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Sustainable and Climate Smart Agriculture for Food Security: A Review

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

This review provides an in-depth examination of the principles, practices, and challenges associated with sustainable and climate-smart agriculture. Sustainable agriculture, with its focus on soil health, biodiversity, water management, and reduced chemical inputs, is crucial for meeting current food production needs while preserving resources for future generations. Climate Smart Agriculture builds upon sustainability by emphasizing climate adaptation and mitigation strategies, including climate-resilient crop selection, greenhouse gas reduction, and technology integration.

However, several challenges hinder the widespread adoption of these practices. Indian Farmers often lack knowledge and resources, while financial constraints and policy barriers pose significant hurdles. Additionally, climate variability and market access issues further complicate the transition to sustainable and climate-smart agriculture.

Efforts to address these challenges require comprehensive education and training programs, supportive policies, financial incentives, and increased collaboration among governments, NGOs,

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and the private sector. Achieving sustainable and Climate Smart Agriculture is crucial for ensuring food security and resilience in the face of climate change.

Keywords: Sustainable agriculture; climate change; climate smart agriculture; food security; soil health; biodiversity; policy barriers.

1. INTRODUCTION

Sustainable and climate-smart agriculture has increased significant attention in recent years due to the pressing need to address climate change and ensure food security. This review aims to provide an overview of Principles practices, and challenges associated with sustainable and climate-smart agriculture. Due to its crucial role in these countries economic progress, agriculture is accorded sovereign or priority status in the majority of developing countries. In addition to enabling the sustainable and inexpensive distribution of food and maintaining the people's livelihoods, it provides a solid support system for guaranteeing economic stability in times of crisis. However, due to the difficulties posed by climate change and the consequent fragility of farming systems, there are significant risks and uncertainties that must be dealt with by identifying context-specific barriers and effective adaptation methods. Therefore, it is important to address the predicted changes in farming practices that will increase agriculture's resistance and resiliency to the negative effects of climate change. Additionally, agriculture is one of the industries most impacted by climate change (Challinor et al., 2014) Examples of potentially yield-damaging changes that are already being felt in some regions of the world include increased frequency of extreme weather, heat, and variability in pests and diseases especially in some of the world's most vulnerable regions [1] Families use 53% of all agricultural land for food production. (Graeub et al., 2016) Farmers, According to the FAO (2016), measures that have a significant impact on food security and adaptation are frequently but not always also associated with decreased greenhouse gas emissions or enhanced carbon sequestration.

2. CLIMATE CHANGE IMPACTS ON AGRICULTURE

"Climate" is the term used to describe general weather patterns that occur over a wide area. Both weather and climate consider variables such as temperature, precipitation, and humidity. According to the United Nations Framework Convention on Climate Change (UNFCC), climate change is defined as a change in the climate that can be directly or indirectly connected to human activities and that exceeds the natural climate variability that has been observed across similar time periods. Although the weather has always been erratic, the current rapid climate change makes agriculture substantially more vulnerable. The updated climatic estimates should be taken into account when planning for adaptation to climate change in the future. In the general circulation of the atmosphere, the Indian monsoon is one of the most significant climate systems. A period of around four months (June to September) is devoted to the southwest monsoon season, during which the country receives more than 80% of its annual rainfall. The seasonal start, end, total amount of rainfall, and distribution all have a substantial impact on the agricultural industry each year. Over the past century, the surface of the Earth has warmed, and there is now unquestionable evidence that human activity is mostly to blame for this warming. It has also been highlighted that various precipitation-related variables, such as snow cover, sea ice, extreme weather events, etc., have changed. However, these adjustments exposed significant regional inequalities. Every plant type has a certain temperature range that is appropriate for vegetative growth, with growth slowing as temperatures increase or decrease. One of the regional repercussions of global warming may be the monsoon in India in the summer. Similar to animals, plants cannot reproduce at a variety of temperatures.

