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Impacts of Climate-smart Agriculture on Crop Production: A Review

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ABSTRACT

Climate change(CC) factors worldwide have negatively impacted crop production. Temperature, precipitation, and greenhouse gas emissions have influenced soil fertility, irrigation resources, plant physiology, and metabolic activities in crops. Afghanistan has also encountered climate change factors, such as drought, that decreased crop production. A technologically sophisticated solution to the problems facing agriculture due to CC is called Climate-smart Agriculture (CSA). Crop rotation, crop residue management, and soil and water conservation are called Climate-smart Agriculture Practices (CSAP). It is reported that CSAP increased water use efficiency and total water storage by 9–68% and 1–13%, respectively. Furthermore, implementation of CSAP increased wheat yield by 30-45%. Although the adaptability of CSA has been investigated, little is known about the impacts of CSA on crop production. Thus, it is necessary to describe the impacts of CC on crop production and investigate widely. The review was stated to provide some understanding and recommendations on earlier studies on the topic. The review's objective is to determine the optimal CSAP that decreases the adverse effects of CC on crop production. Researchers, consultants to farmers, and policymakers can benefit from synthesizing all this information as it may help provide favorable plans to boost crop production by selecting and using relevant CSAP.

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INTRODUCTION

Several challenges impact the agriculture sector; however, the most significant challenge is climate change, which has recently become the world's most persistent issue (Fusco et al., 2020). Lemi and Hailu (2019) state that the agriculture industry is the most susceptible to climate change and fluctuations. In agriculture, crop production, animal production, and horticulture are the most vulnerable to climate change (Lemi & Hailu, 2019). Due to increasingly varied weather patterns, climate change severely affects agriculture worldwide (Lemi & Hailu, 2019). The main factors of climate are precipitation, temperature, and

greenhouse gases. These factors impact plant metabolism, physiology, pest infestation, soil fertility, and irrigation resources (Malhi et al., 2021). For instance, Salihi et al. (2024) reported that various climatic factors, such as air temperature, atmospheric CO_2, light, water, and soil nutrients, affected rice production. Climate change has significantly affected global agricultural productivity (Okalie et al., 2022). At the same time, crop production is influenced by climate variability worldwide (Lemi & Hailu, 2019). Furthermore, the food and nutritional security of the world has been threatened by climate change (Malhi et al., 2021). Afghanistan is also affected by climate change, extreme weather events, and losses accompanying its poor adaptation status (Omerkhil et al., 2020). For instance, rising temperatures and decreased precipitation in many parts of Afghanistan contribute to the country's recurrent droughts and other climate change-related problems (Sarwari et al., 2023; Wafa et al., 2024).

The Food and Agricultural Organization (FAO) established climate-smart agriculture in 2010 (Imran et al., 2018). Climate-smart agriculture is the technologically advanced response to the challenges faced by agriculture due to climate change (Imran et al., 2018). It is also a new approach to adapting agriculture to climate change conditions (Tadesse & Ahmad, 2023). Moreover, climate-smart agriculture practices include soil and water conservation, hedgerow planting, cop residue management, crop rotation, and perennial crop-based agroforestry systems (Tadesse et al., 2021). Climate-smart agricultural advantages are uniform germination, high yield, financial returns, the meditation of inputs, and increased resource use efficiency (Imran et al., 2018). The reports described climate-smart agriculture as more beneficial than traditional cotton farming (Jamil et al., 2021). It is also found that the main reasons for adopting climate-smart agricultural practices and technologies are limited supply of canal water, climate change, massive groundwater extraction, rapidly declining water table, and increasing soil salinity over time (Imran et al., 2018).

Climate-smart agriculture methods and technologies significantly mitigated the detrimental effects of climate change on crops (Malhi et al., 2021). According to Zizinga et al. (2022), climate-smart agriculture methods increased water storage by 1–13%. As well as, mulching, permanent planting basins, and half-moon pits enhanced the water use efficiency by 9-68% and 8-66% of grain yield than control (Zizinga et al., 2022). Additionally, climate-smart agriculture techniques significantly increased crop productivity and soil organic carbon by 16.4% and 14.7%, respectively (Kichamu et al., 2021). Moreover, adaptation of climate innovative practices increased rice yield by 15.87% (Salihi et al., 2024).

