; Johns, T.; Krinner, G.; et al. Long-term Climate Change: Projections, Commitments and Irreversibility. In *Climate Change 2013—The Physical Science Basis: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M.B., Allen, S., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M., Eds.; Intergovernmental Panel on Climate Change; Cambridge University Press: 2013; pp. 1029–1136.
12. Miranda, P.M.A.; Valente, M.A.; Tomé, A.R.; Trigo, R.; Coelho, M.F.E.S.; Aguiar, A.; Azevedo, E.B. O clima de Portugal nos séculos XX e XXI. In *Alterações Climáticas em Portugal. Cenários Impactes e Medidas de Adaptação—Projecto SIAM II*; Santos, F.D., Miranda, P., Eds.; Gradiva: Lisboa, Portugal, 2006; pp. 45–113.
13. Dastagir, M.R. Modelling recent climate change-induced extreme events in Bangladesh: A review. *Weather Clim. Extrem.* **2015**, *7*, 49–60. https://doi.org/10.1016/j.wace.2014.10.003.
14. Duarte Santos, F. Problemática das alterações climáticas no início do século XXI. In *Alterações Climáticas em Portugal. Cenários Impactes e Medidas de Adaptação—Projecto SIAM II*; Santos, F.D., Miranda, P., Eds.; Gradiva: Lisboa, Portugal, 2006; pp. 17–43.
15. Vautard, R.; Kadygrov, N.; Iles, C.; Boberg, F.; Buonomo, E.; Bülow, K.; Coppola, E.; Corre, L.; van Meijgaard, E.; Nogherotto, R.; et al. Evaluation of the Large EURO-CORDEX Regional Climate Model Ensemble. *J. Geophys. Res. Atmos.* **2021**, *126*, 1–28. https://doi.org/10.1029/2019JD03244.
16. Rummukainen, M. State-of-the-art with regional climate models. *Wiley Interdiscip. Rev. Clim. Change* **2010**, *1*, 82–96. https://doi.org/10.1002/wcc.8.
17. Cunha, L.V.; Ribeiro, L.; Oliveira, R.P.; Nascimento, J. Recursos Hídricos. In *Alterações Climáticas em Portugal. Cenários Impactes e Medidas de Adaptação—Projecto SIAM II*; Santos, F.D., Miranda, P., Eds.; Gradiva: Lisboa, Portugal, 2006; pp. 117–168.
18. García-Díez, M.; Fernández, J.; Vautard, R. An RCM multi-physics ensemble over Europe: Multi-variable evaluation to avoid error compensation. *Clim. Dyn.* **2015**, *45*, 3141–3156. https://doi.org/10.1007/s00382-015-2529-x.

19. Wise, R. M., Fazey, I., Smith, M. S., Park, S. E., Eakin, H. C., Van Garderen, E. A., & Campbell, B. (2014). Reconceptualising adaptation to climate change as part of pathways of change and response. Global environmental change, 28, 325-336.
20. Yao, F.; Qin, P.; Zhang, J.; Lin, E.; Boken, V. Uncertainties in assessing the effect of climate change on agriculture using model simulation and uncertainty processing methods. *Chin. Sci. Bull.* **2011**, *56*, 729–737. https://doi.org/10.1007/s11434-011-4374-6.
21. Pedersen, J.S.T.; Santos, F.D.; van Vuuren, D.; Gupta, J.; Coelho, R.E.; Aparício, B.A.; Swart, R. An assessment of the performance of scenarios against historical global emissions for IPCC reports. *Glob. Environ. Change* **2021**, *66*, 102199. https://doi.org/10.1016/j.gloenvcha.2020.102199.
22. Leggett, J.; Pepper, W.J.; Swart, R.J.; Edmonds, J.; Meira Filho, L.G.; Mintzer, I.; Wang, M.X. Emissions scenarios for the IPCC: An update. *Clim. Change* **1992**, *1040*, 75–95.
23. Nakicenovic, N. (2004). Socioeconomic driving forces of emissions scenarios. In *The Global Carbon Cycle: Integrating Humans, Climate, and the Natural World.*Field, C.B., Raupach M.R., Eds. Island Press: Washington, DC, USA, 2004, Vol. 62, pp. 225-339.
24. Sun, S.; Shi, Q. Global spatio-temporal assessment of changes in multiple ecosystem services under four IPCC SRES land-use scenarios. *Earth's Future* **2020**, *8*, e2020EF001668. https://doi.org/10.1029/2020EF001668.