3. CLIMATE SMART AGRICULTURE

The concept of Climate smart agriculture (CSA) is relevant in this context. CSA refers to agricultural practices that increase agricultural production and system resilience while reducing greenhouse gas emissions (Venkatramanan et al., 2019) [2]. The FAO (2014) advocates for the necessity of strengthening rural communities' adaptive capacity to cope with climate change, increasing climatic variability, and building the ability to adapt to climatic shocks. FAO (2014) recognizes that climate change is a universal and critical challenge for global food security and that there is a need to improve the current way of managing agricultural systems and natural resources to effectively achieve food security. The FAO adopted the exact definition of CSA, which outlines three objectives in the context of landscapes and food systems: (1) sustainably increasing agricultural productivity to support growth in farm incomes, food security, and development; (2) developing resilience to climate change at various scales (from farm to national); and (3) reducing or eliminating greenhouse gas emissions from agricultural operations, which affect the environment, animals, and people. Various configurations of these objectives that are relevant to the local situation are the focus of a strategy known as CSA. It incorporates a variety of policies, institutions, investments, behaviors, technologies, and practices. (Makate et al., [3] As highlighted by the FAO in 2016, Climate Smart Agriculture (CSA) strategies should be context-specific and include capacity-building for stakeholders to mitigate higher implementation costs. While there is ongoing debate about the effectiveness of field-level adaptation practices, numerous CSA programs have predominantly concentrated on implementing strategies at the field and farm levels. Despite the uncertainties surrounding the efficiency of certain field-level adaptations, a consensus exists that the application of agronomic adaptation can result in a significant enhancement of farmer's yields, estimated to be between 15% and 18% [4].

Furthermore, the FAO (2016) emphasizes that practices demonstrating robust adaptation and food security benefits often, though not universally, contribute to the additional advantages of reduced greenhouse gas (GHG) emissions or increased carbon sequestration. The importance of tailoring CSA strategies to local circumstances, coupled with capacity-building efforts, is underscored by the FAO.

Table 1. Impact of climate change in Indian agriculture

Parameters	Impacts	References
Production and Quality	Agricultural yields decreased as a result of rising temperatures and CO2 concentrations. Grain density falls when the C/N ratio rises.	Damatta et al., 2010; Nardone et al., 2010; Bisbis et al., 2018
Soil	Climate change causes the soil to become drier by reducing productivity, increasing soil erosion, and releasing more carbon from the soil.	Porcal et al., 2009; Jones et al, 2009
Irrigation	Water resources are becoming scarce due to rising water demand and falling water supply.	Seckler, Doll, 2002; Zhou et al, 2010
Pest	Unfavorable weather conditions caused by climate change are causing pests and illnesses to expand their ranges and populations.	Das et al., 2011; Skendžić, et al., 2021; Rosenzweig et al., 2001; Pareek et al., 2017
Livestock	Abiotic stressors such as heat stress caused by climate change are contributing to an increase in diseases like foot and mouth disease among cattle.	Baumgard et al., 2012; Kaffenberger et al., 2017;
Fishery	Climate change has a negative impact on fish populations and their ability to reproduce.	Graham & Harrod, 2009; Munday et al., 2008; Moyle et al., 2013; Stenevik & Sundby, 2007
Economic Impact	Increased pest and disease outbreaks due to climate change are leading to reduced agricultural output. Climate change has a negative impact on fish populations and their ability to reproduce.	Ju et al., 2013; Aydinalp & Cresser, 2008; Mahato, 2014.

Although debates persist about the effectiveness of certain field-level adaptation practices, the potential for improved yields through agronomic adaptation is acknowledged. Moreover, the interconnected benefits of enhanced adaptation, food security, and environmental outcomes, such as reduced GHG emissions and increased carbon sequestration, are highlighted as valuable outcomes of well-designed CSA programs.

3.1 Why Climate Smart Agriculture

"Climate-smart agriculture contributes to the resolution of several pressing environmental and food security issues."

