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Review

Adaptation of Agriculture to Climate Change: A Scoping Review

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Abstract: Since agricultural productivity is weather and climate-related and fundamentally depends on climate stability, climate change poses many diverse challenges to agricultural activities. The objective of this study is to review adaptation strategies and interventions in countries around the world proposed for implementation to reduce the impact of climate change on agricultural development and production at various spatial scales. A literature search was conducted in June–August 2023 using electronic databases Google Scholar and Scientific Electronic Library eLibrary.RU, seeking the key words "climate", "climate change", and "agriculture adaptation". Sixty-five studies were identified and selected for the review. The negative impacts of climate change are expressed in terms of reduced crop yields and crop area, impacts on biotic and abiotic factors, economic losses, increased labor, and equipment costs. Strategies and actions for agricultural adaptation that can be emphasized at local and regional levels are: crop varieties and management, including land use change and innovative breeding techniques; water and soil management, including agronomic practices; farmer training and knowledge transfer; at regional and national levels: financial schemes, insurance, migration, and culture; agricultural and meteorological services; and R&D, including the development of early warning systems. Adaptation strategies depend on the local context, region, or country; limiting the discussion of options and measures to only one type of approach—"top-down" or "bottom-up"—may lead to unsatisfactory solutions for those areas most affected by climate change but with few resources to adapt to it. Biodiversity-based, or "ecologically intensive" agriculture, and climate-smart agriculture are low-impact strategies with strong ecological modernization of agriculture, aiming to sustainably increase agricultural productivity and incomes while addressing the interrelated challenges of climate change and food security. Some adaptation measures taken in response to climate change may not be sufficient and may even increase vulnerability to climate change. Future research should focus on adaptation options to explore the readiness of farmers and society to adopt new adaptation strategies and the constraints they face, as well as the main factors affecting them, in order to detect maladaptation before it occurs.

Keywords: climate; climate change; agriculture; adaptation strategies; maladaptation

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1. Introduction

Anthropogenic activities are contributing to current environmental problems such as climate change, natural resource degradation, including soil degradation and biodiversity loss, and environmental pollution. According to the World Economic Forum Global Risks Perception Survey 2021–2022, "Climate action failure" and "Extreme weather" were identified as holding the 1st and 2nd places among the most serious risks on the global scale for the next 10 years [1]. The world's population is currently increasing and is projected to reach 9.5 billion by 2050 [2], which poses challenges for socio-economic progress and requires expanding the contributions of all resources to meet the necessities of a growing number of people [3]. Food security is one of the main problems in the 21st century, and due to the growth of the population, agricultural production, both food and non-food products, will have to increase by 60% by 2050 compared to 2005 [4].

The Sustainable Development Goals (SDGs) are a universal call for global action aimed to "protect the planet and ensure that all people enjoy peace and prosperity". To ensure their achievement, they are all interconnected and integrated, balancing the environmental, social, and economic dimensions of sustainable development [5–8]. Seven out of 17 SDGs are related to agriculture and climate change, namely: No Poverty (SDG1), Zero Hunger (SDG2), Gender Equality (SDG5), Responsible Consumption and Production (SDG12), Climate Action (SDG13), Life Below Water (SDG14), and Life on Land (SDG15) [6–11]. To achieve the goals while addressing current climate change problems, climate-smart agriculture is needed, aimed at sustainable food production, climate adaptation, and resilience [12–22].

1.1. Adaptation Strategies—Definitions for Agriculture

While mitigation means activities aimed at reducing greenhouse gas emissions [23–26], adaptation refers to measures aimed at increasing the ability of people and communities to adapt to climate change and related impacts that will occur in various sectors of human life [23,26–30]. In the light of climate change, adaptation is recognized as actions aimed at reducing vulnerability and/or benefiting opportunities resulting from current or future changes [26,31–33]. In this context, Adaptation Strategy (AS) can be defined as "...a general plan of action for addressing the impacts of climate change, including climate variability and extremes. It will include a mix of policies and measures with the overarching objective of reducing the country's vulnerability. Depending on the circumstances, the strategy can be comprehensive at a national level, addressing adaptation across sectors, regions and vulnerable populations, or it can be more limited, focusing on just one or two sectors or regions" ([34], p. 186). Considering the existence of a large number of definitions of the term "strategy" [35,36], we use the above one with the addition of a local level.

Since the relevance of AS depends on the nature of incentives and the associated vulnerability, discussion of adaptation strategies should begin with an overview of climate and ongoing climate change, as well as their impact on agriculture, answering the question: What is agriculture adapting to? For example, B. Smit and coauthors [37] emphasize that "adaptation in agriculture may be in response to a sequence such as temperature and precipitation conditions, which result in drought (magnitude and/or frequency) which influences crop yield which has consequences for income" ([37], p. 230). At the same time, no country or region has the same adaptation potential, especially depending on their economic and/or social status, which is very important for developing countries, which experience more restrictions compared to developed ones [27,38].

B. Smit and M. Skinner [39] determine the distinctive characteristics of adaptation in agriculture, such as "intent and purposefulness; timing and duration; scale and responsibility; and form" ([39], p. 93). Here "intent and purposefulness" means spontaneous or specifically planned; "timing and duration" is related to anticipatory (proactive), concurrent (during), or responsive (reactive) adaptations. "Scale and responsibility" characteristics are very important in terms of decision-making and planning specific adaptation plans. "Scale" is a spatial level where adaptation occurs, such as plant, plot, field, farm, region, and nation [39]. In this context, "responsibility" means differentiation between the various actors who implement or promote adaptation in the agricultural sector, including farmers as individual producers, private enterprises integrated into agribusiness, and public institutions referring to governmental decisions [37]. Consequently, adaptation "form" refers to the diverse array of structures and procedures that vary depending on spatial and policy levels, shaped by their administrative, financial, institutional, legal, managerial, organizational, political, pragmatic, structural, and technological attributes [39]. At the same time, there are various restrictions on adaptation, or factors affecting agricultural adaptation to climate change, with their different origins: physical, environmental, technological, economic, political, institutional, psychological, or socio-cultural [28,30,40–43].

1.2. Adaptation Strategies: Scaling from National to Farmer Levels

Climate change effects on agricultural activities vary in different regions, depending on economic, social, and environmental patterns, thus calling for a diverse mix of adaptation actions across the regions [25]. They can differ depending on the scale of the system. For instance, adaptation efforts vary at different levels of scale. At the farmer's field level, it might involve actions like planting new species or hybrids. At the farm level, strategies could include diversification or obtaining insurance coverage. On regional or national scales, adaptation may entail changes in the number of farms or adjustments to compensatory programs. On a global level, it might necessitate shifts in international food market patterns [37]. Numerous examples of adaptation plans at the regional level can be found in the national communications submitted by the governments of developing countries [44].

The impact of climate change on agriculture is felt both at the level of individual producers and at the level of the entire population [45]. Two levels of agricultural adaptation are often discussed: farm-based measures, which are built on the rational personal interests of farmers, and policy-driven adaptation with government involvement, based on collective needs [46,47]. The most severe repercussions of these changes are felt within local agricultural communities, as they directly affect employment, income sources, and agricultural production. These communities heavily rely on the agricultural sector, rendering them more susceptible to such impacts. The most vitally damaging effects are expressed in reducing food security (availability, accessibility, stability, and use); aggravating water shortages (availability and quality of freshwater); causing damage to vital infrastructure (economic damage from floods and damage to infrastructure from the melting of polar ice caps); intensifying droughts (desertification); and increasing poverty in local communities [43]. At the same time, the choice at the national level related to the national policy in the field of agriculture and development is crucial [31]. According to Stage [48], the main difference between them is that at the local level, private farms and households can take autonomous adaptation decisions, while at the regional or national level, planned adaptation decisions are made by institutional or governmental authorities [48].

1.3. Adaptation Strategies for Agricultural Development and Production at Different Levels

The literature review shows that a comprehensive discussion has unfolded in the scientific community on the global impact of climate change and adaptation to it on various aspects of human life [19,27,28,37,38,43,49–56]. The multiple attempts are devoted to research involving systematic analysis, categorization and documentation of agricultural adaptation as a whole [23,25,32,39,45,57–59], as well some specific aspects, such as adaptation features in different countries and regions of the world, e.g.,: the Mediterranean region [60], Eastern Europe [61], Nordic countries [33], the USA [62], Canada [39], developing countries [63], low- and middle-income countries [42], Asia [64–66], South Asia [67], African countries [11,18,68], arid and semi-arid tropics of Asia, Africa, and Latin America [69]; in various sectors of agriculture [70], depending on the effects for various crops [71–77], and in different weather outcomes [16,21,58,78,79].

Despite this extensive discourse, there have been only a few studies conducted that include research from countries and regions of the world, showing adaptation actions at different levels of agricultural production, from regional and local farmers' responses to government involvement or national level [31]. Thus, in this study, an attempt is made not to cover all the papers on the topic but more so to fill the above gap in research by compiling a scoping review of the literature. The aim of the current study is to review adaptation strategies and actions in countries around the world proposed for implementation in order to reduce the impact of climate change on their agricultural development and production at different levels. The study was completed in three stages: (i) identifying the climate diversity and climate change patterns; (ii) determining the impact of climate change on agricultural production; and (iii) recognizing adaptation strategies and actions in the agricultural sector, including at the local (farms), regional (institutions), and national (governments) levels. We believe that our results would benefit not only future research aimed at studying the development of effective strategies for the adaptation of the agricultural sector in different countries but also the influencing factors and barriers to the adjustment of agriculture to climate change.

The remainder of the paper is structured as follows: Section 2 presents the Materials and Methods of this study. Section 3 provides the Results of the main findings, including a table that summarizes the outputs from all the papers selected for the review. Section 4, Discussion, includes some additional aspects, such as: shortcomings and advantages that arise from climate change to agriculture, in Section 4.1; discussion of the pros and cons of the "bottom-up" and "top-down" approaches (Section 4.2); unique agricultural techniques such as intercropping are considered in Section 4.3; involvement of Indigenous Knowledge in the adaptation process is shown in Section 4.4; biodiversity-based agriculture and smart agriculture are debated in Sections 4.5 and 4.6; and maladaptation concepts are discussed in Section 4.7. In the final Section 5, we present the main conclusions and implications of this study, including recommendations.

2. Materials and Methods

A literature search was conducted in June-August 2023 using electronic databases Google Scholar and Scientific Electronic Library eLibrary.RU, the largest Russian information and analytical portal in science, technology, medicine, and education, containing abstracts and full texts. The following questions were identified prior to the review process and subsequently taken into account when reviewing the literature: (i) What are current or future climate changes? (ii) How does climate change affect and is projected to affect agricultural production? (iii) What necessary adaptation actions (policies and measures) are noted? We were seeking the key phrases "climate change" and "agriculture adaptation measures" to search in Google Scholar and the key words "climate" and "agriculture adaptation" to search in eLibrary. We also looked for studies cited in the recognized papers.

The scoping nature of the literature review does not require full coverage of all papers on this topic, but those enveloping all climate types over different continents. The several first relevant studies were selected for the review, all of them published not earlier than 1999. The review criteria stipulated that publications eligible for inclusion should encompass countries with diverse climates, along with considerations of climate change and its associated impacts or adaptation strategies, without bias in the selection. Ultimately, our search identified 65 studies that were deemed suitable for the review, and we did not impose any restrictions on the study design.

It is important to note that challenges associated with the effects of climate change and the necessary adaptation measures are influenced not only by climatic factors but also by other biophysical variables, such as agro-climatic zones, soil types, and others. In this review, we do not classify our findings based on these specific assumptions. Instead, we seek to clarify and consolidate the relevant challenges and opportunities, taking into account a number of factors related to climate change. However, the results presented in this document can be used in conjunction with the identified prerequisites to assess the applicability of a particular task or opportunity in a particular context.

3. Results

From the reviewed papers, 59 in English and 6 in Russian were included in the table. Most of the articles were from European countries (25) [33,47,71,80–102] and Asia (21) [13,17,103–121], several from African countries (12) [11,68,69,122–130], also South America (4) [131–134] and North America (2) [135,136], and one paper from Australia [137]. Of these papers, six [17,100,122,131,136,137] were published at the Special Issue of Climate (MDPI) "Agroecological Approaches for Climate-Smart and Biodiverse Agriculture" (https:

//www.mdpi.com/journal/climate/special_issues/ecosystem, accessed on 1 September 2023), which originally inspired us to conduct this review. The studied areas include a wide range of climates, from equatorial to temperate, with various humidity variations (arid, semi-arid, humid, monsoon, Mediterranean, maritime), organized as from the temperate and subtropical climates of Europe (including Russia) to various climates in Asia, Africa, the Southern and Northern Americas, and Oceania (Australia).

3.1. Climate Change

Most of the descriptions of the climate change in different regions include increase of the mean annual or seasonal temperatures, changes in precipitation, both increase and/or decrease depending on the study area, higher frequencies of extreme weather events [33,83–85,89,99,133], such as heat waves, droughts and associated wild fires e.g., [71,81,82,98,101,115,122,124,137] or floods [98,101], changing rainfall patterns [43]; changes in physical and geographical zoning [93,94], changes in agroclimatic indices such as Growing Degree Days [96,97] or Temperature-Humidity Index [135], growing season length of crops [118]; the sea level rise [118]; changes in coastal zones [110,116] or alteration of permafrost and glaciers melting [47,113,116]. An increase in the frequency, duration, and intensity of droughts as the most dangerous effects of climate change on agriculture has been detailed globally, in all regions, and in many countries [47,68,69,71,80–82,89,99,101,102,112,115,116,122,124].

Some studies note the changes that have already happened in the last 10–30 years (e.g., in [11,80,82,89,99,109,117,129]). Others, based on different models, describe the predicted changes in the future by the years 2050–2100 according to various scenarios [71,86,87,90,98,103,105,108,119,123,128,134,135] or degrees of warming, e.g., +1 °C [93,104] or +2 °C [69]. In some papers, both current (past years) and future projections of climate change are discussed [114,125,126].

3.2. Changes in Agriculture Due to the Effect of Climate Change

Changes in climate can have different impacts on agriculture. Agricultural productivity is related to weather and climate, fundamentally depends on climatic stability, and, consequently, leads to challenges for food potential. Higher temperatures and reduced precipitation lead to growing aridity, water deficits, desertification, and increases in evapotranspiration, which lead to reduced yield potential, decreasing yields and the growing areas [114,125,126], deterioration of livestock conditions [17,47,69,85,126,137], and reduced reproduction and milk production [47,80]. Possible climate changes in the future may mean that some plants, such as coffee plants, will no longer be able to recover from the effects of natural disasters [131].

High temperatures and changes in precipitation also affect biotic factors, causing indirect effects such as intense weed growth, the incidence of pests and diseases, the introduction of new insects and diseases [13,47,111,112,122,131,134], or abiotic factors, such as widespread loss of nutrients [97,119]. Sea intrusion in coastal agricultural areas leads to agricultural land loss, pollutes freshwater resources, and increases salinity [11,47,109,110,112,115]. Another outcome is soil erosion and a decrease in its fertility [11,13,47,69,83,90,94,108,112,119,122]. Negative impacts are expressed in economic losses, increased labor, and equipment costs [89,137].