25. Van Vuuren, D.P.; Edmonds, J.; Kainuma, M.; Riahi, K.; Thomson, A.; Hibbard, K.; Hurtt, G.C.; Kram, T.; Krey, V.; Lamarque, J.-F.; et al. The representative concentration pathways: An overview. *Clim. Change* **2011**, *109*, 5–31. https://doi.org/10.1007/s10584-011-0148-z.
26. O'Neill, B.C.; Kriegler, E.; Riahi, K.; Ebi, K.L.; Hallegatte, S.; Carter, T.R.; Mathur, R.; van Vuuren, D.P. A new scenario framework for climate change research: The concept of shared socioeconomic pathways. *Clim. Change* **2014**, *122*, 387–400. https://doi.org/10.1007/s10584-013-0905-2.
27. Riahi, K.; van Vuuren, D.P.; Kriegler, E.; Edmonds, J.; O'Neill, B.C.; Fujimori, S.; Bauer, N.; Calvin, K.; Dellink, R.; Fricko, O.; et al. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Glob. Environ. Change* **2017**, *42*, 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009.
28. Shrestha, S.; Bach, T.V.; Pandey, V.P. Climate change impacts on groundwater resources in Mekong Delta under representative concentration pathways (RCPs) scenarios. *Environ. Sci. Policy* **2016**, *61*, 1–13. https://doi.org/10.1016/j.envsci.2016.03.010.
29. Riahi, K.; Rao, S.; Krey, V.; Cho, C.; Chirkov, V.; Fischer, G.; Kindermann, G.E.; Nakicenovic, N.; Rafaj, P. RCP 8.5—A scenario of comparatively high greenhouse gas emissions. *Clim. Change* **2011**, *109*, 33. https://doi.org/10.1007/s10584-011-0149-y.
30. Kogo, B.K.; Kumar, L.; Koech, R. Climate change and variability in Kenya: A review of impacts on agriculture and food security. *Environ. Dev. Sustain.* **2021**, *23*, 23–43. https://doi.org/10.1007/s10668-020-00589-1.
31. Corwin, D.L. Climate change impacts soil salinity in agricultural areas. *Eur. J. Soil Sci.* **2021**, *72*, 842–862. https://doi.org/10.1111/ejss.13010.
32. Mukhopadhyay, R.; Sarkar, B.; Jat, H.S.; Sharma, P.C.; Bolan, N.S. Soil salinity under climate change: Challenges for sustainable agriculture and food security. *J. Environ. Manag.* **2021**, *280*, 111736. https://doi.org/10.1016/j.jenvman.2020.111736.
33. Rolim, J.; Teixeira, J.L.; Catalão, J.; Shahidian, S. The impacts of climate change on irrigated agriculture in southern Portugal. *Irrig. Drain.* **2017**,66(1), 3–18. https://doi.org/10.1002/ird.1996.
34. Lorite, I.J.; Gabaldón-Leal, C.; Ruiz-Ramos, M.; Belaj, A.; De la Rosa, R.; León, L.; Santos, C. Evaluation of olive response and adaptation strategies to climate change under semi-arid conditions. *Agric. Water Manag.* **2018**, *204*, 247–261. https://doi.org/10.1016/j.agwat.2018.04.008.
35. Soares, D.; Rolim, J.; Fradinho, M.J.; Paço, T.A. D. Climate Change Impacts on Irrigation Requirements of Preserved Forage for Horses under Mediterranean Conditions. *Agronomy* **2020**, *10*, 1758. https://doi.org/10.3390/agronomy10111758.
36. Branquinho, S.; Rolim, J.; Teixeira, J.L. Climate Change Adaptation Measures in the Irrigation of a Super-Intensive Olive Orchard in the South of Portugal. *Agronomy* **2021**, *11*, 1658. https://doi.org/10.3390/agronomy11081658.
37. Sunil, A.; Deepthi, B.; Mirajkar, A.B.; Adarsh, S. Modeling future irrigation water demands in the context of climate change: A case study of Jayakwadi command area, India. *Model. Earth Syst. Environ.* **2021**, *7*, 1963–1977. https://doi.org/10.1007/s40808-020-00955-y.
38. Shahzad, A.; Ullah, S.; Dar, A.A.; Sardar, M.F.; Mehmood, T.; Tufail, M.A.; Shakoor, A.; Haris, M. Nexus on climate change: Agriculture and possible solution to cope future climate change stresses. *Environ. Sci. Pollut. Res.* **2021**, *28*, 14211–14232. https://doi.org/10.1007/s11356-021-12649-8.