Greenhouse gases (CO_2, NO_2, and NH_4) in the atmosphere have been increasing rapidly in the atmosphere recently, which caused global warming. Furthermore, the temperature is also increasing due to greenhouse gas emissions in the atmosphere. Moreover, water resources are decreasing, and many parts of the world suffer from drought; however, the perception changed in other parts. Agriculture in Afghanistan is also affected by climate change, such as drought, decreasing water resources, lack of water sheath management, and crop yield loss due to pests, diseases, and other plant physiological activities. In order to reduce the effects of climate change on crop production, many strategies, practices, and

technologies are used in the world (Okalie et al., 2022). Climate-smart agriculture is one of the most recently introduced and important technologies and practices adopted in different parts of the world and reduced the negative impacts of climate change (Tadesse & Ahmad, 2023). Most current studies are conducted on climate-smart agriculture adaptation and its effects on agricultural products, soil fertility, and agricultural practices separately in African countries; however, there is limited information regarding the impacts of climate-smart agriculture practices and adaptation on crop production. The main objectives of the review are as follows:

1. To simultaneously address the effects of climate-smart agriculture, methods, and their adaptation on crop production.
2. To anticipate further research work to improve crop production under climate change conditions.

METHODS & MATERIALS

The library research method has been used for the review. Firstly, an international reliable journal targeted in the field of study using different famous search engines. Secondly, the latest relevant published manuscripts in the journals have been searched, downloaded, and arranged using Mendeley. Thirdly, every single manuscript was studied carefully, and the relevant information from each was marked, collected, summarized, cited, and paraphrased accordingly. Finally, the above-mentioned information is used in different parts of the manuscript when needed.

FINDINGS

The Impacts of Climate Change on Agriculture

The agriculture sector has been affected by many threats, while the most important threat is climate change, which has been the leading global issue in recent years (Fusco et al., 2020). Climate change has affected agriculture production and food security (Fusco et al., 2020). Climate change is the most important environmental and human problem (Okalie et al., 2022). In addition, one of the most significant global concerns impacting agricultural products is climate change (Andati et al., 2023). Lemi and Hailu (2019) state that the agriculture industry is the most susceptible to climate change and fluctuations. In agriculture, crop production, animal production, and horticulture are the most vulnerable to climate change (Lemi & Hailu, 2019). Furthermore, climate change significantly impacts global agricultural productivity (Okalie et al., 2022). Due to increasingly varied weather patterns, climate change severely affects agriculture worldwide (Lemi & Hailu, 2019). Global climate variability also impacts crop productivity (Lemi & Hailu, 2019). For instance, Maize production is constrained due to climate change and limited water availability, especially in rainfed agriculture (Zizinga et al., 2022). Furthermore, the world's food and nutritional security have been threatened by climate change (Malhi et al., 2021).

The main determinants of climate are perception, temperature, and greenhouse gases (Malhi et al., 2021). These factors impact plant metabolism, physiology, pest infestation, soil fertility, and irrigation resources (Malhi et al., 2021). Since the Green Revolution, greenhouse gas emissions into the atmosphere have increased significantly, contributing to global warming and rising the atmosphere temperature (Malhi et al., 2021; Salihi, 2024). For example, the global temperature is predicted to rise by 2°C by the end of this century and is increasing regularly (Malhi et al., 2021). Additionally, the concentration of CO_2 in the Atmosphere is rising quickly and increasing temperature (Salihi et al., 2023).

Afghanistan and Climate Change

South Asian countries are among the countries most affected by climate change, mainly due to poverty and complex socioeconomic challenges (Omerkhil et al., 2020). At the same time, Afghanistan is less well-adapted to the changing climate and suffering from climate change problems (Omerkhil et al., 2020). For instance, Afghanistan frequently faces drought and other climate change-related challenges due to rising temperatures and decreased precipitation (Sarwari et al., 2023). Additionally, the evidence indicates that Afghanistan's temperature has increased dramatically since 1950, rising by 0.6 to 1.8°C (Shokory et al., 2023). According to Sarwari et al. (2023), the temperature negatively affected wheat and barley yields by 271 and 221 kg ha^{-1} for every 1 ◦C increase in mean temperature. Furthermore, comparing streamflow records from 1968 to 1977 with those from 2008 to 2016, the available data further suggests that Afghanistan's total surface water volume has declined (Shokory et al., 2023).