However, in temperate climates, yield gains are potentiated by longer growing seasons and the northward expansion of area for cereal cultivation, e.g., wheat, rice, and maize [33,80,84,88,89,92,101] or cotton [101,106], increasing pasture lands [135]. An increase in atmospheric CO_2 concentrations can lead to yield growth due to CO_2 fertilization [91]. Some countries and regions are shown to have both a negative effect in southern areas (climate losers) and a positive impact in northern parts (climate winners) [71,93].

3.3. Adaptation Strategies and Actions

Agricultural adaptation strategies and actions (ASA) can be grouped into different categories, depending on the spatial scale of adaptation options. Of the 65 papers included in the review, 22 consider adaptation actions at the local scale, or farmer's level; 8 at the regional scale, or institutional level; 4 at the national scale, discussing decisions and solutions at the governmental level; and 31 studies provide a comprehensive range of ASA scales, including Local-to-Region, Region-to-Nation, or Local-to-Nation strategies and actions. Additionally, two papers referred to as "Local scale" discuss the adaptation of plant species to possible climate changes [100,122].

3.3.1. Agricultural Adaptation Strategies and Actions: Local Scale

Our results show that most studies focus on the local scale (Local), involve mainly practical farmers' decisions, and activate a vast massif of techniques and methods. Among the farm production practices are often mentioned such as: (i) use of different crops or crop varieties, and plant breeding or development of new crop varieties more suitable to the changing climate—higher temperatures and/or reduced precipitation and hence, water availability, in a given region; flood, landslides, and drought-resilient; salt water resistant; insect and pest resistant [11,13,17,33,69,81,82,86–89,91,99,100,102–104,106–108,110,112,113, 116–118,120–123,126,128,133]; (ii) crop rotation and intercropping to improve soil quality and fertility [69,83,84,119,124]; (iii) adjustments in planting dates such as changes in harvest and sowing dates, e.g., later sowings, sowings to suit rainfall variability, etc. [13,17,47,81, 102,116,118,120,123,124,126,128,129]. Technologies are (can be) introduced for water and soil management, among them: (i) the adoption of water saving technologies such as efficient and sustainable irrigation practices including drip irrigation, micro irrigation and others, and the optimization of an irrigation schedule [11,88,89,91,98,100,102,106,108, 110,112–114,117,120,124,126,129,132,136]; (ii) waste water reuse [109]; (iii) mulching and contour plugging; the use of living barriers, which improves soil drainage and reduces water-logging; and increasing the soil capacity of moisture-holding [11,47,99,118,131].

Adaptation strategies employed by farmers can significantly increase yields [112]. The actual effects of climate change and variability largely hinge on farm characteristics such as intensity, size, and land use. These factors influence farm management and adaptation practices. Given that various farm types adapt differently, a greater diversity of farm types can mitigate the impacts of climate variability at the regional level. Nevertheless, certain farm types may still remain vulnerable.

3.3.2. Agricultural Adaptation Strategies and Actions: Regional Level

Region-scale ASAs (Region) involve mainly formal decision-makers and employ methods and tools that include the same adaptation practices as at the local level, when these strategies and options are managed by various institutions—Union Councils, private companies, NGOs—at the regional level [71,85,95,118]. These ASAs include (i) farmers' education, knowledge transfer and management changes [103,104,107,115,118]; (ii) introduction and running of regional early warning weather systems [85,115]; (iii) using modern weather services by integrating them into various digital platforms [96]; (iv) improving agricultural consulting, insurance and credit services [85,97,107,112,115,118,129,134]; (v) reducing the agricultural dependence on chemicals and synthetic fertilizers [17,92,110,111,125]; (vi) modernization of and investments in irrigation systems [11,13,101,102,107,110,112,118,129]; (vii) use of agroforestry [13,85,111,125] and (viii) alternative agricultural techniques [121]; (ix) sequester carbon support biodiversity through habitat and green corridor creation [85,119].

3.3.3. Agricultural Adaptation Strategies and Actions: National Level

At the national level (Nation), governmental programs and insurance include the provision of information to farmers about potential climate change impacts and adaptation measures. The government support mechanism is generally response-focused. National Action Plans for Adaptation [26] or National Strategic Plans [99] and National Agricultural Policies [121] to climate change are currently being developed and implemented in many countries around the world, concerning the major vulnerabilities of each country. Weather forecasts and information on climate change trends have public-good properties of non-rival consumption and high costs of exclusion [137]. It should be supplied by the government, not the competitive market, which can lead to the information being under-provided. Government roles should also include: (i) investment in R&D [93,95,97,113,115]; (ii) provision of transport, irrigation, and other infrastructure, and provision of a safety net for those who fail to successfully adapt to climate change [80,137]. Technological developments at the national scale include (iii) the development of early warning systems for risk communication to prevent loss from natural disasters [68,113,115]. Anticipatory disaster risk reduction and climate change adaptation planning are at the national level, as neither instrumental observation nor local awareness schemes alone are suitable for adaptation planning [113]. Other important adaptation strategies are (iv) selection and breeding of new drought/heat resistant/tolerant crop varieties [85,102,105]; (v) creating relevant genebanks [134]; (vi) developing agroforestry systems [69]; (vii) developing and implementing more efficient methods of irrigation [11,68]; and (viii) using renewable energy sources in modern agricultural systems [92]. Governmental support for (seasonal) migrations and alternative livelihood opportunities could help improve the sustainability of agriculture and its resistance to climate change and should be recognized as complementary to the current adaptation tactics and strategies [11,44,113,123]. National Agricultural Policy [121] also addresses the issues of environmental protection in agriculture, which, among others, implies developing farming systems and agro-technologies on a landscape basis [93] and supporting natural and agricultural biodiversity through the creation of habitat and green corridors [95]. Last but not least, Nation ASAs emphasize the importance of developing the international agricultural market, taking into account the opportunities and limitations of global change [91].

All results from the research studies mentioned above are listed in Table 1, where the papers are arranged according to continents, from Europe to Asia, Africa, the Americas, and Oceania, and inside the continents—according to the climate from temperate to equatorial climate zones, including tropical and subtropical, and all varieties of humidity. The following characteristics of studies involved in the review were extracted: study area and its climate, climate change characteristics, consequent changes in agriculture, spatial scale on which adaptation strategies and actions (ASAs) are proposed or executed, which are Local, Region, and Nation, and agricultural ASAs suggested or already used in the studied regions.

Table 1. Climate change and Agricultural Adaptation Strategies and Actions (ASAs). The periods are underlined for which the assessment of climatic changes was conducted.

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
1	[80]	Europe	Temperate	20th century: increase in surface air temperature (0.8 °C), precipitation (10–40%), drought in southern Europe (20%); reduced summer precipitation	Area of cereal cultivation expands northward; reduced reproduction and milk production in dairy cows; for cooler regions: reduced feed requirements, increased survival, lower energy costs; lower yields due to limited moisture supply	Nation	Later sowings in northern Europe; shorter rotations and regular thinning in the forests; soil management and planting techniques for the continental and Mediterranean forests
2	[81]	Europe	Temperate-to-Subtropical	Current and projected (by 2050) changes: increased incidents of heat waves and droughts	Negative effects on the continental climate in the Pannonian zone (Hungary, Serbia, Bulgaria, and Romania)	Local	Changing the timing of cultivation; selecting other crop species and cultivars
3	[82]	Europe	Temperate-to-Subtropical Mediterranean	1990 to 2003: increase in temperatures, water shortage, the incidence of heatwaves and related droughts	Reduction of crop yields and the area for cropping; generally lower yields in warmer climates	Local-to-Region	Changing crop rotations and inputs; irrigation management; fertilizer-intensive farmers; and higher exposure to extreme conditions stimulate adaptation
4	[47]	Europe	Boreal, Atlantic-to-Temperate-to-Alpine, Mediterranean	Four climate change scenarios for 2080s: increased temperature and precipitation (rainfall); increased risk of floods, drought and water scarcity; loss of glaciers and alteration of permafrost	Disruption of zoning areas and decreased crop productivity; increased area with the need for supplemental irrigation; deterioration of water quality; deterioration of soil quality and desertification; sea level rise intrusion in coastal agricultural areas; increased risk of agricultural pests, diseases, and weeds; deterioration of livestock conditions; improvement in livestock productivity	Local	Changing crop sowing days; growing heat-resistant cultivars; improving soil structure; contour plugging to improve soil drainage and reduce waterlogging; increasing the water-holding capacity of soils; increasing the collection of winter rainwater to increase the supply for subsequent irrigation; pests and diseases: the introduction of resistant or less-susceptible varieties; vaccination as a measure of adaptation to livestock diseases
5	[83]	Europe	Temperate	Scenario period 2040–2065 relative to baseline 1980–2005: warmer temperatures and more frequent extreme weather events	2040–2065: Yield losses for current crop varieties; decrease in spring-sown crops due to shortened growth duration and intensified drought; soil organic carbon decrease	Region	Crop rotations; crop residue management; re-initialization

Table 1. *Cont.*

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
6	[33]	Europe, Nordic countries	Temperate	Differences between 2071–2100 compared to 1961–1990: temperature increase 1–3 °C during spring, summer and autumn; stable or increased precipitation, with 30% increase in northern Sweden during spring; warmer and wetter conditions; more frequent extreme weather events	The vegetation period starts 10–50 days earlier and ends 5–50 days later, increasing agricultural production potential	Local	Northward expansion of crops; introduction of "new" crops and varieties; crop-, soil-, and water management; chemical plant protection; plant breeding
7	[84]	Finland	Temperate	The end of the 21st century: warming and lengthening of growing season; reduced time with snow cover; higher precipitation; potential increase in weather variability and extremes (windiness, heavy rains, warm spells)	Potential impact on crop yields; increasing pest risks; yield gains potentiated by longer growing seasons	Local	Intercropping: mixing of forage crops (grasses and legumes) and under-sowing cereals with perennial grasses; multi-species or cultivar-rich forage mixtures; maintaining and improving soil quality and fertility via intercropping
8	[85]	Great Britain (Scotland)	Temperate	Projections up to 2030, 2050, and 2100: wetter and warmer winters, drier and warmer summers, a higher frequency of extreme events	Hotter, drier summers impact the current crop growth; opportunities for new types of crops in the future; the negative impact of flooding and severe storms; wetter and warmer weather increases grass growth, supporting the livestock industry in the west and northern regions; extreme heat provides challenges for crops and livestock	Region-to-Nation	Adjusting planting and harvesting dates, selecting resilient crop types to withstand extreme weather, altering pasture and soil management practices, facilitating knowledge transfer, implementing management changes such as providing advice, establishing early weather warning systems, and promoting farmer cooperatives. Additionally, adaptations involve changes in fertilizer application frequency to enhance both inorganic and organic fertilizer efficiency, improved soil management techniques to respond better to wetter and drier conditions, which can support carbon sequestration and retention, as well as the utilization of agroforestry to sequester carbon, stabilize at-risk soils, provide shade and shelter to livestock, create diverse income sources, and support biodiversity by establishing habitats and green corridors; and the provision of transport, irrigation, and other infrastructure

Table 1. *Cont.*

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
9	[86,87]	Netherlands Flevoland Province	Temperate maritime	By 2050: 2 °C increase in global temperature, including changes in air circulation resulting in drier summers; 1 °C increase in global temperature, without changes in air circulation	Average climate change improves farm performance in terms of farm economic results; extreme events reverse the positive impacts of average climate change and pose large risks	Local	Combination of crop and farm level adaptation: shift to (more) winter wheat in systems dominated by root crops
10	[88]	Belgium, Loam Region	Temperate maritime	The end of the 21st century: a shift in climate conditions to drier summers and wetter winters	The positive impact of warmer temperatures on some crops, such as winter wheat, and the expected increase in extreme events such as heatwaves and longer drought periods will negatively affect summer crop yields, particularly sugar beet and potatoes	Local	Land-use changes: expanding the area dedicated to less susceptible crops like winter wheat; reducing the portion of land allocated to barley, sugar beet, potatoes, and grain maize; farming practices to mitigate crop stress: irrigation and techniques for conserving soil and water, such as drip irrigation for potatoes; the cost-effectiveness of irrigation practices may not be justified due to the significant financial burdens they would impose on farmers
11	[89]	France, Paris	Temperate	Current climate change in seasonal patterns (e.g., temperature, frost, wind) and in extreme events (e.g., droughts, heat waves)	Negative impacts on (i) vegetables (e.g., increased pressure from arthropods, metabolic disorders, decrease in crop yield and quality), (ii) farm management (e.g., increased and more difficult labor, more complex crop planning), and (iii) profitability (e.g., production losses, increased labor, and equipment costs); positive impacts (e.g., potential to extend the growing season or grow tunnel crops outside)	Local	Use of cover crops, mulching, agroforestry, and diversification; alterations in crop planning; implementation of equipment to regulate or ameliorate climatic conditions in enclosed environments like tunnels and efficient irrigation systems
12	[90]	Switzerland, Swiss Central Plateau	Temperate	2050: model ETHZ-CLM: strong climate change signal in summer with +3.5 °C and −24% in seasonal precipitation; model SMHIRCA-HadCM3Q3: moderate changes for the summer season with +1.3 °C and −11% in seasonal precipitation, but an important increase of +21% in seasonal precipitation during the fall	2050: a decrease in productivity by 0–10 %, an increase in soil loss by 25–35 %, and an increase in N-leaching by 30–45 %	Region	Adjustments in crop distribution, including an increase in the proportion of early-harvested winter cereals at the expense of irrigated spring crops; reduced tillage practices; irrigated areas should be directed toward soils with lower water retention capacity at lower elevations; some pre-alpine grasslands may also be converted into croplands

Table 1. *Cont.*

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
13	[91]	Austria	Temperate	Past 40 years: increase in annual temperature (0.8–1.8 °C); changes in precipitation (−2.2% ... +6.2%)	Increasing forage yields; likely benefits for grassland from higher temperatures and CO_2 fertilization	Local-to-Nation	Development of the National Adaptation Strategy for Agriculture: Robust adaptation measures should be (i) founded on integrative systems perspectives considering interplay between soil, plants, and water; (ii) sustainability considerations involving farming inputs and natural production factors are essential; (iii) incorporation of global change dynamics, including international market developments. Farmers: adopting irrigation systems, reducing tillage, implementing winter cover crop planting
14	[92]	Russia, European part	Temperate	By 2030 (compared to 1990–2020): sharp fluctuations in temperature; heavy rains in the central part; the onset of drought and dehydration of rivers in the south; southern part: increase of water resources shortage	In the central strip, yields will improve due to longer insolation, making it possible to grow agricultural plants that were previously cultivated only in the south	Region	Reducing the agricultural dependence on chemicals and synthetic fertilizers; creating incentives to promote the use of renewable energy sources in all modern agricultural systems
15	[93]	Russia	Temperate	+1 °C warming: precipitation increase in the north and decrease in the south; changes in physical and geographical zoning	The growth of aridity in the south of the country. In the northern part, the thermal regime is expected to improve. In the whole country, climate change will not significantly affect the agricultural sector.	Nation	Inventory and reassessment of agricultural resources and the assortment of cultivated plants; revision of the principles of environmental protection measures; formation of the ecological framework of natural zones due to new agricultural technologies; developing farming systems and agro-technologies on a landscape basis
16	[94]	Russia	Temperate	Current: changes in the annual and seasonal amplitudes of temperature and humidity, contributing to the displacement of the boundaries of bioclimatic zones to the north	Soil degradation, strengthening of erosion processes, and decrease in farmland fertility	Region-to-Nation	Expanding the cultivation of drought-resistant crop varieties and hybrids; undertaking land reclamation; transitioning to minimal or zero tillage technologies to prevent soil erosion; enhancing moisture retention; increasing use of fertilizers and plant protection products