39. Soares, D.; Rolim, J.; Fradinho, M.J.; do Paço, T.A. Production of Preserved Forage for Horses under Water Scarcity Conditions: A Case Study. *Water* **2022**, *14*, 388. https://doi.org/10.3390/w14030388.
40. Del Buono, D. Can biostimulants be used to mitigate the effect of anthropogenic climate change on agriculture? It is time to respond. *Sci. Total Environ.* **2021**, *751*, 141763. https://doi.org/10.1016/j.scitotenv.2020.141763.
41. FAO. *Climate Change and Food Security: Risks and Responses*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2016.
42. Ehleringer, J.R.; Cerling, T.E. C3 and C4 photosynthesis. *Encycl. Glob. Environ. Change* **2002**, *2*, 186–190.
43. Cheng, M.; McCarl, B.; Fei, C. Climate Change and Livestock Production: A Literature Review. *Atmosphere* **2022**, *13*, 140. https://doi.org/10.3390/atmos13010140.
44. Gabaldón-Leal, C.; Webber, H.; Otegui, M.E.; Slafer, G.A.; Ordóñez, R.A.; Gaiser, T.; Lorite, I.J.; Ruiz-Ramos, M.; Ewert, F. Modelling the impact of heat stress on maize yield formation. *Field Crops Res.* **2016**, *198*, 226–237. https://doi.org/10.1016/j.fcr.2016.08.013.

45. Minoli, S.; Jägermeyr, J.; Asseng, S.; Urfels, A.; Müller, C. Global crop yields can be lifted by timely adaptation of growing periods to climate change. *Nat. Commun.* **2022**, *13*, 1–10. https://doi.org/10.1038/s41467-022-34411-5.
46. Zhao, J.; Bindi, M.; Eitzinger, J.; Ferrise, R.; Gaile, Z.; Gobin, A.; Holzkämper, A.; Kersebaum, K.-C.; Kozyra, J.; Kriaučiūnienė, Z.; et al. Priority for climate adaptation measures in European crop production systems. *Eur. J. Agron.* **2022**, *138*, 126516. https://doi.org/10.1016/j.eja.2022.126516.
47. Yang, C.; Fraga, H.; Van Ieperen, W.; Santos, J.A. Assessment of irrigated maize yield response to climate change scenarios in Portugal. *Agric. Water Manag.* **2017**, *184*, 178–190. https://doi.org/10.1016/j.agwat.2017.02.004.
48. Hussain, A.; Bangash, R. Impact of climate change on crops' productivity across selected agro-ecological zones in Pakistan. *Pak. Dev. Rev.* **2017**, *56*, 163–187. https://doi.org/10.1016/B978-0-323-91001-9.00016-5.
49. Maitah, M.; Malec, K.; Maitah, K. Influence of precipitation and temperature on maize production in the Czech Republic from 2002 to 2019. *Sci. Rep.* **2021**, *11*, 1–11. https://doi.org/10.1038/s41598-021-89962-2.
50. Lizaso, J.I.; Ruiz-Ramos, M.; Rodríguez, L.; Gabaldon-Leal, C.; Oliveira, J.A.; Lorite, I.J.; Sánchez, D.; García, E.; Rodríguez, A. Impact of high temperatures in maize: Phenology and yield components. *Field Crops Res.* **2018**, *216*, 129–140. https://doi.org/10.1016/j.fcr.2017.11.013.
51. Hatfield, J.L.; Boote, K.J.; Kimball, B.A.; Ziska, L.H.; Izaurralde, R.C.; Ort, D.; Thomson, A.M.; Wolfe, D. Climate Impacts on Agriculture: Implications for Crop Production. *Agron. J.* **2011**, *103*, 351–370. https://doi.org/10.2134/agronj2010.0303.
52. Shrestha, S.; Ciaian, P.; Himics, M.; Van Doorslaer, B. Impacts of climate change on EU agriculture. *Rev. Agric. Appl. Econ. (RAAE)* **2013**, *16(395-2016-24317)*, 24–39.
53. Fraga, H.; Moriondo, M.; Leolini, L.; Santos, J.A. Mediterranean olive orchards under climate change: A review of future impacts and adaptation strategies. *Agronomy* **2020**, *11*, 56. https://doi.org/10.3390/agronomy11010056.
