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Advancements and Challenges in Climate-Smart Agriculture

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ABSTRACT

A Comprehensive Review explores the multifaceted realm of climate-smart agriculture (CSA) in a structure of engaging with the pressing challenges caused by climate change to global food security. It delves into the conceptual framework of climate-smart agriculture, emphasizing its triple-win objectives of enhancing productivity, fostering adaptation, and mitigating climate-related risks. The paper meticulously dissects the key components of climate-smart agriculture, ranging from sustainable land management to integrated pest management, while also highlighting implementation strategies and recent advancements in research and innovation. It addresses the challenges and opportunities associated with mainstreaming climate-smart agriculture into agricultural policies and practices, learning information through case studies and exemplary initiatives worldwide. The paper underscores the imperative of extending climate-smart agriculture efforts to achieve sustainable agricultural development in the face of a changing climate, calling for concerted action from stakeholders across sectors. Implications for future paths in research furthermore policy and practice, lessons learned and best practices established, finance and resource accessibility, barriers for the exchange of technology and knowledge, climate-smart advisory services for farmers and climate information platforms etc. Climate-smart agriculture aims to achieve triple-win objectives by enhancing productivity, increasing resilience to climate-related risks and reducing greenhouse gas emissions its key components include sustainable land management, climate-resilient crop varieties, water use efficiency and integrated pest management.

Keywords: *Climate change, internet technology, cultivation weather index-based farming, climate-smart agriculture.*

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INTRODUCTION

Global Warming is an undeniable scientific truth supported by several decades' worth of meteorological data of climate smart agriculture [1]. Human-caused emissions regarding climate-smart farming trap the warmth within the environment, accelerating Climate Variability [2, 3]. Specifically, the rise in Wider impacts of climate-smart agriculture concentration include increased frequency of severe weather conditions, lethal warming waves, and severe droughts, which pose major risks to the productivity agricultural sector [4]. In particularly significant 150 years, the temperature has risen by roughly 40%, with the last 30 years accounting for half of this increase [1].More severe weather conditions, lethal heat waves, intense droughts, and major risks to the productivity of agriculture are only a few of the larger consequences of the amount concentrated in climate-smart agriculture, which also affects net crop revenue [5] and the worth of farmland [6]. Approximately 25% of all anthropogenic greenhouse gas emissions worldwide are attributed to agriculture, indicating the size of its carbon footprint [2]. Specifically, the primary sources of agricultural carbon dioxide (CO_2) emissions are the burning of crop leftovers and the breakdown of soil organic matter. Methane (CH_4) emissions from agriculture are caused by soil that has inundated beneath rice growing, gastrointestinal oxidation in animal digestive systems, and the decomposition of manure and agricultural wastes in damp environments. Manure, compost, and nitrogenous soil are the primary sources about nitrous oxide (N_2O) in agriculture emissions. The two main global drivers of the rise in greenhouse gas emissions, which are expected to continue rising in the future, are economic and population growth [7]. Ensuring food security and lowering greenhouse gas emissions are thought to be the most important thing [8].Climate-smart Agricultural Growth ought to be adjusted and transformed to address the problems posed due to climate change [3]. The climate-smart agriculture framework offers a venue for evaluating livelihood assets' functionality and condition by regulatory frameworks, procedures, and technologies required for the change of agriculture regarding restorative practices [9]. Climate-smart agriculture is to accelerate synergies between cross-scale adaptation and mitigation to strengthen ties between national, international, as well as regional agriculture players[10].Offers a result of three wins that can constantly increase agricultural revenue, productivity, and adaptation to climate change while lowering or even eliminating greenhouse gas emissions and so promoting the achievement of sustainable development and food security nationwide growth objectives, offering a paradigm of resolution for the issues for the encountered by international growth in agriculture [3,11].