Table 1. *Cont.*

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
17	[95]	Russia, Ulyanovsk Region	Temperate	1961–2010: higher temperatures and droughts; increase in climate change amplitudes	Decrease in the yield of grain crops; reduction of the area of grain and fodder crops	Region-to-Nation	Expanding crops of later-ripening and higher-yielding varieties of cereals and legumes, soybeans, and late-ripening varieties of forage crops; investing in R&D to develop crops that are more resistant to changing climatic conditions, especially high temperatures and droughts
18	[96]	Russia, Vologda Region	Temperate	Current: strengthening of regional differentiation in Growing Degree Days, distribution of frost-free periods, precipitation	Reducing the efficiency of the present system of agricultural production	Region	Using modern weather services by integrating them into various digital platforms for farming and performing mechanized work to increase the efficiency of agricultural production
19	[97]	Russia, Leningrad Region	Temperate	By 2030, compared to current: increasing air and water temperature; duration of the frost-free period; Growing Degree Days, precipitation, frequency, and intensity of natural anomalies	Intensive phosphorus and nitrogen leaching from agricultural lands causes a widespread loss of nutrients	Region-to-Nation	Improving state support for agricultural insurance, land reclamation, seed production, and the development of biotechnologies that ensure the effectiveness of budgetary support and accelerate the pace of adaptation of agricultural production to climate change
20	[98]	Europe, Mediterranean	Subtropical	Changes by the 2050s compared to 1961–1990: 1.5 °C temperature increase; up to 40% decrease in precipitation; increased evaporation; reduced soil moisture; changes in the annual precipitation patterns	Crop productivity decrease caused by shortening of the growing period; subsequent negative effects on grain filling; in some regions, reduced water quality due to higher water temperatures and lower levels of runoff	Local	Conservation tillage; irrigation management
21	[99]	Italy	Subtropical	Current: drought; wind; hail; flood events; late frost; damage by extreme maximum and minimum temperatures; intense precipitation; loss of suitability of the territory; saltwater intrusion; erosion; phytosanitary damage	Every year, potential damage to Italian crops from all climate events = 10–40% of production (yield and income, in quantity and value); 2009–2018 extreme events cost the agricultural sector EUR 14 billion: damage to structures, infrastructure, and production	Local	Eight thematic groups: soil management; soil conditioners and fertilizers; agronomic techniques; crop protection; water resources management; engineering, digitization, and training; innovative breeding techniques and animal welfare; winemaking techniques

Table 1. *Cont.*

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
22	[100]	Greece	Subtropical	Current: below-normal precipitation; warmer temperatures	Drought stress caused by water scarcity and increased evapotranspiration; plant damage; increased risk of wildfires	Local	Reduced irrigation; pruning; grafting; de-leafing; fertilization
23	[71]	Greece	Subtropical	By 2050: temperature increase; increase in duration and intensity of droughts, accompanied by significant reductions in summer soil moisture	Crops for which the effect of climate change is mostly negative (tomato, pepper, potato, olive trees); mostly benefited (cabbage, tobacco); with mixed regional effects (barley, grapevine, cucumber); northern and central Greece and Sterea Ellada and Attiki are climate winners, west and southern Greece are climate losers	Region	Adjustment of sowing dates to help plants avoid extreme temperatures; additional irrigation water through increased irrigation rates or high-efficiency irrigation systems; increased N-fertilization necessary to address nutrient deficiencies resulting from reduced precipitation; vineyards: changes in cultivation and management practices or relocation
24	[101]	Greece	Subtropical	2010–2099: increase in annual mean and maximum summer temperatures; increase in evapotranspiration; decrease in annual precipitation; more intensive summer droughts, floods, and soil erosion	Water cycle intensification, crop yield reduction, soil losses, declining water resources, increase in irrigation needs, a decrease in yield for some crops (maize, sunflower, and beans); a mostly negative effect for tomato, potato, and olive trees; increase in yield of rice, wheat, cotton, peach, and orange trees	Region-to-Nation	Modernizing irrigation systems; maintaining irrigation networks; recycling treated water for irrigation; selecting heritage crop varieties that exhibit drought and salt tolerance; suitable summer pruning; incorporation of shredded tree branches to enrich the soil surface
25	[102]	Cyprus	Subtropical	2031–2060: continual, gradual, and relatively strong warming; prolonged droughts; reduction of annual precipitation	Yield loss up to 9%; increase of the early winter sowing season (14–18%); tomato yield decrease (20–30%); almost stable olive yield; higher yield losses (24–38%) for late-matured grape varieties	Local-to-Nation	Green manure for vegetables; deficit irrigation strategies (regulated reduced irrigation) in olive groves; zero tillage and early sowing in wheat/barley crops; organic mulching for olive groves; artificial shading of vineyards; integrated pest management; intercropping with legumes; breeding drought/heat-resistant/tolerant crop varieties

Table 1. *Cont.*

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
26	[103]	Japan (Kazuno, Nagano), South Africa (Elgin)	Temperate humid (Kazuno) Subtropical humid (Nagano, Elgin)	By 2060: temperature increase	Apple (*Malus pumila var. domestica*) farming in: • Kazuno: climatically well suited and will be so in 2060; • Nagano: negative effects of high temperatures, such as paler color and softening of fruits; • Elgin: the climate is already close to the warmer margin with insufficient winter chill units; further warming will push this region beyond the critical threshold, with apple production no longer being commercially viable	Local-to-Region	Farm: Kazuno: drastic change by introducing peaches (*Prunus persica var. vulgaris*), a species better suited to a warm climate than apples; Region: Nagano: adopting technical remedies against the poor coloring and changing cultivars to those with lower chill unit requirements and higher tolerance against sunburn; Elgin: maintaining apple production by changing cultivars
27	[104]	Kazakhstan	Temperate	Different warming scenarios: (1) GFDL, (2) and (3) incremental; increase in: (1) +4.9 °C annual air temperature, +24% precipitation (2) +3 °C annual air temperature, +20% precipitation (3) +3 °C annual air temperature, no change in precipitation	Dramatically change in spring wheat yields: (1) Significant drying of soils: increased evapotranspiration from the higher temperatures outweighs the increased precipitation; the wheat cultivating area could decrease by >10% (2) Soil moisture increase (3) Soil moisture decrease; reduce the area suitable for wheat cultivation by more than 50%	Local-to-Nation	Snow reserving; choice of planting date; forecasts on agricultural pest and disease outbreaks; informing farmers about coping with climate change; regular local workshops on different techniques for growing wheat; sustainable seed banks with wide varieties available; change land management to reduce soil erosion; incorporating results into Kazakhstan's National Action Plan
28	[105]	China	Tropical in the far south, Subarctic in the far north, Alpine in Tibetan Plateau	B2 scenario, RCM projections by 2020s, 2050s, and 2080s: mean temperature increase by 1.2, 2.2, and 3.2; precipitation increase by 4%, 7%, and 10%, respectively	Increased instability in agricultural production since the 1980s; more severe droughts and heat waves in some places; increased crop damage from spring frost; northward and westward movement of winter wheat plantations in Northeast China; decrease (95%–10%) of crop productivity by 2030	Nation	Strengthening agricultural infrastructure; breeding stress-resistant crop varieties; developing new agricultural technologies (including biotechnology); promoting the large-scale planting of superior crop varieties in suitable areas for bolstering the agricultural sector's resilience to disasters

Table 1. *Cont.*

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
29	[106]	China	Tropical in the far south Subarctic in the far north Alpine in Tibetan Plateau	Current: temperature increase, precipitation decrease	Next 20–80 years: drop in rainfed yields of rice, wheat, and maize (20–36%); increase in cotton yields	Local-to-Nation	Nation: focus on smaller-scale irrigation and drainage projects; construction of water storage facilities; optimization of water utilization; encouraging research into seed varieties resistant to drought, waterlogging, high temperatures, diseases, and pests. Local (farm): choosing more adaptive, multi-functional, and high-yield crops; embracing water-saving technologies like plastic sheeting, drought-resistant varieties, stubble retention, low-till methods, and surface-level plastic irrigation pipes
30	[107]	China, Yongqiao District	Subtropical humid, dry winter	Current: temperature increase, precipitation decrease	Future crop loss, heat waves during the crop's flowering phase in July/August, and rainfall shortages affect stable crop harvests; more risky situations in the future	Local-to Region	Planting new crop varieties and adopting new technologies; increasing investments in irrigation systems; education and insurance adaptation practices
31	[108]	China, Huai River Basin	Temperate semi-humid and monsoon	2035s, RCP4.5, and RCP8.5 scenarios: mean temperatures increase by 1.34 and 1.65 °C; ensemble mean precipitation increases by 3.79% and 5.65%, respectively	Higher evapotranspiration from soil and plants leads to a higher magnitude of blue water footprint; lower precipitation increases the effect of temperature on blue water consumption	Local-to-Region	Switching to a more efficient irrigation technique (e.g., drip irrigation); switching to plant crops that require the least amount of water but produce the highest yields
32	[109]	Vietnam, Can Tho City	Tropical	1999–2008: air temperature increase (0.2 °C); solar radiation increase (by 200 h); air humidity decrease (5%); precipitation decrease (200 mm year^{-1})	Saline water invasion in inland areas is polluting freshwater resources and limiting agricultural production, particularly monocrop rice cultivation	Local-to-Region	Wastewater reuse

Table 1. *Cont.*

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
33	[110]	Vietnam, Ca Mau Peninsula	Tropical	By 2030: rise of sea levels: risk of further penetration of salt water with more severe intensity in coastal areas	Effect on tree growth: trees are stunted, and the yield is low depending on the salt concentration	Local-to-Region	Land use planning; transforming the agricultural model by selecting rice varieties tolerant to salt; augmenting salt tolerance by introducing rich Ca^{2+} fertilizers; adopting the alternate wetting and drying technique to optimize irrigation water usage and enhance the irrigation system; conversion of paddy land into aquaculture areas or the implementation of a rice-shrimp rotation model
34	[111]	Indonesia, West Java	Equatorial	Current: changes in rainfall patterns, especially the onset of the dry season and its duration	Decrease in productivity and quality of crop yields; indirect effects: increasing pests and diseases	Region	Expanding the arable land area through social forestry practices' intensifying pesticide use and employing more inorganic fertilizers. Alternatively, focus on increasing organic farming or transitioning to the cultivation of perennial crops
35	[112]	Nepal	Tropical savanna	Current: increased temperature; change in the timing of rainfall, including the late start of monsoons; decreased availability of surface and ground water; long-spell drought; less frequent but heavy rainfall causing floods and landslides	Reduction in the rice area planted, grain quality and yield; increased evapotranspiration thus require more irrigation; more infestation of insects and diseases; introduction of new insects and diseases; poor germination; water stress causing less tiller number, delay panicle initiation, reduce grain and panicle number; delay in transplantation; shortage of irrigation water; loss of crop due to heavy rainfall/hailstorm; destruction of water resources and irrigation canal; soil erosion; degradation of soil quality	Local-to-Region	Cultivating short-duration varieties; opting for insect and pest-resistant varieties; altering the planting locations of these varieties; improving irrigation methods; increasing weed control efforts; employing additional pesticides; implementing soil conservation techniques; reducing tillage; practicing seed priming; adjusting sowing/planting/harvesting dates; adopting direct-seeded rice cultivation; raising seed rates; growing drought-tolerant varieties; enhancing the use of chemical fertilizers; increasing the application of farmyard manure; establishing waterways to manage heavy rainfall; cultivating flood-tolerant varieties; transitioning to non-rice crops

Table 1. *Cont.*

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
36	[17]	Nepal, Terai	Tropical savanna	Current: abnormal changes in temperature and precipitation; the occurrence of extreme events: a decrease in the number of rainy days and an increase in the intensity of monsoon precipitation, floods, and landslide occurrences	Decline in production of cereal crops, attributed to increasing water stress that resulted from rising temperatures and reduced rainy days; decline in agricultural production; and direct loss of agricultural land and livestock due to the increased incidence and severity of climate-induced hazards	Local-to-Region	Climate-smart practices for grain yield improvement: no tillage; fertilizer (based on crop sensor readings); residue; green manuring
37	[113]	Western Nepal	Temperate-to-Tropical	Current: rapid glacier melt and snowpack loss, extreme precipitation and temperature events, and alteration of water availability	Negative impacts on water resource availability and agricultural productivity	Local-to-Nation	Promotion of crop varieties resilient to flood, landslides, and drought: transition to flood-resistant hybrid types of rice and sugar cane plantations in the flood-prone fields; use of bio-dams to mitigate the effect of floods and deforestation; methods of row spacing (intercropping) and agroforestry; provision of sustainable irrigation facilities; reliable services for dissemination of agricultural information; introduction of rainwater harvesting; spread of flood- and drought-resistant types of crops; support for alternative livelihood opportunities; development of reliable early warning systems to inform about risks
38	[114]	Sri Lanka	Tropical monsoon	Ratnapura: 1901–2000: mean annual temperature increase by 0.5 °C By 2050s: rainfall decrease (9%–17%)	Temperature rise leads to increased evapotranspiration, soil moisture loss, and crop physiology; disturbance to the normal cropping calendar; frequent crop failure and yield loss	Local	Five groups of adaptation measures: crop management, land management, irrigation management, income diversification, and rituals; transition of planting time to suit rainfall variability; implementation of micro irrigation; reduction of irrigation depth; and crop diversification

Table 1. *Cont.*

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
39	[115]	Iran, Fars Province	Temperate-to-Tropical	Current: severe droughts	Reduced quality and quantity of agricultural water resources (saltiness and bitterness)	Local-to-Nation	Cost management; development and diversification of income sources; social capital management (including use of facilities and loans); environmental stress management; use of educational and consulting services; additional: general and governmental adaptation interventions such as infrastructure development, removal of organizational barriers, creation of information and dissemination infrastructures
40	[116]	Pakistan, Khyber Pakhtunkhwa Province	Subtropical-to-Temperate, monsoon, semiarid	Current: temperature increase; prolonged summer seasons and short winters; fluctuating rainfall patterns, frequent floods, severe droughts, intense heat waves, melting of glaciers, and rise in sea level; unpredicted rainfall, disastrous floods, severe droughts, and storms	Great agricultural losses result in remarkable differences in expected crop yields	Local	Change crop type, variety, and planting dates; plant Eucalyptus on lands around the river to reduce soil erosion as a result of floods; change fertilizers, seed quality, and shaded trees; change the variety of crops
41	[117]	Pakistan	Subtropical-to-Temperate, semiarid	1980–2013: Significant increase in the summer and winter temperatures; rainfall: (1) slight increase in both summer and winter rainfall; (2) significant decrease in both winter and summer rainfall; (3) slight decrease in winter rainfall and an insignificant increase in summer rainfall, with large fluctuations over the years	B2 and A2 scenarios, decrease in productivity of main staple crops, wheat and rice, by 6–8% and 16–19%, respectively	Local	Development of heat-resistant and drought-resistant varieties; irrigation and soil conservation measures; and crop insurance schemes informing and training farmers on adequate strategies for adaptation to climate change; changing crop varieties, resource use, adaptation of planting dates, and planting shady trees
42	[118]	Pakistan, southern and central Punjab	Subtropical desert	Past 10 years: decreased winter and summer rainfall; increased temperature; the growing season length of crops; the sea level rise	Reductions in wheat yields; negative impact on productivity of cotton; severe adverse impact of GSL reduction on wheat and rice	Local-to-Region	Changing crop variety and type; planting dates; planting trees; increasing and/or replacing fertilizer; rational use of soil and water; income from non-agricultural activities; and diversification