54. Tubiello, F.; Rosenzweig, C.; Goldberg, R.; Jagtap, S.; Jones, J. Effects of climate change on US crop production: Simulation results using two different GCM scenarios. Part I: Wheat, potato, maize, and citrus. *Clim. Res.* **2002**, *20*, 259–270. DOI:10.3354/cr020259.
55. Wiréhn, L. Nordic agriculture under climate change: A systematic review of challenges, opportunities and adaptation strategies for crop production. *Land Use Policy* **2018**, *77*, 63–74. https://doi.org/10.1016/j.landusepol.2018.04.059.
56. Tanasijevic, L.; Todorovic, M.; Pereira, L.S.; Pizzigalli, C.; Lionello, P. Impacts of climate change on olive crop evapotranspiration and irrigation requirements in the Mediterranean region. *Agric. Water Manag.* **2014**, *144*, 54–68. https://doi.org/10.1016/j.agwat.2014.05.019.
57. Juhola, S.; Klein, N.; Käyhkö, J.; Neset, T.S. S. Climate change transformations in Nordic agriculture? *J. Rural Stud.* **2017**, *51*, 28–36. https://doi.org/10.1016/j.jrurstud.2017.01.013.
58. Bastas, K.K. Impact of Climate Change on Food Security and Plant Disease. In *Microbial Biocontrol: Food Security and Post Harvest Management*; Springer: Cham, Switzerland, 2022; pp. 1–22. https://doi.org/10.1007/978-3-030-87289-2_1.
59. Skendžić, S.; Zovko, M.; Živković, I.P.; Lešić, V.; Lemić, D. The impact of climate change on agricultural insect pests. *Insects* **2021**, *12*, 440. https://doi.org/10.3390/insects12050440.
60. Farquhar, G.D.; Dubbe, D.R.; Raschke, K. Gain of the feedback loop involving carbon dioxide and stomata. *Plant Physiol.* **1978**, *62*, 406–412.
61. del Pozo, A.; Brunel-Saldias, N.; Engler, A.; Ortega-Farias, S.; Acevedo-Opazo, C.; Lobos, G.A.; Jara-Rojas, R.; Molina-Montenegro, M.A. Climate Change Impacts and Adaptation Strategies of Agriculture in Mediterranean-Climate Regions (MCRs). *Sustainability* **2019**, *11*, 2769. https://doi.org/10.3390/su11102769.
62. Iglesias, A.; Garrote, L. Adaptation strategies for agricultural water management under climate change in Europe. *Agric. Water Manag.* **2015**, *155*, 113–124. https://doi.org/10.1016/j.agwat.2015.03.014.
63. Fader, M.; Shi, S.; von Bloh, W.; Bondeau, A.; and Cramer, W. Mediterranean irrigation under climate change: More efficient irrigation needed to compensate for increases in irrigation water requirements. *Hydrol. Earth Syst. Sci.* **2016**, *20*, 953–973 https://doi.org/10.5194/hess-20-953-2016.
64. Rocha, J.; Carvalho-Santos, C.; Diogo, P.; Beça, P.; Keizer, J.J.; Nunes, J.P. Impacts of climate change on reservoir water availability, quality and irrigation needs in a water scarce Mediterranean region (southern Portugal). *Sci. Total Environ.* **2020**, *736*, 139477. https://doi.org/10.1016/j.scitotenv.2020.139477.
65. Seneviratne, S.; Nicholls, N.; Easterling, D.; Goodess, C.; Kanae, S.; Kossin, J.; Luo, Y.; Marengo, J.; McInnes, K.; Rahimi, M.; et al. Changes in climate extremes and their impacts on the natural physical environment. In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*; Field, C.B., Barros, V., Stocker, T., Qin, D., Dokken, D., Ebi, K., Mastrandrea, M., Mach, K., Plattner, G.-K., Allen, S., et al., Eds.; A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC); Cambridge University Press: Cambridge, UK; New York, NY, USA, 2012; pp. 109–230.
66. Lickley, M.; Solomon, S. Drivers, timing, and some impacts of global aridity change. *Environ. Res. Lett.* **2018**, *13*, 104010. https://doi.org/10.1088/1748-9326/aae0137.
67. Giorgi, F. Climate change hot-spots. *Geophys. Res. Lett.* **2006**, *33*, 101029. https://doi.org/10.1029/2006GL025734.