Additional cutting-edge technologies include coordinated control over fertility in the soil procedures, climate index-based security and planting a diversified crop, conservation agriculture, enhanced water management technology, and crop breeding they included within the range of climate-smart agriculture [12]. Researchers have shown, by several significant investigations on the climate-smart agriculture. In the previous several decades, these climate-smart agriculture. In different places, Security of food, earnings, and employment can all be increased by practices and technologies. For instance, increasing production, farmers' income, and food security can be achieved by the application of enhanced variety of crops that can respond to environmental stress [12], such as drought resistant bean[13] and drought-resistant maize [14]. Agricultural systems that are greater variety yield more crops and are more stable, profitable, and beneficial to livelihoods overall [15,16]. Consider Assefa et al. [16] carried out three years of cropping system tests in Bangladesh using improved rice-maize, rice-mung bean, and rice-sunflower varieties additionally traditional rice-fallow with rice-mung bean types. According to their findings, the double cropping systems of rice, corn, and sunflower showed the highest crop yields, and the main yield difference between enhanced Varieties might get as high at 30%. Furthermore, a strong correlation has been shown between the implementation of integrated soil fertility management techniques and cropping arrangements and enhanced Crop yields and soil nutrient uptake [17, 18]. Mhlanga together with others [17] conducted an experimental investigation to determine how Zimbabwe's farming patterns and soil factors affected the production of maize. The maximum yields and zinc uptake were recorded in the traditional tillage in addition to mulching and rotating (CT + M + R) and mulch together with rotation and no-tillage (NT + M + R) systems. Utilizing some advanced and cutting-edge technology, including satellite remote sensing, can also boost crop output[19,20,21], internet access of things [22,23], and also synthetic intelligence[24,25].Aside from aiding in the management of agricultural production plans and strategies at the regional, national, and international levels, the use of remote sensing in agriculture also offers tactical control data pertaining to climate-smart agriculture operations at the farm level. Better insights based on field information collecting can be produced by merging the artificial intelligence and the internet of things technology. Agricultural methods can then be methodically planned to produce the most output with the least amount of amount of physical work. As an example, Astor & Co. [19] employed 3D RGB UAV imagery and hyperspectral data to calculate the renewable resource biomass of eggs, tomatoes, and cabbage throughout India. Occupied Wicaksono along with others [23] created an internet-based system and used it to manage and cultivate rice to be able to increase the creation of East Java's agricultural area.

Reviews that are currently available on climate-smart agriculture usually concentrate on either cutting-edge technologies or practical elements regarding climate-smart farming [12,13, 14,15, 16,17, 18, 19, 20,21,22,23].The best of our knowledge however, very little research has thoroughly examined the advancements, difficulties, and potential prospects in climate-smart agriculture. Moreover, climate-smart agriculture has made more rapid advancements and breakthroughs in the recent ten years. In-depth analysis of the current developments, difficulties, and prospects supportive of climate-smart farming will is beneficial and timely.

Goals for the description and advancement of climate-smart agriculture

The United Nations Food and Agriculture Organization (FAO) formally suggested climate-smart agriculture, food security and climate change at the 2010 Conference of Hague on Agriculture. Climate-smart farming is a structure for agricultural development and production that can increase agricultural productivity sustainably; boost adaptability, and decrease greenhouse gases emissions and preserving country's food safety [26]. By making an effort to address concerns to sustainable agricultural growth and food security brought on by climate change, it integrates the three elements of the surroundings, the community, and economics [9].

The particular goals regarding climate-smart farming are primarily seen in three aspects

Enhancing agricultural systems' ability to change with the climate change, maintain food safety, along with boost farmers' incomes through sustainably increasing their production efficiencies; lowering or getting rid of the GHG(greenhouse gases) reducing the emissions of farming systems to the greatest extent feasible and increasing the ability to sequester carbon. Ultimately, the agricultural systems' tripartite three-win objectives of increased output, stress tolerance, and decreased emissions of greenhouse gases are accomplished [3,9]. In spite of the fact that climate-smart agriculture strives to accomplish all three goals not every technique applied in every situation will lead to three successes. To reach answers that are acceptable locally, climate-smart agriculture needs to take into account these three objectives from both short-term and long-term viewpoints, at local to global sizes. Depending on the circumstances and setting, each aim will have a different relative relevance. Priority one for achieving the three goals of climate-smart agriculture ought to be prioritized, and a balance between the three must be established [3].

Recent Advancementsclimate-smart farming practices in different countries

Agriculture is the primary economic driver of many emerging nations. In poor nations, food security and agricultural productivity are threatened by climate change in a number of ways. When establishing climate-smart agriculture the most crucial development objectives in these developing nations priorities should be ensuring food security, promoting economic growth, and increasing agricultural output efficiency. The absence amount of water used for irrigation during the dry seasons is Maharashtra's largest problem with agricultural production. Irrigation water management systems including, drip irrigation, pipe wells, well digging, rainfall collection, and other groundwater extraction techniques, can help end the drought. The efficient use of fertilizer and water can be increased by in addition to nutrient management techniques such straw residue assimilation, compost made from earthworms, farmyard manure, sprinkler irrigation and other micro irrigation techniques [27, 28, 29].