4. CSA DEALS WITH MALNUTRITION, INEQUALITY, AND FOOD SECURITY

Despite the recent emphasis on agricultural development and food security, there are still over 800 million people globally suffering from undernourishment, with an additional billion facing malnutrition. Concurrently, one-third of all food produced is wasted, and more than 1.4 billion individuals are overweight. It is expected that the world's population will reach 9.7 billion by 2050. Global dietary preferences are also undergoing significant changes, with increased income driving a desire for meat-rich diets. If current consumption patterns and food waste habits persist, it is projected that we will require a 60% increase in agricultural output by 2050 United Nations [5] Community Supported Agriculture Plays a crucial role in reducing global food waste while enhancing food security for underprivileged and marginalized communities.

5. CLIMATE SMART AGRICULTURE ADDRESSES THE RELATIONSHIP BETWEEN AGRICULTURE AND POVERTY

Agriculture is the main source of nutrition, employment, and income for many people in developing nations. About 75% of the world's poor live in rural areas and depend heavily on agriculture for their livelihoods [6] Hence, agriculture plays a crucial role in alleviating poverty. Notably, agricultural growth is often the most effective and fair way to reduce poverty and improve food security.

6. CLIMATE SMART AGRICULTURE ADDRESSES THE RELATIONSHIP CLIMATE CHANGE AND AGRICULTURE

The impact of climate change is already being felt through increased global temperatures. In the future, temperatures are expected to become more volatile, leading to changes in rainfall patterns and more extreme weather events such as hurricanes, floods, heat waves, snowstorms and droughts. These events can cause rising sea levels, salinization, soil erosion, reduced soil infiltration, and disruption of entire ecosystems. All of these changes will have far-reaching effects on agriculture, forestry, and fishing. Moreover, plant pests and diseases are anticipated to escalate in frequency and extend to new areas, presenting additional challenges to agricultural productivity (Mishra et al., 2022) The agricultural sector is profoundly influenced by climate change, establishing a reciprocal relationship between the two. Between 19% and 29% of global greenhouse gas emissions are attributed to forestry, land use change, and agriculture. Notably, this percentage surges to 74% when focusing on the least developed countries, as highlighted by (Vermeulen et al., 2012).

It is crucial to note that 70% of all greenhouse gas emissions, assuming temperature increases are constrained within 2°C, will emanate from agriculture (see Fig. 3). Assessing the affordability of mitigation options developed in the forestry, transportation, and energy sectors becomes imperative in addressing these challenges.

7. CLIMATE SMART VILLAGES

Some areas have not adopted Climate smart village practices, like as water management or mitigation alternatives. Because development professionals lack concrete examples of how innovations can be successfully incorporated into agricultural systems, there is a poor acceptance of new technologies. They need to understand how farmers can apply various treatments on actual farms while maximizing synergies and minimizing trade-offs. This is complicated by climate change since different places will be affected differently. Because of this, successful implementation an integrated strategy that considers how science, technology, and decision-making relate to regional socioeconomic factors and cultural norms. In climate-smart villages, farmers not only adopt advanced farming practices but also explore new services. These services include customized weather forecasts for precise planning of planting, harvesting, and other on-farm activities. Farmers receive advisories and weather forecasts through mobile phones, which are also used to facilitate the purchase of index-based insurance. This insurance provides them with a degree of protection in case of extreme weather events.

This revised version maintains the original meaning while enhancing the grammar and overall readability of the statement. https://www.cgiar.org/innovations/climate-smart-villages-and-valleys/.