68. Gabaldón-Leal, C.; Lorite, I.J.; Mínguez, M.I.; Lizaso, J.I.; Dosio, A.; Sanchez, E.; Ruiz-Ramos, M. Strategies for adapting maize to climate change and extreme temperatures in Andalusia, Spain. *Clim. Res.* **2015**, *65*, 159–173. https://doi.org/10.3354/cr01311.
69. Funes, I.; Savé, R.; de Herralde, F.; Biel, C.; Pla, E.; Pascual, D.; Zabalza, J.; Cantos, G.; Borràs, G.; Aranda, X. Modeling impacts of climate change on the water needs and growing cycle of crops in three Mediterranean basins. *Agric. Water Manag.* **2021**, *249*, 106797. https://doi.org/10.1016/j.agwat.2021.106797.

70. Masia, S.; Trabucco, A.; Spano, D.; Snyder, R.L.; Sušnik, J.; Marras, S. A modelling platform for climate change impact on local and regional crop water requirements. *Agric. Water Manag.* **2021**, *255*, 107005. https://doi.org/10.1016/j.agwat.2021.107005.
71. Esteve, P.; Varela-Ortega, C.; Blanco-Gutiérrez, I.; Downing, T.E. A hydro-economic model for the assessment of climate change impacts and adaptation in irrigated agriculture. *Ecol. Econ.* **2015**, *120*, 49–58. https://doi.org/10.1016/j.ecolecon.2015.09.017.
72. Yetik, A.K.; Şen, B. Evaluation of the Impacts of Climate Change on Irrigation Requirements of Maize by CROPWAT Model. *Gesunde Pflanz.* **2022**, 1–9. https://doi.org/10.1007/s10343-022-00751-x.
73. Dono, G.; Cortignani, R.; Doro, L.; Giraldo, L.; Ledda, L.; Pasqui, M.; Roggero, P.P. Adapting to uncertainty associated with short-term climate variability changes in irrigated Mediterranean farming systems. *Agric. Syst.* **2013**, *117*, 1–12. https://doi.org/10.1016/j.agsy.2013.01.005.
74. Saadi, S.; Todorovic, M.; Tanasijevic, L.; Pereira, L.S.; Pizzigalli, C.; Lionello, P. Climate change and Mediterranean agriculture: Impacts on winter wheat and tomato crop evapotranspiration, irrigation requirements and yield. *Agric. Water Manag.* **2015**, *147*, 103–115. https://doi.org/10.1016/j.agwat.2014.05.008.
75. Hatfield, J.L.; Dold, C. Water-use efficiency: Advances and challenges in a changing climate. *Front. Plant Sci.* **2019**, *10*, 103. https://doi.org/10.3389/fpls.2019.00103.
76. Ungureanu, N.; Vlăduț, V.; Voicu, G. Water scarcity and wastewater reuse in crop irrigation. *Sustainability* **2020**, *12*, 9055. https://doi.org/10.3390/su12219055.
77. Hemathilake, D.M.K.S.; Gunathilake, D.M.C.C. Agricultural productivity and food supply to meet increased demands. In *Future Foods*; Academic Press: Cambridge, MA, USA, 2022; pp. 539–553. https://www.sciencedirect.com/science/article/pii/B9780323910019000165 (Accessed on 10 November 2022)
78. Alexandratos, N.; Bruinsma, J. World agriculture towards 2030/2050: The 2012 revision. ESA Working paper No. 12-03. Rome, FAO, 2012. https://doi.org/10.22004/ag.econ.288998.Valentini, R.; Sievenpiper, J.L.; Antonelli, M.; Dembska, K. (Eds.). *Achieving the Sustainable Development Goals through Sustainable Food Systems*; Springer International Publishing: Cham, Switzerland, 2019.
79. FAO. *World Food and Agriculture—Statistical Yearbook 2020*; FAO: Rome, Italy, 2020. https://doi.org/10.4060/cb1329en.
80. Saddique, Q.; Khan, M.; Rahman, M.H.U.; Jiatun, X.; Waseem, M.; Gaiser, T.; Waqas, M.M.; Ahmad, I.; Chong, L.; Cai, H. Effects of elevated air temperature and CO_2 on maize production and water use efficiency under future climate change scenarios in Shaanxi Province, China. *Atmosphere* **2020**, *11*, 843. https://doi.org/10.3390/atmos11080843.