Table 1. *Cont.*

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
43	[119]	India	Tropical-to-Sub-equatorial	Projected climate change: increased variability in summer monsoon precipitation	Land degradation due to soil erosion and nutrient depletion	Local-to-Nation	Conservation agriculture: reasonable disturbance of soil cover; contiguous crop rotation; conservation tillage, or without tillage; preservation of plant residues; organic farming; green manure application; mixed crop-livestock systems; biodiversity conservation approach
44	[13]	India, Uttar Pradesh	Subtropical humid with a dry winter	Current warming; increasing the incidence of strong winds; longer summers and shorter winters	Effect on agricultural productivity through physiological changes in crops and reduce grain quality; effect on other factors of production agriculture, such as water availability, soil fertility, and pests	Local-to-Region	Changes in agricultural and farming practices as a passive response: transition of sowing and harvesting dates, cultivation of short-duration varieties, inter-cropping, changes in the structure of crops, investment in irrigation and agroforestry
45	[120]	India	Tropical-to-Sub-equatorial	Projected increase in temperatures	Damage to crops, with greater challenge to wheat; lower heat-induced yield losses	Local	Adaptation between crops: types of crops, e.g., for growing more heat-resistant varieties of rice; cultivation of sorghum and maize, more resistant to heat than rice; transition to wheat as a crop that grows in cooler seasons; intra-crop adaptations: investments in irrigation to protect against heat and drought stress; transition of sowing dates to avoid heat stress; application of fertilizer or other agricultural resources for heat control; shading trees and planting to protect crops from high temperatures
46	[121]	Bangladesh	Subtropical monsoon	Projected temperature increase	Upset about rainfed rice crop choices	Local-to-Nation	Change the choice of crop in favor of irrigation-based Boro, Aus, and other crops; cultivate climate change-tolerant crop varieties, e.g., from the traditional rain-fed Aman variety to the irrigation-dependent Boro rice; use alternative farming practices (integrated farming, floating gardens)

Table 1. *Cont.*

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
47	[11]	Africa	Equatorial-to-Temperate semi-arid	Last 50–100 years: increased warming trend of 0.5 °C or more; increased heat; extreme weather events; droughts; more rapid minimum temperature warming than maximum temperature; annual precipitation has decreased in the eastern and western Sahelian regions; there has been an increase and intensification of droughts due to reduced precipitation; there has been increased evapotranspiration in Eastern and Southern Africa; and heavy precipitation events have increased in East Africa	Food crises due to droughts, crop pests (i.e., desert locusts), poor soil fertility, high salinity, and increased crop diseases and pests	Local-to-Nation	Variations and management of crops; water and soil management; financial schemes; migration, insurance, and culture; agricultural and weather services. Dominant strategies: crop diversification (51.5%), planting drought-tolerant varieties (45%), changing planting dates (42%), planting early-maturing crops (22%). Building more infrastructure for irrigation, water, and soil management; promotion of crop insurance; use of improved varieties; expansion of opportunities for diversification of livelihood, in addition to the established adaptation practices
48	[122]	Southwestern Morocco, Agadir	Subtropical-to Temperate arid, semi-arid, dry sub-humid	Current: enhanced drought periods; increased temperatures	Direct or indirect influence on vegetable crop production: water availability, temperature extremes during production cycles, soil fertility, pest populations	Local	Use of local crop varieties to mitigate the effects of drought due to fluctuations in water supplies
49	[69]	Asia, Africa, and Latin America	Tropical arid and semi-arid	+2 °C warming scenario: increasing surface temperature; increase in frequency and intensity of extreme rainfall events; higher drought frequencies	Reduced grain yields; effect on forest distribution, productivity, and health; a northward shift of tropical wet forests into areas currently occupied by tropical dry forests; soil erosion and sedimentation in mountain regions; negative impacts on sheep breeding and lamb wool productivity	Local-to-Nation	Utilization and processing of agricultural and secondary products and waste; cultivation of crops resistant to saltwater; adoption of practices that integrate crops and livestock; adjustment of crop varieties in response to shifting climate conditions; implementation of agro-forestry techniques; adoption of minimum or zero-tillage methods; utilization of traditional agro-silvi-pastoral systems; selection of appropriate crop varieties; practice of intercropping or relay cropping of grains with legumes; establishment of mixed systems combining trees, grasses, and crops; crop rotation; use of organic fertilizers with limited synthetic fertilizer application; effective utilization of crop residues

Table 1. *Cont.*

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
50	[68]	Sub-Saharan Africa	Equatorial-to-Tropical	Current: increasing temperatures; variable rainfall trends; increased droughts and flood frequencies; prevalence of storms and forest fires	2050: effect on crop production 10–20%, up to 50%	Nation	Changing crop dates; dam, well, and irrigation scheme construction; conservation agriculture; application of optimum fertilizer; harvesting of rainwater; crop diversification; management of disease and pests; water, irrigation, and flood management; insurance based on weather index; information and early-warning systems
51	[123]	Kenya	Tropical-to Temperate Humid-to-Semi-arid	End of the 21st century: median temperature increase to 34 °C	2050: significant yield losses (8–22%) of key staple crops	Local-to-Region	Alterations in agricultural practices: modifications in field selection, adjustments to planting dates, alterations in planting density, diversification of crop varieties; enhancements in livestock handling techniques, such as livestock selection, feeding methods, and animal health protection; changes in timing and location of cattle herding; improvements in land utilization strategies, including fallow land treatment, tree planting or safeguarding, irrigation, and water harvesting; conservation measures for soil and water resources; soil tillage practices; soil fertility management; livelihood strategies, encompassing the combination of cultivated crops and livestock production; blend of agricultural and non-farm activities; temporary or permanent migration
52	[124]	Kenya	Tropical-to Temperate Humid-to-Semi-arid	Current: frequent droughts, periodic floods, and unpredictable rainfall patterns	Threats to food and livelihood security	Local	Climate-smart agriculture: irrigation, changes in cultivation calendar; using certified seed; crop rotation; soil testing

Table 1. *Cont.*

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
53	[125]	Nigeria	Tropical-to-Temperate	1971–2000: air temperatures increase with a faster increase in minimum temperatures (0.8°C) Future: no specific trend in rainfall deviations	Agricultural productivity declination	Local-to-Region	Mixed cropping or intercropping practices; minimum or zero tillage methods; mixed farming and agroforestry; mixed crop-livestock-agroforestry system; integrated soil nutrient management; conservation tillage and slow-forming terraces; mulching; using vaccines, antibiotics, and anti-stress agents; planting trees for shade and to serve as windbreakers; proper water treatment; use of feed with a high nutrient content, crossing animals, and improving grazing areas; reduce the size of the herd to ensure adequate ventilation and improve the livestock-keeping system
54	[126]	Nigeria	Tropical	Past 30 years: increase in average minimum and maximum temperatures by about 0.25 °C and 0.15 °C, respectively; very high variability of rainfalls. Future: temperatures will continue to increase	Influence on crop and livestock production, hydrologic balances, input supplies, and other components of agricultural systems	Local	Tree planting; mixed farming; mixed cropping; soil conservation; using different crop varieties; transition of planting dates and irrigation; mulching; zero tillage; making ridges; early or late planting operations
55	[127]	Nigeria, Enugu State	Tropical wet and dry (savannah)	Projections for humid regions of southern Nigeria: increases in rainfall, cloudiness, and rainfall intensity. Projections for the savannah areas of northern Nigeria: temperature increase; reductions in rainfall; and soil moisture availability	Increased temperatures and a decrease in water availability reduce the length of growing seasons and yield potential; proliferation of pests and diseases; agricultural land loss due to a rise in the sea level	Local	Using resistant crop and animal varieties/species; using organic manure; mixed farming; diversifying crop production enterprises
56	[128]	Ghana, Sekyedumase District	Tropical Sub-humid	By 2050: temperature increase by 1.3–1.6; increase in inter-annual rainfall variability; increase in the intensity of rainfall events; decrease in the number of rainy days	Long drought periods during the reproductive (particularly grain filling) stage of crops affect grain size, weight, and hence yield	Local	Diversification of crops; transition of crop planting dates

Table 1. *Cont.*

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
57	[129]	South Africa, Limpopo Province	Subtropical-to-Temperate	Past four decades: increase in average minimum and maximum monthly temperatures; increase in the number of warmer days; decrease in the number of cooler days; increase in average rainfall; increased frequency and intensity of floods and droughts	Floods destroy crops, infrastructure, and the harvesting period	Local-to-Region	Efficient management of irrigation systems; water-efficient crop cultivation; optimization of irrigation scheduling; implementation of management approaches to minimize water wastage; insurance and subsidies; resizing of land holdings; transitioning from crop cultivation to livestock rearing; shortening of crop growing period
58	[130]	South Africa and Ethiopia	Subtropical	Projections: warming is expected to be greater than the global average; temperature increases mostly in the summer; precipitation decreases	Great threats to food and water security	Local	Using different crops or crop varieties; shade tree planting; soil conservation; transition of planting dates; irrigation; changing the area of cultivated land; animal feed supplementing
59	[131]	South-central Mexico	Subtropical-to-Temperate	Current: temperature increase; increase of warm nights and extreme minimum temperatures; decrease in cold periods, cold nights, and cool days; changes in the quantity and distribution of precipitation. The rainfall pattern is more irregular, with more stormy events	Coffee yield decreased by up to 34% due to changes in coffee growth, flowering, and fruiting. Increases in the incidence rates of pests and diseases (rust and coffee berry borer). Damage to coffee plants from natural disasters	Local	Use of coffee agroforestry systems with diversified species of multipurpose trees and shrubs; use of shade cover to avoid water stress during heatwave periods; slowing down the speed of downstream runoff water to reduce soil loss due to water erosion by using living barriers
60	[132]	Mexico, State Tlaxcala	Subtropical-to-Temperate	Climate change scenarios for the years 2020 and 2050 compared to 1961–1990: increase in minimum temperature; reduction of frost threats; severe droughts	Decrease in maize yields (Ceres-Maize model)	Local	Greenhouse construction; compost use; dripping irrigation
61	[133]	Brazil	Subtropical Temperate humid	Current: increase in extreme temperatures; decrease in average precipitation; more frequent intense precipitation; intensification of extreme weather events	More frequent heat stress; scarcity of drinking water; damage to agricultural production and rural properties by increased flooding	Local	Use of landraces tolerant to drought and other climate extremes

Table 1. *Cont.*

##	Study	Study Area	Climate	Climate Change	Effect on Agriculture	ASAs Scale	Agricultural Adaptation Strategies and Actions
62	[134]	Colombia	Tropical	By 2050s: increase in annual mean temperature by 2.5 °C, with a maximum of 2.7 °C in the Arauca department and a minimum of 2 °C in Chocó and Nariño; precipitation increase by 2.5%, with a minimum change of −1.4% in Cesar and a maximum of 5.6% in Huila. The driest periods throughout the year are likely less dry, while the wettest periods are projected to become wetter	Loss of plant genetic resources, desertification and salinization of agricultural lands, reductions in rice yield, loss of coffee growing environments; increases in incidence of coffee berry borer; increase in the risk of Fusarium head blight in wheat; change in soil water availability, enhancing drought in some regions and flooding risks in others; change in precipitation affects biotic factors (pests, diseases, weeds); increased pest and disease prevalence	Region-to-Nation	Postponement of harvesting and sowing dates; construction of walls and barriers to prevent salinization and protect coastal ecosystems; adaptation subsidies and an agricultural insurance system for producers on mountain slopes and in dry areas; placement of heat-resistant varieties in appropriate genebanks
63	[135]	USA	Temperate-to-Tropical	Three periods: 2010–2039, 2040–2069, and 2070–2099: temperature and summer temperature-humidity index increase; annual precipitation increases; summer precipitation decreases	Reducing crop land and increasing pasture land	Region-to-Nation	Shift of land use from cropping to grazing; decrease of crop land and increase of pasture land
64	[136]	USA, IL, Carbondale	Subtropical humid	Current: hotter and drier growing season	Drought is one of the most limiting factors in extensive green roof systems; water deficiency leads to a decrease in herb productivity but improves essential oils and antioxidant potential	Local	Improvement of roof materials, water-retaining gels, mulching, and subsurface irrigation systems to enhance the management of extensive green roofs for food production; supplemental irrigation to maximize quality and yield
65	[137]	Australia	Tropical-to-Temperate Semi-arid	Current: Southwest and southeast farming regions: average rainfall is falling and more variable. North: rainfall increase, increase in the severity of cyclones. South: higher temperatures, less rainfall, more frequent and longer drought periods, higher risks of bush fires	Changes in growth rates of different plant and animal species; output responses to different plant and animal production methods; changes to the best times for planting and harvesting; effects on comfort and productivity of farm animals; decreased suitability of farm labor working conditions in many northern regions	Local-to-Nation	Contributions from the government; changes in personal subsidiary farms

4. Discussion

Current climate change faces various challenges for the global community in all spheres of livelihood, including agricultural development and production. Climate change adaptation actions in agriculture incorporate a wide diversity of activities at different scales linked to declining agricultural exposure and vulnerability to changes, such as technological developments or changes in production practices [87].

Of the 65 papers included in the review, 48% consider adaptation measures at the whole range of ASA scales, from Local to Region and Nation, emphasizing the fact that all levels of decision-making should be involved and interconnected in the adaptation process. Developments at one level can help in the implementation of plans at another level, and vice versa, failures in the implementation of decisions at any level can lead to maladaptation as a whole. For example, several studies show the need for regional-scale measures such as investments in training and education, easier access to credits, which can help to adopt local adaptation actions, and facilitating the adjustment process among the poorest farmers at the local scale [128,130].

To describe the picture in "large strokes", the results identify five groups of the most relevant adaptation measures stimulated by the impacts of climate change. The ASAs in agriculture that can be distinguished at the Local and Region scales are: (i) crop varieties and management, including changes in land use and innovative breeding techniques; (ii) water and soil management, including agronomic techniques; (iii) farmers' education and knowledge transfer; at the Region and Nation scales: (iv) financial schemes, insurance, migration, and culture; (v) agricultural and weather services, R&D, including the development of early warning systems [11,99,138].

More considerations are addressed below, emphasizing additional aspects on the topic of agricultural adaptation to climate change.

4.1. Climate Change and Agriculture: Shortcomings and Advantages

Climate change has a multiplicative effect on the climate system. In recent decades, tropical Asian countries have reported increasing surface temperature trends and decreasing trends in rainfall. Even with only small changes in climate, the frequency and intensity of extreme events may change in Africa. In Latin America, the climate is affected by the El Niño-southern oscillation, and depending upon the phases of the phenomenon, there is a close relationship between the increase and decrease of precipitation. Local farmers in these regions use crop cultivation strategies such as inter- or mixed cropping. They allow minimal risks and ensure certain productivity even in lean years [69].

Droughts are one of the most dangerous consequences of climate change caused by a decrease in precipitation and/or an increase in temperature, in terms of further implications for agriculture. Drought stress leads to a water deficit, which is also caused by increases in evapotranspiration under a warming climate [139]. Related to droughts, water shortages are one of the key risks for agriculture in the future. Thus, it is essential to research the capability of crops to grow in a water deficit. As it was shown by Sperdouli with coauthors [100], some of the tomato cultivars have no difference in photochemical efficiency under 50% less water. Such research is helpful for estimating minimum irrigation levels for effective photosynthesis.