Climate-smart Agriculture

The Food and Agricultural Organization (FAO) established climate-smart agriculture in 2010 (Imran et al., 2018). It is a novel idea that has been applied to characterize a variety of adaptation techniques (Chandra et al., 2017). Climate-smart agriculture is the technologically advanced response to the challenges faced by agriculture due to climate change (Fusco et al., 2020). Additionally, according to Fusco et al. (2020), climate-smart agriculture improves resilience, boosts productivity, decreases greenhouse gas emissions, and increases national food security and sustainable development. Furthermore, climate-smart agriculture techniques have been introduced to improve traditional agricultural practices (Kichamu et al., 2021). Moreover, increasing crop productivity and adapting to climate change are two primary goals of climate-smart agriculture (Andati et al., 2023). Additionally, Tadesse and Ahmad (2023) reported that climate-smart agriculture is a novel strategy for adjusting agriculture to the current climate change conditions.

Climate-smart Agriculture Practices

Climate-smart agriculture techniques include crop rotation, crop residue management, hedgerow planting, conservation of soil and water, and perennial crop-based agroforestry systems (Tadesse and Ahmad, 2023). In Africa, conservation tillage, crop residue retention, and green manure are the most popular climate-smart agricultural techniques (Kichamu et

al., 2021). Microdosing mineral fertilizer, seed priming, new cereal types, horticulture, poultry, and goat production are climate-smart agriculture methods (Sissoko et al., 2023). The most noteworthy and adaptable smart agricultural technique types are listed in Table 1 below.

Table 1: *The most important adapted climate-smart agriculture practices*

Types of practices	Practices	Source
Water-smart practices	Laser land leveling	Malhi et al., 2021
	Rainwater harvesting	Malhi et al., 2021, Tadesse & Ahmad, 2023
	Micro-irrigation	
Nutrient-smart practices	Raised-bed planting	Malhi et al., 2021
	Precision nutrient application	
	Crop residue management	
Weather-smart activities	Stress-tolerant varieties	
	ICT-based agrometeorological services	
Carbon-smart activities	Zero tillage	
	Legumes	
Knowledge-smart activities	Agricultural extensions to enhance capacity-building	
Agronomical practices	Crop rotation	
	High yielding disease resistant tolerant varieties	
	Changing planting or harvesting dates	
	Intercropping and adaptation of agricultural inputs	
Integrated soil fertility management	Inorganic fertilizer application	
	Compost preparation and application	
Conservation agriculture	Soil and water conservation	Tadesse & Ahmad, 2023
	Crop diversification contour planting	
	Use of earth catchment construction	
	Conservation tillage	
	Crop rotation	
	Minimum tillage	
	Mulching	
Irrigation	Terracing or bunding	
	Water management practices	

Advantages of Climate-smart Agriculture Adaptation

Climate-smart agriculture's key benefits are uniform germination, high yield and financial returns, input concentration, and improved resource usage efficiency (Imran et al., 2018). Additionally, it has been found that, compared to conventional farming, maize productivity has a more significant chance of being increased by climate-smart agriculture practices, especially in sub-humid locations with unpredictable and low precipitation (Zizinga et al.,

2022). Furthermore, climate-smart agriculture strategies boosted soil moisture storage and improved the efficiency of maize growth, production, and water usage (Zizinga et al., 2022). Moreover, traditional cotton farming is less advantageous than climate-smart agriculture (Jamil et al., 2021). For instance, cotton producers have employed climate-smart agriculture technology, soil and crop management techniques, and irrigation to reduce climate change's adverse effects, water scarcity, and groundwater depletion (Jamil et al., 2021).

Many dynamic agricultural practices are required to enable farmers to adapt to climate change and produce enough food to feed the world's growing population, reducing the adverse effects of climate change (Okalie et al., 2022). It is reported that implementing climate-smart agriculture methods on cotton crop cultivation mitigated the adverse effects of climate change (Jamil et al., 2021). According to Imran et al. (2018), it is also discovered that the primary drivers behind the adoption of climate-smart agricultural techniques are the scarcity of canal water, climate change, drought-prone areas, extensive groundwater extraction, a quickly dropping water table, and a gradual increase in soil salinity.