Within the Mekong Delta of Vietnam, farmers have increased crop yields, decreased production expenses, and ensured food security by employing outstanding rice varieties, planting and harvesting schedule optimization, minimizing synthetic fertilizers, along with changing irrigation methods [30, 31, and 32]. Farmers in Nepal implement management practices that can enhance soil physical properties, soil biological activity, and soil water usage efficiency qualities. These practices include crop rotation, no tillage, and returning straw to the field [33]. In addition to reduced erosion, the improved soil can raise plant height, increase the number of tillers, and boost wheat grain output. Local cotton growers in Pakistan implement the concept of climate-smart agriculture, leveling the soil using lasers and bed seeders. Improved drought- and waterlogging-resistant cultivars, reduced fallow and tillage, and other drainage control and indirect water use techniques help to improve local cotton quality and indirectly reduce greenhouse gas emissions [34].

In Africa, considerable Reforms in agriculture are needed to address the two interconnected and growing issues of climate change and food security [26]. For instance, improved crop types, farms that rotate their cereals and legumes and mulch their surface crops organically are examples of protective agricultural practices utilized in Zambia, South Central Africa [35]. By increasing Carbon fixation and soil fertility capacity, these measures in Zambia possess the capacity to significantly increase average grain yields and effectively ensure local food security. Furthermore, Africa's Malawi has embraced the complex of agroforestry system, ordered agroforestry fallow in which fast-growing legume trees or bushes are planted, and ongoing intercropping of two primary fertilizer species in agroforestry [36, 37]. They also collected foggy water for use in irrigation coastal desert agricultural production, or they combined fog water and seawater to accurately drip-irrigate agricultural roots to conserve irrigation water [38]. In addition, they must consider the development and application of regulations, incorporate cutting-edge technology, increase the adaptability of the farming system, and lower greenhouse gas emissions while boosting productivity [39]. One of the most prolific and resource-rich agricultural areas in the world California, in the United States, prioritizes the prudent administration of water resources and the decrease of greenhouse gas greenhouse gases in order to accomplish climate-smart agriculture [40]. The state of California has successfully reduced greenhouse gas emissions by enacting several laws and regulations and implementing pertinent agricultural technological measures through the public research system.

For instance, the dairy sector must cut 40% reduction in methane emissions by 2030 in accordance with the most recent methane rule [41]. When it comes to water resources management, the Californian government sees improving water for agriculture usage efficiency in the role of solution. By building to improve water recovery and storage, use micro sprinkler irrigation systems or drip irrigation capacity, and modernizing subterranean water pumps, the regional administration assists farmers in overcoming high investment costs, lowering greenhouse gas emissions, and adapting to water constraints [42, 43]. People are more aware of how climate change is affecting agricultural development where agriculture is practiced throughout Europe more developed [44]. Switzerland's reaction to the GHG emission plan produces renewable energy recycles agricultural waste to the biogas facility at no cost, and supplies the farm using premium feed additives and fertilizers that are enhanced by the biogas facility [45]. In Cyprus, agricultural defense is also included productivity are increased, pesticide consumption is decreased, and agricultural environments are made more sustainable through the employment of agricultural robots for pesticide application [46].

Challenges in climate-smart agriculture

Food security is predicated on the safety of water. The scarcity of water for agriculture supplies is currently a severe barrier to both the sustainable growth of worldwide food security and climate-smart farming. There will be a 55% growth in the demand for water worldwide. The demand for water is expected to rise by 55% globally. The world's water users in agriculture are being impacted by the current, quickly worsening water deficit [48]. According to a study, Turkey's sweet corn output and protein content were negatively impacted by water scarcity in agriculture. As the degree of water deficit increased, so the content of Fe, Zn, and Cu in kernels; the fresh ear yield; the marketable ear number; and the leaf area index [49]. According to a study, there was a way to small danger of scarcity of agricultural water resources in 2010 in the arid Northwest of China [50]. It was projected that by 2030, the probability of a lack of agricultural water resources will have increased up to a degree of medium-high danger. Zhang and al.'s findings [51] for water and grain yield usage demonstrated that in the typical dryland agricultural zone of the Loess Plateau in China, Rainfall reduced crop yield and water use efficiency scarcity. According to a study, in dry environments, applying phosphorus, nitrogen, and water together aided in the ecological regeneration of coal-mining regions [52]. Planning and long-term management of agricultural water resources depend heavily on their assessment. For instance, seasonal variations in South Korea's rainfall and water quality make the irrigation-based agriculture particularly vulnerable to water scarcity [53, 54]. The availability water resources for agriculture has decreased recently due to a lack. In the form of liquid and its unequal dispersal at temporal and spatial scales brought on by climatic variability, for example heat waves and droughts [55]. The distribution of heat, light, water, and other climate resources for agriculture has altered due to climate fluctuation and change. Smallholder agriculture suffers greatly from climate variability, which lowers crop yields, incomes, and causes food insecurity [56]. According to a Ghanaian survey, climate unpredictability had a significant impact on subsistence farming. It also led to food concern in 58% of families and the inability to purchase the quantity and quality of food that they preferred in 62% of cases [57]. Increased average temperatures, longer growing seasons, more hot days and nights, more erratic precipitation patterns, and higher CO2 concentrations are some of the climate change's immediate effects on agriculture [58]. It is predicted that the world's crop production would continue to alter because of the direct consequences of space climate change and time, particularly in poorer nations where the main source of food crops is income [59]. Typically, accepted that some places will see increases in expected yields while other regions will see decreases [60]. Consider long and associates, [61] estimated the wheat production in China's Basin of the Yellow River and discovered a significant geographical variance in wheat yield, with an average decrease of 0.19% between 2020 and 2050 compared to the baseline period (1975–2005). Daloz and associates [62] demonstrated how the Indo-Gangetic Plain's wheat yields are directly impacted by climate change. The rise in maximum and average temperatures, along with the amount that precipitation there is during the growing season caused at 1-8% decrease in yield of wheat.