On the one hand, in the northern areas of temperate regions, climate change is anticipated to increase the food production potential and expand suitable areas for crop cultivation. As a result of prolonged growing seasons and higher CO_2 concentrations, increases in net primary productivity (35–54%) are projected in northern Europe [80,140]. Expansion to the North is often considered a decision to address the problems of agriculture caused by climate change in lower-latitude countries [141]. On the other hand, there might be an increased need for plant protection, a risk of nutrient leaching and speeded decomposition in soil organic matter [33], or challenges for agricultural systems located on arable permafrost-affected soils, such as equipment problems, waterlogging of soil, damage to infrastructure, losing topsoil, and soil fertility [141]. Moreover, the reduced duration of snow cover and frost at the soil level may have a negative effect on forest production and can decrease recreational possibilities. In southern areas, climate change is predicted to bring more negative changes with limited benefits [80].

4.2. "Bottom-Up" and "Top-Down" Approaches: Pros and Cons

Generally speaking, "top-down" and "bottom-up" are two different approaches to problem solving, analysis, and decision-making in various fields, including business, psychology, and software development. The "top-down" approach starts with the big picture and breaks it down into smaller parts, while the "bottom-up" approach starts with individual components and combines them into a larger whole [142]. In environmental science, "top-down" approaches usually define critical parameters that relate to comprehensive social benefits and more detailed goals of institutions or operations and denote observations or activities planned in the context of a global, international, or national framework, often with a focus on national and international assessments and scientific research. "Bottom-up" approaches refer to surveillance or action initiatives defined and implemented at a lower level and subsequently transferred to higher-level authorities, often with an emphasis on achieving the results sought by the local communities [142].

Initially, in changing conditions, farmers adapt in their own way, mostly reactively and independently, without having the required comprehension and financial resources to operate for a long time. In order to avoid making wrong decisions, regional and national administrations must respond properly. While "bottom-up" approaches with adaptation options at the Local scale, or at the local level, are aimed at producing and realizing actions to formulate and implement policies with the interest of the local community to fight against recent past or present vulnerabilities [52], "top-down" approaches convey the policies developed by the government at the Region-to-Nation scales with the involvement of technical specialists and based on climate projections and modeled impacts [59].

In many cases, "bottom-up" approaches lag behind "top-down" approaches applied to carbon emission budgets and targets suitable for climate change mitigation aimed at reducing greenhouse gas emissions [143]. As a rule, a "top-down" approach is preferable when the difficulties faced by "bottom-up" approaches, such as the absence of information, inducements, and resources, which are obstacles to effective policy realization, are found [144]. Adaptation actions, which were mainly carried out using a "top-down" approach, may lead to actions that do not meet the actual demands of fragile communities [54,59,144,145]. The fight against climate change is a global problem, but adaptation measures should be taken at the local scale and with the real participation of the community. "Bottom-up" approaches are likely to be a crucial element of adaptation measures at the local level, especially considering the areas' variety, and should be implemented in accordance with their specific conditions and vulnerabilities.

"Bottom-up" approaches are seen as an effective management method and a way to ensure that local communities and marginalized groups of society have a voice in climate policy. At the community level, they may be appropriate for some climate change adaptation realities. However, for other climate change adaptation measures—for example, in the field of infrastructure, "top-down" approaches may be preferable. At the same time, some unpredictable threats from the "bottom-up" approaches can be raised. In countries with low preparedness for the present climate change risks, local and individual countermeasures can eventually increase societal disparities, lead to long-term maladaptation, and even encourage the aggravation of the climate crisis [146].

Adaptation strategies depend on local conditions, region, or country; limiting the discussion of possible options and measures to only one type of approach—"top-down" or "bottom-up"—can lead to unsatisfactory solutions for those areas that have been most affected by climate change but have insignificant resources to adjust to it [52,59].

4.3. Intercropping as a Cultivation Technique

Adapting a crop system to weather variability and climate change is crucial for sustainable and durable food production. Resistance to unexpected weather conditions depends, among other circumstances, on the intercropping or alternation of crops with the inventive cultivation of many interacting crop species or genotypes together in time and space, which enriches the diversity of the farming fields and landscapes [72,113,125]. It can serve as a means of solving the problems of crop cultivation in northern agriculture caused by climate change [84,102]. In a qualitative study in Finland, it was revealed that intercropping leads to increased yield, self-sufficiency in nutrients and proteins, preservation and care of soil, reduction of pathogen pressure, and regulation of water dynamics [84]. The most notable intermediate crops are: nitrogen-fixing legumes; deep-rooted species, e.g., Lucerne (*Medicago sativa* L.); special crops, e.g., herbs in feed mixtures; as well as winter oilseeds and cereals sown in autumn [84].

Local crop varieties, or crop landraces, are heterogeneous mixtures of genotypes that give plant phenotypes with small but important differences in field conditions [147]. The genetic variety of such mixtures allows agricultural crops to adapt to drought, heat, saline soil, or other extreme environmental conditions. Landraces with their high heterogeneity can help mitigate such problems as crop failures, reduced yields, loss of quality, and an increase in the number of problems with insects and disease, which can worsen under climate change conditions [122]. The genetic diversity contained in landrace populations is an important part of the global diversity of crops and is considered of primary significance for future international agricultural production [69,122]. Thus, small landholders can use landraces as a means of adaptation to changing climates [133].

Other multiple-purpose farming systems and strategies to combine a variety of crops and animals will make more effective applications of natural resources, involving frameworks and approaches to land management such as agroforestry, alley cropping, and permaculture. Future systems will be spatially diverse and adjusted to certain local environmental conditions and will include ecological design based on whole-system ecologically based thinking.

4.4. Traditional and Indigenous Knowledge

Adaptation measures are most effective when they correspond to local conditions and their incentives, opportunities, and resources, including the use of traditional knowledge and community participation. Traditional knowledge (TK) is determined as the local knowledge of a cultural group or a society, as opposed to the global, widespread knowledge acquired by researchers at universities and private institutions [148]. TK is a complex experience of local farmers collected over thousands of years and described by high production capacity, conservation of biodiversity, low energy consumption, and mitigation of climate change. It can serve as a guide in the development of sustainable farming systems [119,149]. Traditional agriculture is usually located on small farms that integrate crops and livestock, thus reducing their reliance on external inputs such as fossil fuels, fertilizers, and pesticides [69,149,150]. Having experience farming in different extreme weather events, traditional farms are also resistant to environmental changeability with minimal external influences [151,152].

Traditional agriculture includes such practices as agroforestry, crop rotation, intercropping, traditional organic composting, cover cropping, and integrated crop-animal farming, which can be accepted as the model methods for climate-smart agriculture. These practices enhance agricultural sustainability and help in mitigating climate change [153]. Highly productive traditional farming in marginal regions, for example, intercropping integrated into animal husbandry and/or agroforestry, constitutes the potentially effective farming skills of traditional farmers based on a deep appreciation of the natural environment laws [154]. Sharing the experience gained by local producers and integrating local knowledge into regional and national adaptation policies will help develop more effective adaptation strategies to decrease vulnerability to climate change [131].

Looking further and deeper into TK practices, Indigenous TK describes ways of learning and a comprehensive approach to living off the land and learning from it [10]. Indigenous peoples' knowledge and adaptation are collective information and expertise in the field of biodiversity, controlled by the community and improved from generation to generation, performing a key role in the management of natural resources via traditional practices [154]. In the current unfavorable environmental scenarios, Indigenous TK developed for generations in the process of a long interactive assimilation of Indigenous peoples with their local environments after several trials and errors and is recognized as scientific and consistent knowledge [119]. For example, in the Sakha Republic, Russia, local Indigenous people have for centuries effectively used permafrost landscapes such as alases (pools of a thaw lake) for hay production [155]. According to Shaffril and colleagues [65], traditional Indigenous knowledge should be integrated into current adaptation strategies as follows: (1) promote the recognition of TK and the role of Indigenous peoples in policy design and formulation; (2) develop a strategic adaptation scheme that meets the requirements, capabilities, and concerns of Indigenous peoples; and (3) announce particular spheres and study content that future research should be focused on [65].

4.5. Biodiversity-Based Agriculture

Agricultural ecosystems, like other ecosystems, depend on biodiversity, and species of animals and plants depend on sustainable agricultural landscapes [85]. But in the last decades, due to intensive monoculture farming, agrobiodiversity has reduced, with the main sown crops being corn, wheat, rice, soyabean, and others [156–158]. It is estimated that in the 20th century, 75% of the world's food crop diversity was lost due to the replacement of local varieties by genetically uniform, high-yielding varieties [12].

Biodiversity-based, or "ecologically intensive agriculture", is a strong ecological modernization of agriculture that relies on high biological diversification of farming systems [159] and intensification of ecological interactions between components of the biophysical system that contribute to productivity, fertility, and resistance to external perturbations [160]. Biodiversity-based agriculture, as a way of adapting to current climate change, addresses several agricultural aspects of the current climate crisis; it supports ecosystem services and reduces the use of chemicals. Its inherent complexities are only a little understood, which leads to a little awareness that can be used as an indication supporting its regulation [85,119,161].

Providing the world with food depends on protecting our valuable ecosystems and their biodiversity. Environmental protection actions in agriculture should be addressed in existing NAPs [121]. In food production, preference should be given to ecosystem rehabilitation and conservation, which requires a far-sighted rational management strategy and fundamental changes in models and practices of economic development, products, and production. Food systems must be restructured in such a way as to have a neutral and positive impact on the environment, as well as to ensure healthy nutrition and food safety, and strategies with a low impact on the environment should become a priority task [21].

4.6. Climate Smart Agriculture

To better adapt to climate change, farmers must develop or transform their agricultural systems by replacing old procedures and practices with climate-smart agricultural practices [162,163]. Climate-smart agriculture (CSA) is an integrated agricultural approach to agricultural management aimed at sustainable growth of agricultural productivity and incomes, solving the interrelated problems of food security and climate change, reorienting agricultural development for achieving mitigation and adaptation goals, and effectively controlling agricultural growth [17,22,124,164,165]. CSA includes a range of adaptations and climate change mitigation practices aimed at sustainably increasing productivity (food, fiber, and fuel production), reducing GHG emissions, improving resilience, and promoting national food security and development goals [12,22,124,166]. CSA considers not only environmental but social and economic scope as well, to expand advantages and diminish compromises, consequently involving institutional, policy, and technological practices [165]. CSA activities are a combination of technologies and practices implemented in the agricultural system at various scales [15,165]. They include both long-existing traditional practices and innovative agricultural technologies known and promoted extensively, such as agroforestry, conservation agriculture, biodiversity-based agriculture, water management, and sustainable land management practices or technologies [16,18,165]. At the farm level, the implementation of CSA practices depends on the social-economic environment, which is influenced by institutional patterns, resource accessibility, and climatic conditions. The use of a combination of methods allows farmers to expand the synergy between CSA practices and technologies, increasing farms' productivity in the face of intersecting challenges [18,124,167].

While it is desirable to reach all the goals, in the real world of agriculture, trade-offs will be necessary to find a compromise between the goals of productivity, sustainability, and mitigation. Today, CSA is a key concept for many organizations working at the nexus of climate change adaptation and agriculture. CSA is a set of guidelines that can be used to identify successful agricultural production models among different methods. Any agricultural technology compared to standard existing practices can ameliorate the objectives of CSA and be indicated as climate-smart [168].

Just a decade ago, it was argued that the concept of CSA was vague and with no firm criteria, with "no specific direction, no new science agenda, no ability to negotiate and prioritize contentious, conflicting agendas, and no compelling reason to increase or shift investment" [169]. Nowadays, we can justify the main directions of the future development of the CSA as follows: (i) involvement of advanced Internet technologies to provide the information security of agriculture; (ii) improvement of the crop structure and management methods; (iii) provision of "Internet + weather" services; (iv) enhancement of the agricultural service quality; and (v) development and use of agricultural weather insurance [22]. These ideas and strategies will consolidate ecological conservation, stimulate sustainable advancements in agriculture, and extenuate the effects of climate change.

4.7. Catching Maladaptation before It Happens

The adaptation of farmers to climate change is facing many challenges of various origins, such as physical, environmental, economic, institutional, technological, socio-cultural, psychological, or political [28,30,41–43,114,130]. Some adaptation measures taken in response to climate change may be insufficient and even elevate vulnerability to it. New areas of concern arise, particularly maladaptation—a concept widely used to denote the negative effects of adaptation to climate change [26], in farmers' programs, and at regional or national adaptation policies [58,170]. The term "maladaptation" is defined as "changes in natural or human systems that inadvertently increase vulnerability to climatic stimuli; an adaptation that does not succeed in reducing vulnerability but increases it instead" ([171], p. 378). Some adaptation practices can serve short-term goals but involve future costs for society from a long-term perspective, causing unpredictable negative changes. At the same time, the review study conducted in South Asian countries shows that short-term adaptation options, such as improved agricultural technologies, may fail without long-term investments in institutional changes [67].

The bad tidings comprise the point that there is a dramatic ambiguity in the climate forecasts themselves. The mysteries of uncertainty arise from knowing what future climate to expect before communicating planned decisions. The solution may be to apply sensitivity analysis, which can show areas with high sensitivity to climate change and the degree of their potential impact [172]. These assumptions about the likely success of adaptation can be made based on a very small amount of research. The potential for achieving some degree of success on a global scale, even if entirely warranted, likely conceals noteworthy variations at the regional level in terms of their effects, adaptability, and the underlying assumptions regarding vulnerability. Exposure to multiple stresses and impacts leads to growing uncertainties and higher vulnerabilities [6,103]. In short, it is not easy to find the right solution anyway, and unfortunately, there will be winners and losers [31,172].

The general assumption is that some incursions unintentionally exacerbate, reallocate, or even generate new resources of vulnerability, which are caused by (i) superficial comprehension of "sensitivity" and "vulnerability" concepts; (ii) uneven involvement of the interested participants in the development and fulfillment of the adaptation programs; (iii) inclusion of adaptation strategies and actions into already operating development projects; and (iv) lack of critical attitude to how to define an "adaptation success" [55]. Three types of maladaptive consequences can be grouped as (i) restoring vulnerability; (ii) changing vulnerability; and (iii) undermining sustainable development [173].

Future research should focus on adaptation options to examine farmers' and societal readiness and the difficulties they face in adopting new adaptation strategies, as well as their essential influencing factors, to catch maladaptation before it happens [174].

5. Conclusions and Recommendations

The objective of this study is to review adaptation strategies and interventions in countries around the world proposed for implementation to reduce the impact of climate change on agricultural development and production at various levels. The attempt is not so much to cover all works on the topic but rather to fill a gap in studies showing adaptation actions at different levels of agricultural production, ranging from regional and local farmer responses to government involvement or national level, by compiling a scoping review of the literature. The study was completed in three stages: (i) identifying the climate diversity and climate change patterns; (ii) determining the impact of climate change on agricultural production; and (iii) recognizing adaptation strategies and actions in the agricultural sector, including at the local (farms), regional (institutions), and national (governments) levels. The search identified 65 studies that were selected for the review. The studied areas include a wide range of climates, from equatorial to temperate, with various humidity variations (arid, semi-arid, humid, monsoon, Mediterranean, maritime). Most descriptions of climate change in different regions include increases in mean annual or seasonal temperatures, changes in precipitation, both upward and downward, depending on the study area, and increases in the duration, frequency, and intensity of extreme weather events, including heat waves and droughts. The negative impacts of climate change are expressed in terms of reduced crop yields and crop area; impacts on biotic and abiotic factors; economic losses, increased labor, and equipment costs. However, there are positive impacts in temperate climates, which are reflected in increased crop yields, enhanced by longer growing seasons and the northward expansion of crops such as wheat, rice, and maize.