It is also reported that climate-smart agriculture is important in enhancing food production under climate change in Africa (Kichamu et al., 2021). Meanwhile, climate-smart agriculture practices in rainfed agricultural systems enhanced crop yields and water use efficiency compared to conventional farming under climate change (Zizinga et al., 2022). Moreover, integrating climate-smart agriculture practices can potentially improve soil organic carbon, soil total nitrogen, and crop productivity (Kichamu et al., 2021). The technologies and practices significantly reduced the negative effects of climate change on crops (Malhi et al., 2021). Among the above-mentioned practices of climate-smart agriculture, micro-dosing of mineral fertilizer and seed priming was adopted by more than 85% of households in the study in Mali (Sissoko et al., 2023). It is demonstrated that the introduction of newly developed agricultural technologies increased yields, households` cereal surplus, and food diversity (Sissoko et al., 2023). Among the climate-smart agriculture adaptation technologies, water harvesting, strong policy, use of advanced technology, strong institutional framework, enabling the use of existing opportunities, and introduction of stress-tolerant crop varieties are very important to decrease the effects of climate change (Lemi & Hailu, 2019). Many agronomical practices in climate-smart agriculture can increase agricultural production under current climate change regimes and contribute to reducing greenhouse gas emissions (De Pinto et al.,2020). Adapting climate-smart agriculture practices can improve the production of wheat, maize, and rice production under climate change conditions (De Pinto et al., 2020; Salihi et al., 2024). Moreover, applying humic acid as a sustainable organic substance offers a promising approach to improving wheat production (Salihi et al., 2024).

Effects of Climate-smart Agriculture on Crop Production

Climate-smart agriculture technologies and practices can increase water availability and water use efficiency in rainfed agriculture (Zizinga et al., 2022). According to Zizinga et al. (2022), climate-smart agriculture methods increased total water storage by 1–13%.

Additionally, mulching, half-moon pits, and permanent planting basins increased the water use efficiency by 9–68% and 8–66% of grain production, respectively (Zizinga et al., 2022).

Furthermore, climate-smart agriculture techniques greatly increased crop productivity and soil organic carbon by 16.4% and 14.7%, respectively (Kichamu et al., 2021). It is also reported that cotton production using smart agriculture practices and technologies is financially, environmentally, and socially better than conventional cotton cultivation (Imran et al., 2018). Seed management technologies increased potato production by 61%, along with soil nutrients management, crop improvement practices, seed management, and crop protection techniques by 50%, 41%,40%, and 39%, respectively (Andati et al., 2023).

Climate Adaptation Strategies in Afghanistan

It is reported that in Afghanistan, the majority of the farmers (>80%) perceived a "high to a very high" degree of climate-induced impact on loss of employment, labor scarcity, pest and disease outbreaks, and decline in groundwater level (Sarwary et al.,2021). Nonetheless, the methods used by the peasant smallholders in the area to mitigate climate risks were determined by household factors such as dwelling style, LPG usage, animal population, irrigated land area, education, secondary occupation, and male population (Omerkhil et al., 2020).Farmers widely used crucial coping and climate adaptation techniques, such as shifting cropping patterns, digging new bore wells, and diversifying their farms (Sarwary et al., 2021). In terms of policy, viable measures to shield farm households from climate extremes include the installation of automatic weather stations, agro-advisory services, weather-based climate-smart agricultural methods, and crop insurance (Sarwary et al., 2021). One practical way to practice climate change adaptation in Afghanistan is to organize capacity-building programs on crop-specific climate-smart agricultural practices, such as in-situ moisture conservation, biomass mulching, alternate wetting and drying irrigation methods, introducing drought-tolerant varieties, direct seeding, water harvesting, and recycling for farmers' supplemental irrigation through the trained personnel from extension and line departments (Sarwary et al., 2021).

DISCUSSION

For the last few decades, agriculture and crop production have been affected negatively by global factors of climate change, which has been the most significant issue recently. Similar findings were also reported by Fusco et al. (2020), Mahil et al. (2021), Salihi et al. (2023), Lemi & Hailu (2019), (Okalie et al., 2022), and (Omerkhil et al., 2020). For instance, changes in perception, increasing temperature, and rapid emission of greenhouse gases have affected agriculture production negatively, causing malnutrition. Malihi et al. (2021) also reported that perception, temperature, and greenhouse gases affected plant metabolism and physiology. Furthermore, Sarwari et al. (2023) reported that wheat and barley yields decreased due to increased temperatures in Afghanistan. Moreover, Zizinga et al. (2022) stated that climate change has also reduced maize productivity in rainfed agriculture. Thus, food security globally is negatively affected by climate change. Fusoco et al. (2020) stated a similar report.