Food security is predicted to be threatened by extreme climate conditions, such as protracted drought, severe maximum daily rainfall and drought if greenhouse gas emissions continue at their current rate [63]. Furthermore, regional climates may be significantly altered by variations in both the weather and precipitation brought on by climate change, which could result in changes in crop distribution [64]. Climate change can alter the specific nutrients, proteins, carbs, and so forth when combined with income increase. Thus, learning how to access a variety of nutrient-dense food sources is essential for low-income countries in order to improve their sustainable nutrition security in the face of climate change [65].The obstacles to the long-term viability of climate-smart agriculture are further compounded by greenhouse gas emissions from agriculture. Ecosystem imbalance is a result of emissions of greenhouse gases [66]. Agricultural ecosystems contribute about 56% of all non-CO2 emissions worldwide, making them the second greatest source of anthropogenic greenhouse gas emissions [67]. According to estimates, seven countries-Argentina, Australia, Brazil, Canada, Chile, China, India, and the United States-account for 49% of global agricultural emissions and more than half of global soil emissions [68]. According to data from South Korea, the country's agricultural industry emits roughly 3.4% of its total greenhouse gas emissions, of which 58% are caused by crop growing [69]. Agricultural methods have the potential to release water and nitrogen footprints in addition to greenhouse gas emissions [70, 71]. Data support and product details are essential to the management, production, transportation, and scaling of climate-smart agriculture. The issue of an abundance of agricultural data will also be a challenge for climate-smart agriculture. If misleading information is not accurately discovered, it will have an impact on the long-term growth of climate-smart agriculture.

Prospective Courses of climate-smart agriculture

Utilizing State of the Art Utilizing Internet Technology to Protect Agricultural Data

Technology for remote sensing is extensively employed in many domains due to its quick, large-scale, dynamic, real-time, macro, and affordable access. The use of remote sensing collects information from spacecraft or autonomous aerial vehicles can become accustomed to identify and track the physical features of the earth's surface. The geographical temporal resolution, spectrum resolution, and resolution are the trio of most frequently occurring characteristics of data from remote sensing [72].The pixel dimension of a picture determines its spatial resolution, this has an impact on the imagery's capacity to identify things. The interval of spectral sampling, size, and quantity that determine spectral resolution impact the sensor's capacity to identify electromagnetic spectrum targets. How frequently collected data is known as the temporal resolution. These days, remote sensing is a significant tool with many potentials uses in regional-scale climate-smart agriculture because of the constant improvement of the temporal, spatial, and spectral resolutions of observation from remote sensing, together with the creation of products and methods for remote sensing inversion [20,73]. Accurate crop management has been achieved with the application of image-based remote sensing. Hyper spectral images, however, have greatly improved the ability to distinguish between crop diseases, nutrients, in addition to canopy constructions [74]. Additionally, three-dimensional (3D) agricultural mapping spectrum dynamics, generic reflectometry, and photographs have shed light on farming production [75]. The China Agriculture Remote Sensing Monitoring System, for example was created by the Department of Agriculture of China's Application Center for Remote Sensing and has been present in use since 1998 [76]. For China's staple crops-wheat, corn, rice, soybeans, cotton, canola, and sugarcane-this system can track crop growth, planting area, yield, and information on agricultural disasters. Using the spectral index to calculate the quantity of information of rice mixed components, Yuan et al. [77] discerned the ghostly distinction between background and rice. Additionally, thermal, hyperspectral, and multispectral imaging sensors offer practical settings for agricultural strain research [78, 79, and 80]. By integrating a remotely operated aerial vehicle (ROAV) with a wireless sensor network on the ground, it is possible to further improve the management of fertilizer and pesticides in the field [81].