Recommended strategies and actions for agricultural adaptation that can be emphasized at local and regional levels are crop varieties and management, including land use change and innovative breeding techniques; water and soil management, including agronomic practices; farmer training and knowledge transfer; at regional and national levels, financial schemes, insurance, migration, and culture; agricultural and meteorological services; and R&D, including the development of early warning systems.

In many cases, measures to adapt agriculture to climate change are currently represented by guidelines based on administrative boundaries (Nation or Region scale). On the contrary, it is necessary to develop recommendations based on climate realities that are acceptable not for the country(ies) as a whole but for agricultural units (Local scale) located in a certain climate. It is not entirely obvious whether the future climate will present mainly challenges or opportunities, so the recommended measures may even oppose one another. The adaptation choices are not easily made since they may lead to unknown or even negative outcomes.

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References

1. McLennan, M. *The Global Risks Report*, 17th ed.; World Economic Forum: Cologny/Geneva, Switzerland, 2022; 116p.
2. Godfray, H.C.J.; Beddington, J.R.; Crute, I.R.; Haddad, L.; Lawrence, D.; Muir, J.F.; Pretty, J.; Robinson, S.; Thomas, S.M.; Toulmin, C. Food Security: The Challenge of Feeding 9 Billion People. *Science* **2010**, *327*, 812–818. [CrossRef]
3. Zeifman, L.; Hertog, S.; Kantorova, V.; Wilmoth, J. *A World of 8 Billion*; Policy Brief No140; UN DESA: New York City, NY, USA, 2022.
4. Alexandratos, N.; Bruinsma, J. *World Agriculture: Towards 2030/2050*; ESA Working Paper No. 12-03; FAO: Rome, Italy, 2012.
5. Resolution A/RES/70/1. Transforming Our World: The 2030 Agenda for Sustainable Development. In Proceedings of the Seventieth United Nations General Assembly, New York, NY, USA, 25 September 2015; United Nations: New York, NY, USA, 2015. Available online: http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E (accessed on 12 August 2023).
6. Pradhan, P.; Costa, L.; Rybski, D.; Lucht, W.; Kropp, J.P. A Systematic Study of Sustainable Development Goal (SDG) Interactions. *Earths Future* **2017**, *5*, 1169–1179. [CrossRef]
7. Soergel, B.; Kriegler, E.; Weindl, I.; Rauner, S.; Dirnaichner, A.; Ruhe, C.; Hofmann, M.; Bayer, N.; Bertram, C.; Bodirsky, B.L.; et al. A sustainable development pathway for climate action within the UN 2030 Agenda. *Nat. Clim. Chang.* **2021**, *11*, 656–664. [CrossRef]
8. Fuldauer, L.I.; Thacker, S.; Haggis, R.A.; Fuso-Nerini, F.; Nicholls, R.J.; Hall, J.W. Targeting climate adaptation to safeguard and advance the Sustainable Development Goals. *Nat. Commun.* **2022**, *13*, 3579. [CrossRef] [PubMed]
9. Lal, R. Advancing climate change mitigation in agriculture while meeting global sustainable development goals. In *Soil and Water Conservation: A Celebration of 75 Years*; Soil and Water Conservation Society: Ankeny, IA, USA, 2020.
10. Shahmohamadloo, R.S.; Febria, C.M.; Fraser, E.D.G.; Sibley, P.K. The sustainable agriculture imperative: A perspective on the need for an agrosystem approach to meet the United Nations Sustainable Development Goals by 2030. *Integr. Environ. Assess. Manag.* **2022**, *18*, 1199–1205. [CrossRef]
11. Magesa, B.A.; Mohan, G.; Matsuda, H.; Melts, I.; Kefi, M.; Fukushi, K. Understanding the farmers' choices and adoption of adaptation strategies, and plans to climate change impact in Africa: A systematic review. *Clim. Serv.* **2023**, *30*, 100362. [CrossRef]
12. *Climate-Smart Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation*; FAO: Rome, Italy, 2010.
13. Tripathi, A.; Mishra, A.K. Knowledge and passive adaptation to climate change: An example from Indian farmers. *Clim. Risk Manag.* **2017**, *16*, 195–207. [CrossRef]
14. Gosnell, H.; Gill, N.; Voyer, M. Transformational adaptation on the farm: Processes of change and persistence in transitions to 'climate-smart' regenerative agriculture. *Glob. Environ. Chang.* **2019**, *59*, 101965. [CrossRef]
15. Amadu, F.O.; McNamara, P.E.; Miller, D.C. Understanding the adoption of climate-smart agriculture: A farm-level typology with empirical evidence from southern Malawi. *World Dev.* **2020**, *126*, 104692. [CrossRef]
16. Arif, M.; Jan, T.; Munir, H.; Rasul, F.; Riaz, M.; Fahad, S.; Adnan, M.; Mian, I.A.; Amanullah. Climate-Smart Agriculture: Assessment and Adaptation Strategies in Changing Climate. In *Global Climate Change and Environmental Policy*; Venkatramanan, V., Shah, S., Prasad, R., Eds.; Springer: Singapore, 2020. [CrossRef]
17. Gairhe, J.J.; Adhikari, M.; Ghimire, D.; Khatri-Chhetri, A.; Panday, D. Intervention of Climate-Smart Practices in Wheat under Rice-Wheat Cropping System in Nepal. *Climate* **2021**, *9*, 19. [CrossRef]
18. Ariom, T.O.; Dimon, E.; Nambeye, E.; Diouf, N.S.; Adelusi, O.O.; Boudalia, S. Climate-Smart Agriculture in African Countries: A Review of Strategies and Impacts on Smallholder Farmers. *Sustainability* **2022**, *14*, 11370. [CrossRef]
19. Azadi, H.; Siamian, N.; Burkart, S.; Moghaddam, S.M.; Goli, I.; Dogot, T.; Lebailly, P.; Teklemariam, D.; Miceikienė, A.; Van Passel, S. Climate smart agriculture: Mitigation and adaptation strategies at the global scale. In *Climate-Induced Innovation: Mitigation and Adaptation to Climate Change*; Springer International Publishing: Cham, Switzerland, 2022; pp. 81–140. [CrossRef]
20. Bazzana, D.; Foltz, J.; Zhang, Y. Impact of climate smart agriculture on food security: An agent-based analysis. *Food Policy* **2022**, *111*, 102304. [CrossRef]
21. Çakmakçı, R.; Salık, M.A.; Çakmakçı, S. Assessment and Principles of Environmentally Sustainable Food and Agriculture Systems. *Agriculture* **2023**, *13*, 1073. [CrossRef]
22. Zhao, J.; Liu, D.; Huang, R. A Review of Climate-Smart Agriculture: Recent Advancements, Challenges, and Future Directions. *Sustainability* **2023**, *15*, 3404. [CrossRef]
23. Smith, P.; Olesen, J. Synergies between the mitigation of, and adaptation to, climate change in agriculture. *J. Agric. Sci.* **2010**, *148*, 543–552. [CrossRef]
24. Intergovernmental Panel on Climate Change (IPCC) 2021. Available online: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf (accessed on 10 August 2023).

25. Malhi, G.S.; Kaur, M.; Kaushik, P. Impact of Climate Change on Agriculture and Its Mitigation Strategies: A Review. *Sustainability* **2021**, *13*, 1318. [CrossRef]
26. Orlove, B. The Concept of Adaptation. *Annu. Rev. Environ. Resour.* **2022**, *47*, 535–581. [CrossRef]
27. 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*, 42539–42559. [CrossRef] [PubMed]
28. Goonesekera, S.M.; Olazabal, M. Climate adaptation indicators and metrics: State of local policy practice. *Ecol. Indic.* **2022**, *145*, 109657. [CrossRef]
29. Schoenefeld, J.J.; Schulze, K.; Bruch, N. The diffusion of climate change adaptation policy. *WIREs Clim. Chang.* **2022**, *13*, e775. [CrossRef]
30. Singh, C.; Iyer, S.; New, M.G.; Few, R.; Kuchimanchi, B.; Segnon, A.C.; Morchain, D. Interrogating 'effectiveness' in climate change adaptation: 11 guiding principles for adaptation research and practice. *Clim. Dev.* **2022**, *14*, 650–664. [CrossRef]
31. Burton, I.; Lim, B. Achieving Adequate Adaptation in Agriculture. *Clim. Chang.* **2005**, *70*, 191–200. [CrossRef]
32. Howden, S.M.; Soussana, J.-F.; Tubiello, F.N.; Chhetri, N.; Dunlop, M.; Meinke, H. Adapting agriculture to climate change. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 19691–19696. [CrossRef] [PubMed]
33. 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. [CrossRef]
34. Niang-Diop, I.; Bosch, H. Formulating an adaptation strategy. In *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*; Lim, B., Spanger-Siegfried, E., Huq, S., Malone, E.L., Burton, I., Eds.; Cambridge University Press: Cambridge, UK, 2005; pp. 185–204.
35. Burton, I.; Malone, E.L.; Huq, S. *Adaptation Policy Frameworks for Climate Change. Developing Strategies, Policies and Measures*; Cambridge University Press: Cambridge, UK, 2005.
36. Biesbroek, G.R.; Swart, R.J.; Carter, T.R.; Cowan, C.; Henrichs, T.; Mela, H.; Morecroft, M.D.; Rey, D. Europe adapts to climate change: Comparing national adaptation strategies. *Glob. Environ. Chang.* **2010**, *20*, 440–450. [CrossRef]
37. Smit, B.; Burton, I.; Klein, R.J.T.; Wandel, J. An Anatomy of Adaptation to Climate Change and Variability. In *Societal Adaptation to Climate Variability and Change*; Kane, S.M., Yohe, G.W., Eds.; Springer: Dordrecht, The Netherlands, 2000. [CrossRef]
38. Iancu, T.; Tudor, V.C.; Dumitru, E.A.; Sterie, C.M.; Micu, M.M.; Smedescu, D.; Marcuta, L.; Tonea, E.; Stoicea, P.; Vintu, C.; et al. A Scientometric Analysis of Climate Change Adaptation Studies. *Sustainability* **2022**, *14*, 12945. [CrossRef]
39. Smit, B.; Skinner, M. Adaptation options in agriculture to climate change: A typology. *Mitig. Adapt. Strateg. Glob. Chang.* **2002**, *7*, 85–114. [CrossRef]
40. Intergovernmental Panel on Climate Change (IPCC). IPCC Fourth Assessment Report: Climate Change 2007. Available online: http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml (accessed on 12 August 2023).
41. Dang, H.L.; Li, E.; Nuberg, I.; Bruwer, J. Factors influencing the adaptation of farmers in response to climate change: A review. *Clim. Dev.* **2019**, *11*, 765–774. [CrossRef]
42. Acevedo, M.; Pixley, K.; Zinyengere, N.; Meng, S.; Tufan, H.; Cichy, K.; Bizikova, L.; Isaacs, K.; Ghezzi-Kopel, K.; Porciello, J. A scoping review of adoption of climate-resilient crops by small-scale producers in low- and middle-income countries. *Nat. Plants* **2020**, *6*, 1231–1241. [CrossRef]
43. Karimi, V.; Valizadeh, N.; Rahmani, S.; Bijani, M.; Karimi, M. Beyond Climate Change: Impacts, Adaptation Strategies, and Influencing Factors. In *Climate Chang.*; Bandh, S.A., Ed.; Springer: Cham, Switzerland, 2022; pp. 49–70. [CrossRef]
44. Government of the Republic of Uzbekistan. *Second National Communication of the Republic of Uzbekistan under the United Nations Framework Convention on Climate Change*; Centre of Hydrometeorological Service under the Cabinet of Ministers of the Republic of Uzbekistan: Tashkent, Uzbekistan, 2009; 189p.
45. Sterie, C.M.; Dragomir, V. Global trends on research towards agriculture adaptation to climate change. *Sci. Pap. Ser. Manag. Econ. Eng. Agric. Rural Dev.* **2023**, *23*, 759–766.
46. Iglesias, A.; Garrote, L.; Quiroga, S.; Moneo, M. *Impacts of Climate Change in Agriculture in Europe*; Office for Official Publications of the European Communities: Luxembourg, 2009. [CrossRef]
47. Iglesias, A.; Garrote, L.; Quiroga, S.; Moneo, M. From climate change impacts to the development of adaptation strategies: Challenges for agriculture in Europe. *Clim. Chang.* **2012**, *112*, 143–168. [CrossRef]
48. Stage, J. Economic valuation of climate change adaptation in developing countries. *Ann. N. Y. Acad. Sci.* **2010**, *1185*, 150–163. [CrossRef]
49. Füssel, H.M. Adaptation planning for climate change: Concepts, assessment approaches, and key lessons. *Sustain. Sci.* **2007**, *2*, 265–275. [CrossRef]
50. Dasgupta, P.; Morton, J.F.; Dodman, D.; Karapinar, B.; Meza, F.; Rivera-Ferre, A.; Sarr, T.; Vincent, K.E. Rural areas. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*; Contribution of Working Group. II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., et al., Eds.; Cambridge University Press: Cambridge, UK, 2014; pp. 613–657. Available online: https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap9_FINAL.pdf (accessed on 1 September 2023).
51. Castells-Quintana, D.; del Pilar Lopez-Uribe, M.; McDermott, T.K. Adaptation to climate change: A review through a development economics lens. *World Dev.* **2018**, *104*, 183–196. [CrossRef]