Meanwhile, drought and water resource restrictions have recently affected Afghanistan, especially agriculture and crop production. Similar findings were reported by Shokory et al. (2023) and Srwari et al. (2023).

At the same time, to decrease the adverse effects of climate change on crop production, several practices and technologies have been developed, such as climate-smart agriculture. Several types of Climat-smart Agriculture have been developed and adapted in different countries worldwide. The most adapted and effective methods were water-smart practices and weather-smart practices. This may be due to crop production's vulnerability to weather conditions and water resource scarcity. Thus, Climate-smart agriculture's adaptation mitigates climate change's adverse effects on crop production and increases crop production under climate change conditions. Similar findings were stated by Kichamu et al. (2021), Mail et al. (2021), and Sissoko et al. (2023).

Moreover, implementing climate-smart practices reduced climate change's negative effects on crop production. De Pinto et al. (2020) reported that the adaptation of climate-smart agriculture improved the production of wheat, maize, and rice. Similarly, Aadesse et al. (2021) reported that implementing and adapting climate-smart agriculture techniques increased wheat yield by 30-45%. Moreover, Salihi et al. (2024) also stated that adopting climate-smart practices increased rice yield by 15.87%.

Regarding adopting Climate-smart agriculture practices in Afghanistan, farmers mostly use shifting cropping patterns, digging wells, and diversification of farms, which may be due to a lack of information and training regarding the other types of Climate-smart agriculture practices and methods. Similar findings were reported by Sarwary et al. (2021). Thus, climate-smart practices, such as moisture conservation practices and mulching using biomass, are new climate-smart irrigation methods that need to adapt to mitigate the negative effects of climate change on crop production in Afghanistan. Sarwary et al. (2021) also stated similar findings.

Future Direction and Challenges in Adapting Climate-smart Agriculture

Climate change is currently one of the most important challenges to agriculture in Afghanistan and the world. Adapting climate-smart agriculture and relevant practices and technologies in African nations was the main focus of previous research in the last few decades. There are reports that climate-smart agriculture has been implemented successfully in certain regions. Additionally, adopting climate-smart agriculture enhanced certain crop yields and decreased the adverse effects of climate change; however, there is a lack of information regarding the adaptation of climate-smart practices in other parts of the world, especially Asia and Afghanistan. Even though implementing all practices and technologies of climate-smart agriculture requires much research in the region, inputs are needed, and it takes time to suggest the best-adapted practices to the susceptible areas to improve crop production.

CONCLUSION

The most important threat that has affected the agriculture sector is climate change. As well as climate change affecting agricultural products. For instance, climate change and restricted water availability decreased maize production under rainfed conditions. Furthermore, nutritional security is also threatened by climate change around the world. South Asian countries, especially Afghanistan, have been affected negatively by climate change, such as drought, decreased precipitation, and surface water reduction. Moreover, the temperature increased significantly in the country and decreased crop production, especially wheat production. Climate-smart agriculture practices are the main driver of adaptation to climate change and the improvement of crop production. The most important and adapted climate smart Agriculture practices are laser land leveling, rainwater harvesting, micro-irrigation, crop residue management, stress-tolerant varieties, zero tillage, crop rotation, changing of planting or harvesting dates, and water management practices, which have the potential to adapt in many parts of the world including Afghanistan to improve crop production under climate change condition. These practices can be adapted in many world regions, including Afghanistan, to improve crop production under climate change conditions.

Furthermore, growth, productivity, water use efficiency, and soil moisture storage have all increased due to climate-smart agricultural methods. Meanwhile, climate-smart agriculture techniques also mitigated the detrimental effects of climate change on crop productivity. Crop productivity increased by the adoption of climate-smart agricultural methods. The introduction of the most significant and appropriate climate-smart agriculture techniques, weather-based crop insurance, and agro consulting services are Afghanistan's top climate change concerns in improving crop productivity and minimizing the adverse effects of the phenomenon. It is recommended that more research should be conducted on the specific climate-smart agriculture techniques used on critical crops in Afghanistan, such as wheat, as well as the impacts of new climate change technology on increasing crop productivity under climate change conditions in the future.

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