Use on the Internet of Things

IoT stands for the Internet of Things universe of networked computers, sensors, and other internet-connected machines. Every gadget has an individual identity as well as the capacity to carry out remote observation and surveillance [82]. The Things Connected (IoT) mostly utilized in agriculture to gather data from many sensor types about crop and environmental characteristics including pH, humidity, and temperature level, tint of the leaves, etc. IoT application evaluation is among the many facets of Application of IoT in agriculture sectors that have been studied [83] and creating The Internet of Things food control infrastructures [84], to verify how well smart agriculture incorporates IoT and agricultural UAV [85,86].Finally, the Internet of Things in climate-smart farming must be secure. This is due to the fact that data is frequently valued at and treated as a trade secret by farmers. Because of this, the Internet of Things' sensor network needs a security plan that works with cloud databases and potential, operational calculation networks [87].

Artificial Intelligence Application

In the future, CSA plans to pursue further advancements in artificial intelligence. Artificial intelligence (AI) is the simulation, extension, and expansion of human intelligence through the use of digital computers or other controlled technologies to sense the environment and gather pertinent information. AI has already proven to have several benefits in a variety of industries. [25]. The most recent developments in big data and computer hardware have made room for the use of AI in farming. Currently, artificial intelligence (AI) is being utilized in many agricultural industries to perform tasks including plant identification, weed forecasting, crop yield forecasting, climate forecasting, and greenhouse gas emission forecasting, pest control, and evaluation of the risk associated with of crop planting. AI can evaluate and incorporate information from various agricultural domains [24,88]. As (AI) models are built, the precision of their predictions and judgments increases with the volume of information. AI in the future, technology should be utilized to enhance the gathering and examination of information from various sources, including the soil, weather, illnesses, and pests.

Enhancement of management strategies and cutting patterns: Instances of various methods of crop diversification, no-till farming, and cropping patterns that can boost agricultural production and lower emissions of greenhouse gases are rotating rice-wheat and rice-potato-sesame crops [75,89], and adding appropriate dryland crops to reduce the need for yearly planting cycle's submergence period [90]. In order in order to boost crop yield and soil quality, particularly on low-fertility soils, it is It is customary to blend chemical fertilizers with organic enhancers[91]. For instance, biochar is thought to work well as a synergist in soil additives because to its enormous potential for repairing the carbon, mending dirt, and enhancing crop and soil quality yield [92]. Including biochar may alter the soil's C/N cycle and nutrient release, which may have an impact on farmland's greenhouse gas emissions [93]. Certain soil conservation techniques, like utilizing agricultural wastes, increasing nitrogen employ effectiveness, and lowering planting density, are advised to be able to lower CO2 emissions [94]. Crop production can be increased by applying crop wastes because they boost soil organic carbon [95].Future CSA development will advance sustainable agriculture development and accomplish the triple bottom line of cutting back on greenhouse gas emissions, preserving food security and adjusting to alterations in climate. Enhancing agricultural strategies and management approaches helps make climate-smart agriculture, or CSA, a reality later on.

Based on agricultural weather index insurance: It eliminates moral hazard and adverse selection associated with traditional insurance while cutting operational costs. It is also straightforward to promote and resolve claims for [96].Many Emerging nations possess begun to introduce insurance based on weather indexes into the agriculture insurance market as a result of the creation of insurance plans based on weather indices for arrange of weather conditions. Insurance based on agricultural weather indices policies for Emerging countries have been progressively available since the start of the twenty-first century in Central Asia and Africa, Ethiopia, India, and other regions [97,98,99,100,101]. In poor nations, a minimum of dozens of insurance plans based on weather indices are in test programs. For instance, in Northern Bangladesh, smallholder farmers are prepared to cover the cost of flood insurance in order to prepare for climate change [102].

Conclusion

This essay examines the current state of CSA, its difficulties, and its prospects. A detailed introduction is given to the latest developments in CSA in both industrialized and developing nations. Nonetheless, the issues and difficulties associated with CSA persist, including the lack of waterresources for agriculture, the unpredictability and influence of climate change, greenhouse gas emissions from agriculture, and the integration of information resources. The primary CSA's development direction (climate-smart agriculture) is anticipated to be utilizing cutting-edge internet-based technologies to future agricultural information protection initiatives include improving cropping patterns and management techniques, offering a "internet + weather" service, improving the standard of agricultural services, and putting in place insurance based on agricultural weather indices.

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