52. Conway, D.; Nicholls, R.J.; Brown, S.; Tebboth, M.G.L.; Adger, W.N.; Ahmad, B.; Biemans, H.; Crick, F.; Lutz, A.F.; De Campos, R.S.; et al. The need for bottom-up assessments of climate risks and adaptation in climate-sensitive regions. *Nat. Clim. Chang.* **2019**, *9*, 503–511. [CrossRef]
53. Hügel, S.; Davies, A.R. Public participation, engagement, and climate change adaptation: A review of the research literature. *WIREs Clim. Chang.* **2020**, *11*, e645. [CrossRef]
54. Berrang-Ford, L.; Siders, A.R.; Lesnikowski, A.; Fischer, A.P.; Callaghan, M.W.; Haddaway, N.R.; Mach, K.J.; Araos, M.; Shah, M.A.R.; Wannewitz, M.; et al. A systematic global stocktake of evidence on human adaptation to climate change. *Nat. Clim. Chang.* **2021**, *11*, 989–1000. [CrossRef]
55. Eriksen, S.; Schipper, E.L.F.; Scoville-Simonds, M.; Vincent, K.; Adam, H.N.; Brooks, N.; Harding, B.; Khatri, D.; Lenaerts, L.; Liverman, D.; et al. Adaptation interventions and their effect on vulnerability in developing countries: Help, hindrance or irrelevance? *World Dev.* **2021**, *141*, 105383. [CrossRef]
56. Nightingale, A.J.; Gonda, N.; Eriksen, S.H. Affective adaptation = effective transformation? Shifting the politics of climate change adaptation and transformation from the status quo. *Wiley Interdiscip. Rev. Clim. Chang.* **2022**, *13*, e740. [CrossRef]
57. Ricart, S.; Castelletti, A.; Gandolfi, C. On farmers' perceptions of climate change and its nexus with climate data and adaptive capacity. A comprehensive review. *Environ. Res. Lett.* **2022**, *17*, 083002. [CrossRef]
58. Karimi, V.; Bijani, M.; Hallaj, Z.; Valizadeh, N.; Fallah Haghighi, N.; Karimi, M. Adaptation and Maladaptation to Climate Change: Farmers' Perceptions. In *Strategizing Agricultural Management for Climate Change Mitigation and Adaptation*; Bandh, S.A., Ed.; Springer: Cham, Switzerland, 2023. [CrossRef]
59. Marques, F.; Alves, F.; Castro, P. Climate Change Perceptions and Adaptation Strategies in Vulnerable and Rural Territories. In *Climate Change Strategies: Handling the Challenges of Adapting to a Changing Climate. Climate Change Management*; Leal Filho, W., Kovaleva, M., Alves, F., Abubakar, I.R., Eds.; Springer: Cham, Switzerland, 2023; pp. 427–439. [CrossRef]
60. Aguilera, E.; Diaz-Gaona, C.; Garcia-Laureano, R.; Reyes-Palomo, C.; Guzmán, G.I.; Ortolani, L.; Sánchez-Rodríguez, M.; Rodríguez-Estévez, V. Agroecology for adaptation to climate change and resource depletion in the Mediterranean region. A review. *Agric. Syst.* **2020**, *181*, 102809. [CrossRef]
61. Gaeva, D.V.; Barinova, G.M.; Krasnov, E.V. Adaptation of Eastern Europe Regional Agriculture to Climate Change: Risks and Management. In *Climate Change Adaptation in Eastern Europe. Climate Change Management*; Leal Filho, W., Trbic, G., Filipovic, D., Eds.; Springer: Cham, Switzerland, 2019. [CrossRef]
62. Ishtiaque, A. US farmers' adaptations to climate change: A systematic review of the adaptation-focused studies in the US agriculture context. *Environ. Res: Clim.* **2023**, *2*, 022001. [CrossRef]
63. Mertz, O.; Halsnæs, K.; Olesen, J.E.; Rasmussen, K. Adaptation to Climate Change in Developing Countries. *Environ. Manag.* **2009**, *43*, 743–752. [CrossRef] [PubMed]
64. Shaffril, H.A.M.; Krauss, S.E.; Samsuddin, S.F. A systematic review on Asian's farmers' adaptation practices towards climate change. *Sci. Total Environ.* **2018**, *644*, 683–695. [CrossRef]
65. Shaffril, H.A.M.; Ahmad, N.; Samsuddin, S.F.; Samah, A.A.; Hamdan, M.E. Systematic literature review on adaptation towards climate change impacts among indigenous people in the Asia Pacific regions. *J. Clean. Prod.* **2020**, *258*, 120595. [CrossRef]
66. Nguyen, T.-H.; Sahin, O.; Howes, M. Climate Change Adaptation Influences and Barriers Impacting the Asian Agricultural Industry. *Sustainability* **2021**, *13*, 7346. [CrossRef]
67. Aryal, J.P.; Sapkota, T.B.; Khurana, R.; Khatri-Chhetri, A.; Rahut, D.B.; Jat, M.L. Climate change and agriculture in South Asia: Adaptation options in smallholder production systems. *Environ. Dev. Sustain.* **2020**, *22*, 5045–5075. [CrossRef]
68. Muchuru, S.; Nhamo, G. A review of climate change adaptation measures in the African crop sector. *Clim. Dev.* **2019**, *11*, 873–885. [CrossRef]
69. Sivakumar, M.V.K.; Das, H.P.; Brunini, O. Impacts of Present and Future Climate Variability and Change on Agriculture and Forestry in the Arid and Semi-Arid Tropics. *Clim. Chang.* **2005**, *70*, 31–72. [CrossRef]
70. Naulleau, A.; Gary, C.; Prévot, L.; Hossard, L. Evaluating Strategies for Adaptation to Climate Change in Grapevine Production—A Systematic Review. *Front. Plant Sci.* **2021**, *11*, 607859. [CrossRef]
71. Georgopoulou, E.; Mirasgedis, S.; Sarafidis, Y.; Vitaliotou, M.; Lalas, D.P.; Theloudis, I.; Giannoulaki, K.-D.; Dimopoulos, D.; Zavras, V. Climate change impacts and adaptation options for the Greek agriculture in 2021–2050: A monetary assessment. *Clim. Risk Manag.* **2017**, *16*, 164–182. [CrossRef]
72. Francis, C.A. Crop Production Resilience through Biodiversity for Adaptation to Climate Change. In *Oxford Research Encyclopedia of Environmental Science*; Oxford University Press: Oxford, UK, 2019. [CrossRef]
73. Fatima, Z.; Ahmed, M.; Hussain, M.; Abbas, G.; Ul-Allah, S.; Ahmad, S.; Ahmed, N.; Ali, M.A.; Sarwar, G.; ul Haque, E.; et al. The fingerprints of climate warming on cereal crops phenology and adaptation options. *Sci. Rep.* **2020**, *10*, 18013. [CrossRef] [PubMed]
74. Sloat, L.L.; Davis, S.J.; Gerber, J.S.; Moore, F.C.; Ray, D.K.; West, P.C.; Mueller, N.D. Climate adaptation by crop migration. *Nat. Commun.* **2020**, *11*, 1243. [CrossRef] [PubMed]
75. Khan, A.; Ahmad, M.; Ahmed, M.; Iftikhar Hussain, M. Rising Atmospheric Temperature Impact on Wheat and Thermotolerance Strategies. *Plants* **2021**, *10*, 43. [CrossRef]
76. 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*, 7079. [CrossRef]

77. Yadav, M.R.; Choudhary, M.; Singh, J.; Lal, M.K.; Jha, P.K.; Udawat, P.; Gupta, N.K.; Rajput, V.D.; Garg, N.K.; Maheshwari, C.; et al. Impacts, Tolerance, Adaptation, and Mitigation of Heat Stress on Wheat under Changing Climates. *Int. J. Mol. Sci.* **2022**, *23*, 2838. [CrossRef]
78. Auffhammer, M.; Schlenker, W. Empirical studies on agricultural impacts and adaptation. *Energy Econ.* **2014**, *46*, 555–561. [CrossRef]
79. Iglesias, A.; Garrote, L. Adaptation strategies for agricultural water management under climate change in Europe. *Agric. Water Manag.* **2015**, *155*, 113–124. [CrossRef]
80. Maracchi, G.; Sirotenko, O.; Bindi, M. Impacts of Present and Future Climate Variability on Agriculture and Forestry in the Temperate Regions: Europe. *Clim. Chang.* **2005**, *70*, 117–135. [CrossRef]
81. Olesen, J.E.; Trnka, M.; Kersebaum, K.C.; Skjelvåg, A.O.; Seguin, B.; Peltonen-Sainio, P.; Rossi, F.; Kozyra, J.; Micale, F. Impacts and adaptation of European crop production systems to climate change. *Eur. J. Agron.* **2011**, *34*, 96–112. [CrossRef]
82. Reidsma, P.; Ewert, F.; Lansink, A.O.; Leemans, R. Adaptation to climate change and climate variability in European agriculture: The importance of farm level responses. *Eur. J. Agron.* **2010**, *32*, 91–102. [CrossRef]
83. Faye, B.; Webber, H.; Gaiser, T.; Müller, C.; Zhang, Y.; Stella, T.; Latka, C.; Reckling, M.; Heckelei, T.; Helming, K.; et al. Climate change impacts on European arable crop yields: Sensitivity to assumptions about rotations and residue management. *Eur. J. Agron.* **2023**, *142*, 126670. [CrossRef]
84. Himanen, S.J.; Mäkinen, H.; Rimhanen, K.; Savikko, R. Farmers in Climate Change Adaptation Planning: Assessing Intercropping as a Means to Support Farm Adaptive Capacity. *Agriculture* **2016**, *6*, 34. [CrossRef]
85. Jenkins, B.; Avis, K.; Willcocks, J.; Martin, G.; Wiltshire, J.; Peters, E. *Adapting Scottish Agriculture to a Changing Climate-Assessing Options for Action*; Ricardo Energy & Environment: London, UK, 2023. [CrossRef]
86. Reidsma, P.; Wolf, J.; Kanellopoulos, A.; Schaap, B.F.; Mandryk, M.; Verhagen, J.; van Ittersum, M.K. Climate change impact and adaptation research requires integrated assessment and farming systems analysis: A case study in the Netherlands. *Environ. Res. Lett.* **2015**, *10*, 045004. [CrossRef]
87. Mandryk, M.; Reidsma, P.; van Ittersum, M.K. Crop and farm level adaptation under future climate challenges: An exploratory study considering multiple objectives for Flevoland, the Netherlands. *Agric. Syst.* **2017**, *152*, 154–164. [CrossRef]
88. De Frutos Cachorro, J.; Gobin, A.; Buysse, J. Farm-level adaptation to climate change: The case of the Loam region in Belgium. *Agric. Syst.* **2018**, *165*, 164–176. [CrossRef]
89. Morel, K.; Cartau, K. Adaptation of organic vegetable farmers to climate change: An exploratory study in the Paris region. *Agric. Syst.* **2023**, *210*, 103703. [CrossRef]
90. Klein, T.; Holzkämper, A.; Calanca, P.; Seppelt, R.; Fuhrer, J. Adapting agricultural land management to climate change: A regional multi-objective optimization approach. *Landsc. Ecol.* **2013**, *28*, 2029–2047. [CrossRef]
91. Martin, S.; Mitter, H.; Schmid, E.; Heinrich, G.; Gobiet, A. Integrated Analysis of Climate Change Impacts and Adaptation Measures in Austrian Agriculture. *Ger. J. Agric. Econ.* **2014**, *3*, 156–176.
92. Shaitura, S.V.; Sumzina, L.V.; Tomashevskaya, N.G.; Filimonov, S.L.; Minitaeva, A.M. The agricultural sector in the context of global climate change. *Bull. Kursk. State Agric. Acad.* **2021**, *4*, 18–24. (In Russian)
93. Ivanov, A.L. Global climate change and its impact on agriculture in Russia. *Agriculture* **2009**, *1*, 3–5. (In Russian)
94. Gordeev, A.V.; Kleshchenko, A.D.; Chernyakov, B.A. *Bioclimatic Potential of Russia: Adaptation Measures in a Changing Climate*; Ministry of Agriculture of the Russian Federation: Moscow, Russia, 2008; 278p. (In Russian)
95. Nemtsev, S.N.; Sharipova, R.B. Problems of increasing the sustainability of agriculture in the Ulyanovsk region in terms of adaptation to modern climate change. *Proc. Samara SC RAS* **2018**, *20*, 363–369. (In Russian)
96. Kipriyanov, F.A.; Savinykh, P.A. Territorial and climatic zoning of the Vologda region and prospects of its use in agriculture. *Perm. Agrar. Bull.* **2019**, *2*, 64–71. (In Russian)
97. Surovtsev, V.N.; Ponomarev, M.A.; Nikulina, Y.N.; Payurova, E.N. Risk Assessment and Directions of Adaptation of Agriculture in the North-West of Russia under Climate Change. *Reg. Ecol.* **2015**, *6*, 13–21. Available online: http://www.ecosafety-spb.ru/images/stories/Publications/RegionalEcology/2015_6(41).pdf (accessed on 15 August 2023). (In Russian).
98. Iglesias, A.; Mougou, R.; Moneo, M.; Quiroga, S. Towards adaptation of agriculture to climate change in the Mediterranean. *Reg. Environ. Chang.* **2011**, *11*, 159–166. [CrossRef]
99. De Leo, S.; Di Fonzo, A.; Giuca, S.; Gaito, M.; Bonati, G. Economic Implications for Farmers in Adopting Climate Adaptation Measures in Italian Agriculture. *Land* **2023**, *12*, 906. [CrossRef]
100. Sperdouli, I.; Mellidou, I.; Moustakas, M. Harnessing Chlorophyll Fluorescence for Phenotyping Analysis of Wild and Cultivated Tomato for High Photochemical Efficiency under Water Deficit for Climate Change Resilience. *Climate* **2021**, *9*, 154. [CrossRef]
101. Kourgialas, N.N. A critical review of water resources in Greece: The key role of agricultural adaptation to climate-water effects. *Sci. Total Environ.* **2021**, *775*, 145857. [CrossRef]
102. 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. [CrossRef]
103. Fujisawa, M.; Kobayashi, K.; Johnston, P.; New, M. What Drives Farmers to Make Top-Down or Bottom-Up Adaptation to Climate Change and Fluctuations? A Comparative Study on 3 Cases of Apple Farming in Japan and South Africa. *PLoS ONE* **2015**, *10*, e0120563. [CrossRef]