81. Koech, R.; Langat, P. Improving Irrigation Water Use Efficiency: A Review of Advances, Challenges and Opportunities in the Australian Context. *Water* **2018**, *10*, 1771. https://doi.org/10.3390/w10121771.
82. Lenderink, G.; Buishand, A.; van Deursen, W. Estimates of future discharges of the river Rhine using two scenario methodologies: Direct versus delta approach. *Hydrol. Earth Syst. Sci.* **2007**, *11*, 1145–1159. https://doi.org/10.5194/hess-11-1145-2007.
83. Navarro-Racines, C.; Tarapues, J.; Thornton, P.; Jarvis, A.; Ramirez-Villegas, J. High-resolution and bias-corrected CMIP5 projections for climate change impact assessments. *Sci. Data* **2020**, *7*, 7. https://doi.org/10.1038/s41597-019-0343-8.
84. Maraun, D. Bias correcting climate change simulations—A critical review. *Curr. Clim. Change Rep.* **2016**, *2*, 211–220. https://doi.org/10.1007/s40641-016-0050-x.
85. Teixeira, J.L.; Pereira, L.S. ISAREG, an irrigation scheduling model. *ICID Bull.* **1992**, *41*, 29–48.
86. Arnold, J.G.; Srinivasan, R.; Muttiah, R.S.; Williams, J.R. Large Area Hydrologic Modelling and Assessment Part I: Model Development. *J. Am. Water Resour. Assoc.* **1998**, *34*, 73–89. https://doi.org/10.1111/j.1752-1688.1998.tb05961.x.
87. Lindström, G.; Johansson, B.; Persson, M.; Gardelin, M.; Bergström, S. Development and test of the distributed HBV-96 hydrological model. *J. Hydrol.* **1997**, *201*, 272–288. https://doi.org/10.1016/S0022-1694(97)00041-3.
88. U.S. Army Corps of Engineers. *HEC-HMS Technical Reference Manual*; U.S. Army Corps of Engineers: Washington, DC, USA, 2000.
89. Donigian, A.S.; Imhoff, J.C.; Bicknell, B.R.; Kittle, J.L.; Nichols, A. *Application Guide for Hydrological Simulation Program Fortran (HSPF)*; U.S. Environmental Protection Agency: Athens, Greece, 1984.
90. Srinivasan, R.; Krysanova, V.; Wechsung, F.; Arnold, J.; Williams, J. *SWIM (Soil and Water Integrated Model) User Manual*; PIK Reports Potsdam Institute for Climate Impact Research: Houston, TX, USA, 2000.
91. Paredes, P.; Rodrigues, G.C.; Alves, I.; Pereira, L.S. Partitioning evapotranspiration, yield prediction, and, economic returns of maize under various irrigation management strategies. *Agric. Water Manage.* **2014**, *135*, 27–39. https://doi.org/10.1016/j.agwat.2013.12.010.
92. Steduto, P.; Hsiao, T.C.; Fereres, E.; Raes, D. *Crop Yield Response to Water*; FAO Irrigation and Drainage Paper 66; FAO: Rome, Italy, 2012.
93. Paredes, P.; de Melo-Abreu, J.P.; Alves, I.; Pereira, L.S. Assessing the performance of the FAO AquaCrop model to estimate maize yields and water use under full and deficit irrigation with a focus on model parameterization. *Agric. Water Manag.* **2014**, *144*, 81–97. https://doi.org/10.1016/j.agwat.2014.06.002.
94. Brisson, N.; Gary, C.; Justes, E.; Roche, R.; Mary, B.; Ripoche, D.; Zimmer, D.; Sierra, J.; Bertuzzi, P.; Burger, P.; et al. An overview of the crop model STICS. *Eur. J. Agron.* **2003**, *18*, 309–332. https://doi.org/10.1016/S1161-0301(02)00110-7.
95. Yaykiran, S.; Cuceloglu, G.; Ekdal, A. Estimation of water budget components of the Sakarya River basin by using the WEAP-PGM model. *Water* **2019**, *11*, 271. https://doi.org/10.3390/w11020271.
96. Ford, J.D.; Keskitalo, E.C.H.; Smith, T.; Pearce, T.; Berrang-Ford, L.; Duerden, F.; Smit, B. Case study and analogue methodologies in climate change vulnerability research. *Wiley Interdiscip. Rev. Clim. Change* **2010**, *1*, 374–392. https://doi.org/10.1002/wcc.48.

