Adaptation of Agriculture to Climate Change

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Given that agricultural productivity is intricately linked to weather and climate conditions and relies heavily on climate stability, climate change introduces a wide range of challenges for agricultural activities. Consequently, there is a pressing need for climate-smart agriculture strategies that prioritize sustainable food production, climate resilience, and adaptation.

Keywords: climate ; climate change ; agriculture ; adaptation strategies

1. Introduction

Human activities are increasingly contributing to pressing environmental issues, including climate change, natural resource degradation (such as soil erosion), loss of biodiversity, and environmental pollution. According to the World Economic Forum Global Risks Perception Survey 2021–2022, "Climate action failure" and "Extreme weather" were identified as the top two most serious global risks for the next decade [1]. Furthermore, with the world's population projected to reach 9.5 billion by 2050 [2], this growth presents significant challenges for socio-economic development, necessitating the expansion of resources to meet the needs of a growing population [3]. One of the foremost challenges in the 21st century is food security, and due to population growth, agricultural production, encompassing both food and non-food products, must increase by 60% by 2050 compared to 2005 [4].

The Sustainable Development Goals (SDGs) represent a universal call to action for global efforts aimed at “protect the planet and ensure that all people enjoy peace and prosperity”. These goals are interconnected and integrated, striking a balance between environmental, social, and economic dimensions of sustainable development [5][6][7][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][7][8][9][10][11]. To achieve these goals while addressing the challenges posed by climate change, climate-smart agriculture strategies are indispensable, focusing on sustainable food production, climate adaptation, and resilience [12][13][14][15][16][17][18][19][20][21][22].

2. Adaptation Strategies—Definitions for Agriculture

While "mitigation" refers to actions aimed at reducing greenhouse gas emissions [23][24][25][26], "adaptation" encompasses measures designed to enhance communities' capacity to cope with climate change and its associated impacts across various sectors of society [23][26][27][28][29][30]. In the context of climate change, adaptation involves actions that decrease vulnerability to or take advantage of opportunities arising from ongoing or future changes [26][31][32][33]. In this context, an Adaptation Strategy (AS) can be broadly defined as a comprehensive plan of action aimed at addressing climate change impacts, encompassing policies and measures to reduce a country's vulnerability ([34], p. 186).

The effectiveness of AS depends on the nature of incentives and associated vulnerabilities. Therefore, discussions surrounding adaptation strategies should begin with an examination of climate conditions and their impact on agriculture, answering the fundamental question: "What is agriculture adapting to?" As an illustration, B. Smit and colleagues [37] underscore the notion that agricultural adaptation can arise as a reaction to a sequence of factors, such as variations in temperature and precipitation. These variations can lead to drought conditions, both in terms of magnitude and frequency, which in turn can impact crop yields, ultimately affecting income [35]. 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][36].

B. Smit and M. Skinner [37] determine the distinctive characteristics of adaptation in agriculture, such as intent and purposefulness; timing and duration; scale and responsibility; and form [37]. 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 [37]. 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 [35]. 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 [37]. 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][38][39][40][41].

3. Adaptation Strategies: Scaling from National to Farmer Levels

Climate change effects on agriculture vary widely across regions, influenced by economic, social, and environmental factors, necessitating a diverse array of adaptation measures [25]. Adaptation efforts differ depending on the scale of the system, ranging from individual farmer actions, such as changing crops or hybrids, to farm-level strategies, including diversification and insurance. Regionally or nationally, adaptation may involve altering the number of farms or adjusting compensation programs. At a global level, it may require shifts in international food trade patterns [35]. Numerous examples of regional-level adaptation plans can be found in the national communications submitted by developing countries' governments [42].

The impact of climate change on agriculture affects both individual producers and entire populations [43].Two levels of agricultural adaptation are commonly discussed: farm-based measures driven by individual farmers' self-interests and policy-driven adaptation involving government intervention to address collective needs [44][45]. Local agricultural communities, heavily dependent on the agricultural sector, bear the brunt of these changes, with adverse effects on employment, income sources, and food production. These impacts manifest as reduced food security, exacerbated water shortages, damage to critical infrastructure, intensified droughts, and increased poverty in local communities [41]. National policies in agriculture and development play a crucial role in shaping these outcomes [31]. According to Stage [46], 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 [46].

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

The existing body of literature extensively examines the global impact of climate change and adaptation across various facets of human life [19][27]28.[35][36][41][47][48][49][50][51][52][53][54]. These researches involve systematic analysis, categorization, and documentation of agricultural adaptation as a whole, as well as specific aspects such as regional variations, effects on different crops, and various weather-related outcomes [23][25][32][37][43][55][56][57], as well some specific aspects, such as adaptation features in different countries and regions of the world, e.g.,: the Mediterranean region [58], Eastern Europe [59], Nordic countries [33], the USA [60], Canada [37], developing countries [61], low- and middle-income countries [40], Asia [62][63][64], South Asia [65], African countries [11][18][66], arid and semi-arid tropics of Asia, Africa, and Latin America [67]; in various sectors of agriculture [68], depending on the effects for various crops [69][70][71][72][73][74][75], and in different weather outcomes [16][21][56][76][77].

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