104. Mizina, S.V.; Smith, J.B.; Gossen, E.; Spiecker, K.F.; Witkowski, S.L. An evaluation of adaptation options for climate change impacts on agriculture in Kazakhstan. *Mitig. Adapt. Strateg. Glob. Chang.* **1999**, *4*, 25–41. [CrossRef]
105. Erda, L.; Yinlong, X.; Shaohong, W. China's national assessment report on climate change (II): Climate change impacts and adaptation. *Adv. Clim. Chang. Res.* **2007**, *3*, 6.
106. Wang, J.X.; Huang, J.K.; Jun, Y. Overview of impacts of climate change and adaptation in China's agriculture. *J. Integr. Agric.* **2014**, *13*, 1–17. [CrossRef]
107. Jianjun, J.; Yiwei, G.; Xiaomin, W.; Nam, P.K. Farmers' risk preferences and their climate change adaptation strategies in the Yongqiao District, China. *Land Use Policy* **2015**, *47*, 365–372. [CrossRef]
108. Dai, C.; Qin, X.S.; Lu, W.T.; Huang, Y. Assessing Adaptation Measures on Agricultural Water Productivity under Climate Change: A Case Study of Huai River Basin, China. *Sci. Total Environ.* **2020**, *721*, 137777. [CrossRef]
109. Trinh, L.T.; Duong, C.C.; Van Der Steen, P.; Lens, P.N. Exploring the Potential for Wastewater Reuse in Agriculture as a Climate Change Adaptation Measure for Can Tho City, Vietnam. *Agric. Water Manag.* **2013**, *128*, 43–54. [CrossRef]
110. Nhung, T.T.; Le Vo, P.; Van Nghi, V.; Bang, H.Q. Salt Intrusion Adaptation Measures for Sustainable Agricultural Development under Climate Change Effects: A Case of Ca Mau Peninsula, Vietnam. *Clim. Risk Manag.* **2019**, *23*, 88–100. [CrossRef]
111. Sumaryanto; Nurfatria, F.; Astana, S.; Erwidodo. Perception and adaptation of agroforestry farmers in Upper Citarum Watershed to climate change. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *917*, 012020. [CrossRef]
112. Khanal, U.; Wilson, C.; Hoang, V.N.; Lee, B. Farmers' adaptation to climate change, its determinants and impacts on rice yield in Nepal. *Ecol. Econ.* **2018**, *144*, 139–147. [CrossRef]
113. Shrestha, R.; Rakhal, B.; Adhikari, T.R.; Ghimire, G.R.; Talchabhadel, R.; Tamang, D.; KC, R.; Sharma, S. Farmers' Perception of Climate Change and Its Impacts on Agriculture. *Hydrology* **2022**, *9*, 212. [CrossRef]
114. Esham, M.; Garforth, C. Agricultural adaptation to climate change: Insights from a farming community in Sri Lanka. *Mitig. Adapt. Strateg. Glob. Chang.* **2013**, *18*, 535–549. [CrossRef]
115. Moayedi, M.; Hayati, D. Identifying strategies for adaptation of rural women to climate variability in water scarce areas. *Front. Water* **2023**, *5*, 1177684. [CrossRef]
116. 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*, 547. [CrossRef] [PubMed]
117. Abid, M.; Scheffran, J.; Schneider, U.A.; Elahi, E. Farmer Perceptions of Climate Change, Observed Trends and Adaptation of Agriculture in Pakistan. *Environ. Manag.* **2019**, *63*, 110–123. [CrossRef]
118. Mustafa, G.; Alotaibi, B.A.; Nayak, R.K. Linking Climate Change Awareness, Climate Change Perceptions and Subsequent Adaptation Options among Farmers. *Agronomy* **2023**, *13*, 758. [CrossRef]
119. Srivastava, P.; Singh, R.; Tripathi, S.; Raghubanshi, A.S. An urgent need for sustainable thinking in agriculture—An Indian scenario. *Ecol. Indic.* **2016**, *67*, 611–622. [CrossRef]
120. Taraz, V. Can farmers adapt to higher temperatures? Evidence from India. *World Dev.* **2018**, *112*, 205–219. [CrossRef]
121. Moniruzzaman, S. Crop choice as climate change adaptation: Evidence from Bangladesh. *Ecol. Econ.* **2015**, *118*, 90–98. [CrossRef]
122. Walters, S.A.; Abdelaziz, M.; Bouharroud, R. Local Melon and Watermelon Crop Populations to Moderate Yield Responses to Climate Change in North Africa. *Climate* **2021**, *9*, 129. [CrossRef]
123. Bryan, E.; Ringler, C.; Okoba, B.; Roncoli, C.; Silvestri, S.; Herrero, M. Adapting agriculture to climate change in Kenya: Household strategies and determinants. *J. Environ. Manag.* **2013**, *114*, 26–35. [CrossRef]
124. Kangogo, D.; Dentoni, D.; Bijman, J. Adoption of climate-smart agriculture among smallholder farmers: Does farmer entrepreneurship matter? *Land Use Policy* **2021**, *109*, 105666. [CrossRef]
125. Onyeneke, R.U.; Nwajiuba, C.A.; Emenekwe, C.C.; Nwajiuba, A.; Onyeneke, C.J.; Ohalete, P.; Uwazie, U.I. Climate change adaptation in Nigerian agricultural sector: A systematic review and resilience check of adaptation measures. *AIMS Agric. Food* **2019**, *4*, 967–1006. [CrossRef]
126. Apata, T.G. Factors influencing the perception and choice of adaptation measures to climate change among farmers in Nigeria. Evidence from farming households in Southwest Nigeria. *Environ. Econ.* **2011**, *2*, 74–83.
127. Ozor, N.; Nnaji, C. The role of extension in agricultural adaptation to climate change in Enugu State, Nigeria. *J. Agric. Ext. Rural. Dev.* **2011**, *3*, 42–50.
128. Fosu-Mensah, B.Y.; Vlek, P.L.G.; MacCarthy, D.S. Farmers' perception and adaptation to climate change: A case study of Sekyedumase district in Ghana. *Environ. Dev. Sustain.* **2012**, *14*, 495–505. [CrossRef]
129. Maponya, P.; Mpandeli, S. Climate change and agricultural production in South Africa: Impacts and adaptation options. *J. Agric. Sci.* **2012**, *4*, 48. [CrossRef]
130. Bryan, E.; Deressa, T.T.; Gbetibouo, G.A.; Ringler, C. Adaptation to climate change in Ethiopia and South Africa: Options and constraints. *Environ. Sci. Policy* **2009**, *12*, 413–426. [CrossRef]
131. Ruiz-García, P.; Conde-Álvarez, C.; Gómez-Díaz, J.D.; Monterroso-Rivas, A.I. Projections of Local Knowledge-Based Adaptation Strategies of Mexican Coffee Farmers. *Climate* **2021**, *9*, 60. [CrossRef]
132. Conde, C.; Ferrer, R.; Orozco, S. Climate change and climate variability impacts on rainfed agricultural activities and possible adaptation measures. A Mexican case study. *Atmósfera* **2006**, *19*, 181–194.
133. Vasconcelos, A.C.F.; Bonatti, M.; Schlindwein, S.L.; D'Agostini, L.R.; Homem, L.R.; Nelson, R. Landraces as an adaptation strategy to climate change for smallholders in Santa Catarina, Southern Brazil. *Land Use Policy* **2013**, *34*, 250–254. [CrossRef]

134. Ramirez-Villegas, J.; Salazar, M.; Jarvis, A.; Navarro-Racines, C.E. A way forward on adaptation to climate change in Colombian agriculture: Perspectives towards 2050. *Clim. Chang.* **2012**, *115*, 611–628. [CrossRef]
135. Mu, J.E.; McCarl, B.A.; Wein, A.M. Adaptation to climate change: Changes in farmland use and stocking rate in the U.S. *Mitig. Adapt. Strateg. Glob. Chang.* **2013**, *18*, 713–730. [CrossRef]
136. Walters, S.A.; Gajewski, C.; Sadeghpour, A.; Groninger, J.W. Mitigation of Climate Change for Urban Agriculture: Water Management of Culinary Herbs Grown in an Extensive Green Roof Environment. *Climate* **2022**, *10*, 180. [CrossRef]
137. Freebairn, J. Adaptation to Climate Change by Australian Farmers. *Climate* **2021**, *9*, 141. [CrossRef]
138. Ricart, S.; Gandolfi, C.; Castelletti, A. Climate change awareness, perceived impacts, and adaptation from farmers' experience and behavior: A triple-loop review. *Reg. Environ. Chang.* **2023**, *23*, 82. [CrossRef]
139. Bouabdelli, S.; Zeroual, A.; Meddi, M.; Assani, A. Impact of temperature on agricultural drought occurrence under the effects of climate change. *Theor. Appl. Climatol.* **2022**, *148*, 191–209. [CrossRef]
140. Olesen, J.E.; Carter, T.R.; Díaz-Ambrona, C.H.; Fronzek, S.; Heidmann, T.; Hickler, T.; Holt, T.; Minguez, M.I.; Morales, P.; Palutikof, J.P.; et al. Uncertainties in projected impacts of climate change on European agriculture and terrestrial ecosystems based on scenarios from regional climate models. *Clim. Chang.* **2007**, *81*, 123–143. [CrossRef]
141. Ward Jones, M.K.; Schwoerer, T.; Gannon, G.M.; Jones, B.M.; Kanevskiy, M.Z.; Sutton, I.; Pierre, B.S.; Pierre, C.S.; Russell, J.; Russell, D. Climate-driven expansion of northern agriculture must consider permafrost. *Nat. Clim. Chang.* **2022**, *12*, 699–703. [CrossRef]
142. Eicken, H.; Danielsen, F.; Sam, J.M.; Fidel, M.; Johnson, N.; Poulsen, M.K. Connecting Top-Down and Bottom-Up Approaches in Environmental Observing. *BioScience* **2021**, *71*, 467–483. [CrossRef]
143. Carter, J.G. Climate change adaptation in European cities. *Curr. Opin. Environ. Sustain.* **2011**, *3*, 193–198. [CrossRef]
144. McNamara, K.E.; Buggy, L. Community-based climate change adaptation: A review of academic literature. *Local Environ.* **2017**, *22*, 443–460. [CrossRef]
145. Fenton, A.; Gallagher, D.; Wright, H.; Huq, S.; Nyandiga, C. Up-scaling finance for community-based adaptation. *Clim. Dev.* **2014**, *6*, 388–397. [CrossRef]
146. Qamar, M.U.; Archfield, S.A. Consider the risks of bottom-up approaches for climate change adaptation. *Nat. Clim. Chang.* **2023**, *13*, 2–3. [CrossRef]
147. Walters, S.A. Essential Role of Crop Landraces for World Food Security. *Mod. Concepts Dev. Agron.* **2018**, *1*, 1–4. [CrossRef]
148. Pulido, J.S.; Gerardo, B. The Traditional Farming System of a Mexican Indigenous Community: The Case of Nuevo San Juan Parangaricutiro, Michoacán, Mexico. *Geoderma* **2003**, *111*, 249–265. [CrossRef]
149. Anex, R.P.; Lynd, L.R.; Laser, M.S.; Heggenstaller, A.H.; Liebman, M. Potential for Enhanced Nutrient Cycling through Coupling of Agricultural and Bioenergy Systems. *Crop Sci.* **2007**, *47*, 1327–1335. [CrossRef]
150. Schiere, H.; Loes, K. *Mixed Crop-Livestock Farming: A Review of Traditional Technologies Based on Literature and Field Experiences*; FAO Animal Production and Health Paper 152; FAO: Rome, Italy, 2001.
151. Altieri, M.A.; Nicholls, C.I.; Henao, A.; Lana, M.A. Agroecology and the design of climate change-resilient farming systems. *Agron. Sustain. Dev.* **2015**, *35*, 869–890. [CrossRef]
152. Denevan, W.M. 2 Prehistoric agricultural methods as models for sustainability. *Adv. Plant Pathol.* **1995**, *11*, 21–43. [CrossRef]
153. Singh, R.; Singh, G.S. Traditional agriculture: A climate-smart approach for sustainable food production. *Energy Ecol. Environ.* **2017**, *2*, 296–316. [CrossRef]
154. Rai, S. Traditional ecological knowledge and community-based natural resource management in northeast India. *J. Mt. Sci.* **2007**, *4*, 248–258. [CrossRef]
155. Crate, S.; Ulrich, M.; Habeck, J.O.; Desyatkin, A.R.; Desyatkin, R.V.; Fedorov, A.N.; Hiyama, T.; Iijima, Y.; Ksenofontov, S.; Mészáros, C.; et al. Permafrost livelihoods: A transdisciplinary review and analysis of thermokarst-based systems of indigenous land use. *Anthropocene* **2017**, *18*, 89–104. [CrossRef]
156. Sardaro, R.; Girone, S.; Acciani, C.; Bozzo, F.; Petrontino, A.; Fucilli, V. Agro-biodiversity of Mediterranean crops: Farmers' preferences in support of a conservation programme for olive landraces. *Biol. Conserv.* **2016**, *201*, 210–219. [CrossRef]
157. Evenson, R.E.; Gollin, D. Assessing the Impact of the Green Revolution, 1960 to 2000. *Science* **2003**, *300*, 758–762. [CrossRef] [PubMed]
158. Matson, P.A.; Parton, W.J.; Power, A.G.; Swift, M.J. Agricultural intensification and ecosystem properties. *Science* **1997**, *277*, 504–509. [CrossRef] [PubMed]
159. Kremen, C.; Iles, A.; Bacon, C. Diversified farming systems: An agroecological, systems-based alternative to modern industrial agriculture. *Ecol. Soc.* **2012**, *17*, 44. [CrossRef]
160. Malézieux, E. Designing Cropping Systems from Nature. *Agron. Sustain. Dev.* **2012**, *32*, 15–29. [CrossRef]
161. Duru, M.; Therond, O.; Martin, G.; Martin-Clouaire, R.; Magne, M.-A.; Justes, E.; Journet, E.-P.; Aubertot, J.-N.; Savary, S.; Bergez, J.-E.; et al. How to implement biodiversity-based agriculture to enhance ecosystem services: A review. *Agron. Sustain. Dev.* **2015**, *35*, 1259–1281. [CrossRef]
162. Shackleton, S.; Ziervogel, G.; Sallu, S.; Gill, T.; Tschakert, P. Why is socially-just climate change adaptation in sub-Saharan Africa so challenging? A review of barriers identified from empirical cases. *WIREs Clim. Chang.* **2015**, *6*, 321–344. [CrossRef]

163. Rippke, U.; Ramirez-Villegas, J.; Jarvis, A.; Vermeulen, S.J.; Parker, L.; Mer, F.; Diekkrüger, B.; Challinor, A.J.; Howden, M. Timescales of transformational climate change adaptation in sub-Saharan African agriculture. *Nat. Clim. Chang.* **2016**, *6*, 605–609. [CrossRef]
164. Ogisi, O.D.; Begho, T. Adoption of climate-smart agricultural practices in sub-Saharan Africa: A review of the progress, barriers, gender differences and recommendations. *Farming Syst.* **2023**, *1*, 100019. [CrossRef]
165. Teklu, A.; Simane, B.; Bezabih, M. Multiple adoption of climate-smart agriculture innovation for agricultural sustainability: Empirical evidence from the Upper Blue Nile Highlands of Ethiopia. *Clim. Risk Manag.* **2023**, *39*, 100477. [CrossRef]
166. Steenwerth, K.L.; Hodson, A.K.; Bloom, A.J.; Carter, M.R.; Cattaneo, A.; Chartres, C.J.; Hatfield, J.L.; Henry, K.; Hopmans, J.W.; Horwath, W.R.; et al. Climate-smart agriculture global research agenda: Scientific basis for action. *Agric. Food Secur.* **2014**, *3*, 11. [CrossRef]
167. Zilberman, D.; Goetz, R.; Garrido, A.; Lipper, L.; Mccarthy, N.; Asfaw, S.; Editors, G.B. Identifying Strategies to Enhance the Resilience of Smallholder Farming Systems: Evidence from Zambia. In *Climate-Smart Agriculture—Building Resilience to Climate Change*; Lipper, L., McCarthy, N., Zilberman, D., Asfaw, S., Branca, G., Eds.; Springer: Cham, Switzerland, 2017; pp. 425–441. [CrossRef]
168. Taylor, M. Climate-Smart Agriculture: What Is It Good For? *J. Peasant. Stud.* **2018**, *45*, 89–107. [CrossRef]
169. Neufeldt, H.; Jahn, M.; Campbell, B.M.; Beddington, J.R.; DeClerck, F.; De Pinto, A.; Gulledge, J.; Hellin, J.; Herrero, M.; Jarvis, A.; et al. Beyond Climate-Smart Agriculture: Toward Safe Operating Spaces for Global Food Systems. *Agric. Food Secur.* **2013**, *2*, 12. [CrossRef]
170. Juhola, S.; Käyhkö, J. Maladaptation as a concept and a metric in national adaptation policy—Should we, would we, could we? *PLos Clim.* **2023**, *2*, e0000213. [CrossRef]
171. Houghton, J.T.; Ding, Y.; Griggs, D.J.; Noguer, M.; van der Linden, P.J. (Eds.) *Climate Change 2001: Mitigation of Climate Change*; The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change; Intergovernmental Panel on Climate Change: Geneva, Switzerland, 2001.
172. Grigorieva, E. Evaluating the Sensitivity of Growing Degree Days as an Agro-Climatic Indicator of the Climate Change Impact: A Case Study of the Russian Far East. *Atmosphere* **2020**, *11*, 404. [CrossRef]
173. Juhola, S.; Glaas, E.; Linnér, B.O.; Neset, T.S. Redefining maladaptation. *Environ. Sci. Policy* **2016**, *55*, 135–140. [CrossRef]
174. Schipper, E.L.F. Catching maladaptation before it happens. *Nat. Clim. Chang.* **2022**, *12*, 617–618. [CrossRef]