97. Doorenbos, J.; Kassam, A.H. *Yield Response to Water*; FAO Irrigation and Drainage Paper No. 33. FAO: Rome, Italy, 1979; p 193.
98. Zhang, L.; Traore, S.; Ge, J.; Li, Y.; Wang, S.; Zhu, G.; Cui, Y.; Fipps, G. Using boosted tree regression and artificial neural networks to forecast upland rice yield under climate change in the Sahel. *Comput. Electron. Agric.* **2019**, *166*, 105031. https://doi.org/10.1016/j.compag.2019.105031.
99. Kamali, B.; Lorite, I.J.; Webber, H.A.; Rezaei, E.E.; Gabaldon-Leal, C.; Nendel, C.; Siebert, S.; Ramirez-Cuesta, J.M.; Ewert, F.; Ojeda, J.J. Uncertainty in climate change impact studies for irrigated maize cropping systems in southern Spain. *Sci. Rep.* **2022**, *12*, 4049. https://doi.org/10.1038/s41598-022-08056-9.
100. Baum, M.E.; Licht, M.A.; Huber, I.; Archontoulis, S.V. Impacts of climate change on the optimum planting date of different maize cultivars in the central US Corn Belt. *Eur. J. Agron.* **2020**, *119*, 126101. https://doi.org/10.1016/j.eja.2020.126101.
101. Ureta, C.; González, E.J.; Espinosa, A.; Trueba, A.; Piñeyro-Nelson, A.; Álvarez-Buylla, E.R. Maize yield in Mexico under climate change. *Agric. Syst.* **2020**, *177*, 102697. https://doi.org/10.1016/j.agsy.2019.102697.
102. Amnuaylojaroen, T.; Chanvichit, P.; Janta, R.; Surapipith, V. Projection of rice and maize productions in Northern Thailand under climate change scenario RCP8. 5. *Agriculture* **2021**, *11*, 23. https://doi.org/10.3390/agriculture11010023.
103. Miranda, P.M.; Cardoso, R.M.; Soares, P.M.M.; Valente, M.A.; Viterbo, P. A mudança climática. *Cultivar* **2018**, *12*, 29–37.
104. Ahmad, I.; Ahmad, B.; Boote, K.; Hoogenboom, G. Adaptation strategies for maize production under climate change for semi-arid environments. *Eur. J. Agron.* **2020**, *115*, 126040. https://doi.org/10.1016/j.eja.2020.126040.
105. Karimi, V.; Karami, E.; Keshavarz, M. Climate Change and Agriculture: Impacts and adaptive responses in Iran. *J. Integr. Agric.* **2018**, *17*, 1–15. https://doi.org/10.1016/S2095-3119(17)61794-5.
106. Talanow, K.; Topp, E.N.; Loos, J.; Martín-López, B. Farmers' perceptions of climate change and adaptation strategies in South Africa's Western Cape. *J. Rural Stud.* **2021**, *81*, 203–219. https://doi.org/10.1016/j.jrurstud.2020.10.026.
107. Maione, M.; Fowler, D.; Monks, P.S.; Reis, S.; Rudich, Y.; Williams, M.L.; Fuzzi, S. Air quality and climate change: Designing new win-win policies for Europe. *Environ. Sci. Policy* **2016**, *65*, 48–57. https://doi.org/10.1016/j.envsci.2016.03.011.
108. Meissner, F.; Haas, A.; Hinkel, J.; Bisaro, A. A typology for analysing mitigation and adaptation win-win strategies. *Clim. Change* **2020**, *160*, 539–564. https://doi.org/10.1007/s10584-020-02681-x.
109. Smith, P.; Clark, H.; Dong, H.; Elsiddig, E.A.; Haberl, H.; Harper, R.; House, J.; Jafari, M.; Masera, O.; Mbow, C.; et al. Agriculture, Forestry and Other Land Use (AFOLU). In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, US, 2014.
110. Albiac, J.; Kahil, T.; Notivol, E.; Calvo, E. Agriculture and climate change: Potential for mitigation in Spain. *Sci. Total Environ.* **2017**, *592*, 495–502. https://doi.org/10.1016/j.scitotenv.2017.03.110.
111. Panchasara, H.; Samrat, N.H.; Islam, N. Greenhouse gas emissions trends and mitigation measures in australian agriculture sector—A review. *Agriculture* **2021**, *11*, 85. https://doi.org/10.3390/agriculture11020085.
112. Pathak, T.B.; Maskey, M.L.; Dahlberg, J.A.; Kearns, F.; Bali, K.M.; Zaccaria, D. Climate change trends and impacts on California agriculture: A detailed review. *Agronomy* **2018**, *8*, 25. https://doi.org/10.3390/agronomy8030025.
113. Dubey, R.; Pathak, H.; Chakrabarti, B.; Singh, S.; Gupta, D.K.; Harit, R.C. Impact of terminal heat stress on wheat yield in India and options for adaptation. *Agric. Syst.* **2020**, *181*, 102826. https://doi.org/10.1016/j.agsy.2020.102826.
114. Yang, C.; Fraga, H.; van Ieperen, W.; Trindade, H.; Santos, J.A. Effects of climate change and adaptation options on winter wheat yield under rainfed Mediterranean conditions in southern Portugal. *Clim. Change* **2019**, *154*, 159–178. https://doi.org/10.1007/s10584-019-02419-4.
115. Yang, X.; Menefee, D.; Cui, S.; Rajan, N.; Fletcher, A. Assessing the impacts of projected climate changes on maize (Zea mays) productivity using crop models and climate scenario simulation. *Crop Pasture Sci.* **2021**, *72*, 969–984. https://doi.org/10.1071/CP21279.
116. Pais, I.P.; Reboredo, F.H.; Ramalho, J.C.; Pessoa, M.F.; Lidon, F.C.; Silva, M.M. Potential impacts of climate change on agriculture-A review. *Emir. J. Food Agric.* **2020**, 32, 397–407. https://doi.org/10.9755/ejfa.2020.
117. Nikolaou, G.; Neocleous, D.; Christou, A.; Kitta, E.; Katsoulas, N. Implementing sustainable irrigation in water-scarce regions under the impact of climate change. *Agronomy* **2020**, *10*, 1120. https://doi.org/10.3390/agronomy10081120.
118. Yang, C.; Fraga, H.; Van Ieperen, W.; Santos, J.A. Assessing the impacts of recent-past climatic constraints on potential wheat yield and adaptation options under Mediterranean climate in southern Portugal. *Agric. Syst.* **2020**, *182*, 102844. https://doi.org/10.1016/j.agsy.2020.102844.
119. Mirzaei, A.; Zibaei, M. Water conflict management between agriculture and wetland under climate change: Application of economic-hydrological-behavioral modelling. *Water Resour. Manag.* **2021**, *35*, 1–21. https://doi.org/10.1007/s11269-020-02703-4.
120. El Chami, D.; Trabucco, A.; Wong, T.; Monem, M.A.; Mereu, V. Costs and effectiveness of climate change adaptation in agriculture: A systematic review from the NENA region. *Clim. Policy* **2022**, 22(4), 1–19. https://doi.org/10.1080/14693062.2021.1997703.
121. Islam, A.T.; Islam, A.S.; Islam, G.T.; Bala, S.K.; Salehin, M.; Choudhury, A.K.; Dey, N.C.; Hossain, A. Adaptation strategies to increase water productivity of wheat under changing climate. *Agric. Water Manag.* **2022**, *264*, 107499. https://doi.org/10.1016/j.agwat.2022.107499.

122. Choudhury, B.U.; Nengzouzam, G.; Islam, A. Runoff and soil erosion in the integrated farming systems based on micro-watersheds under projected climate change scenarios and adaptation strategies in the eastern Himalayan mountain ecosystem (India). *J. Environ. Manag.* **2022**, *309*, 114667. https://doi.org/10.1016/j.jenvman.2022.114667.
123. Akinnagbe, O.M.; Irohibe, I.J. Agricultural adaptation strategies to climate change impacts in Africa: A review. *Bangladesh J. Agric. Res.* **2014**, *39*, 407–418. https://doi.org/10.3329/bjar.v39i3.21984.
124. Ullah, W.; Nafees, M.; Khurshid, M.; Nihei, T. Assessing farmers' perspectives on climate change for effective farm-level adaptation measures in Khyber Pakhtunkhwa, Pakistan. *Environ. Monit. Assess.* **2019**, *191*, 1–18. https://doi.org/10.1007/s10661-019-7651-5.
125. Abbass, K.; Qasim, M.Z.; Song, H.; Murshed, M.; Mahmood, H.; Younis, I. A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environ. Sci. Pollut. Res.* **2022**, 29, 1–21. https://doi.org/10.1007/s11356-022-19718-6.