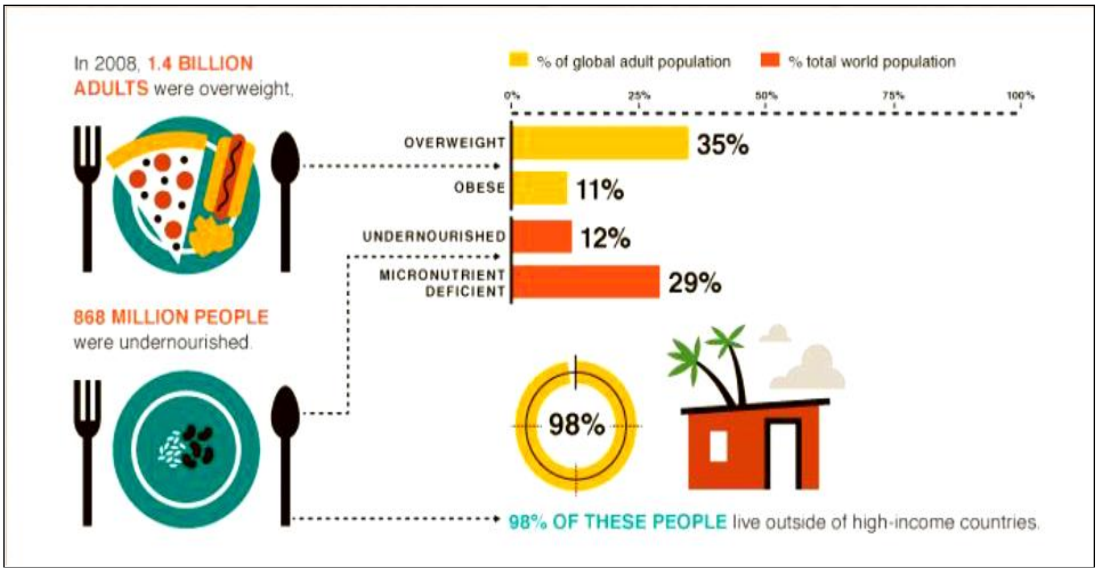

Fig. 1. Food security, inequity and malnutrition
(http://www.fao.org/3/al936e/al936e00.pdf)

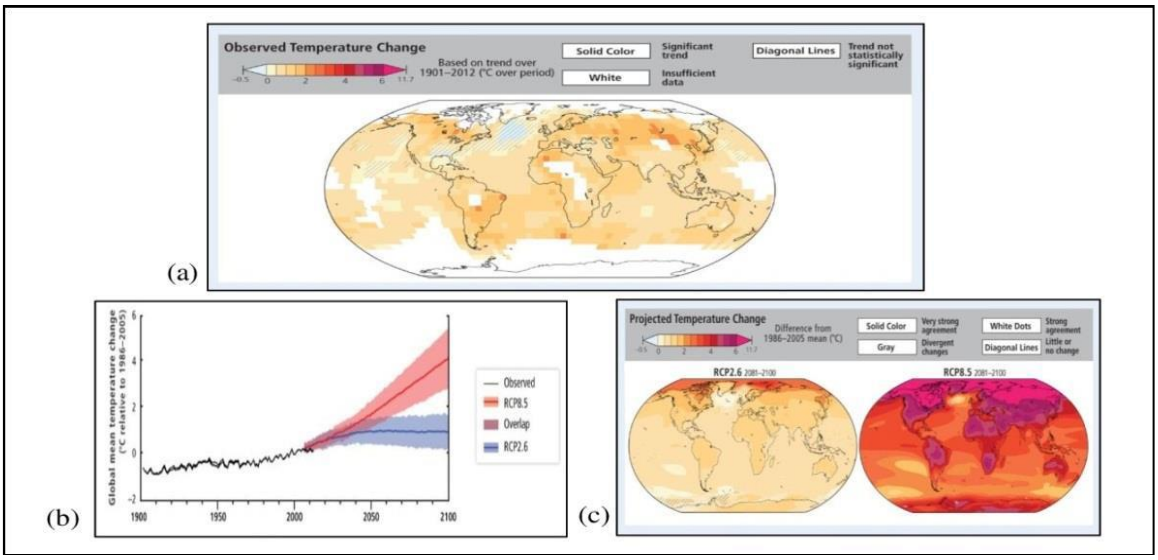

Fig. 2. Observed and projected changes in annual average surface temperature
Source: (Key Figures from the IPCC's AR5 Report)

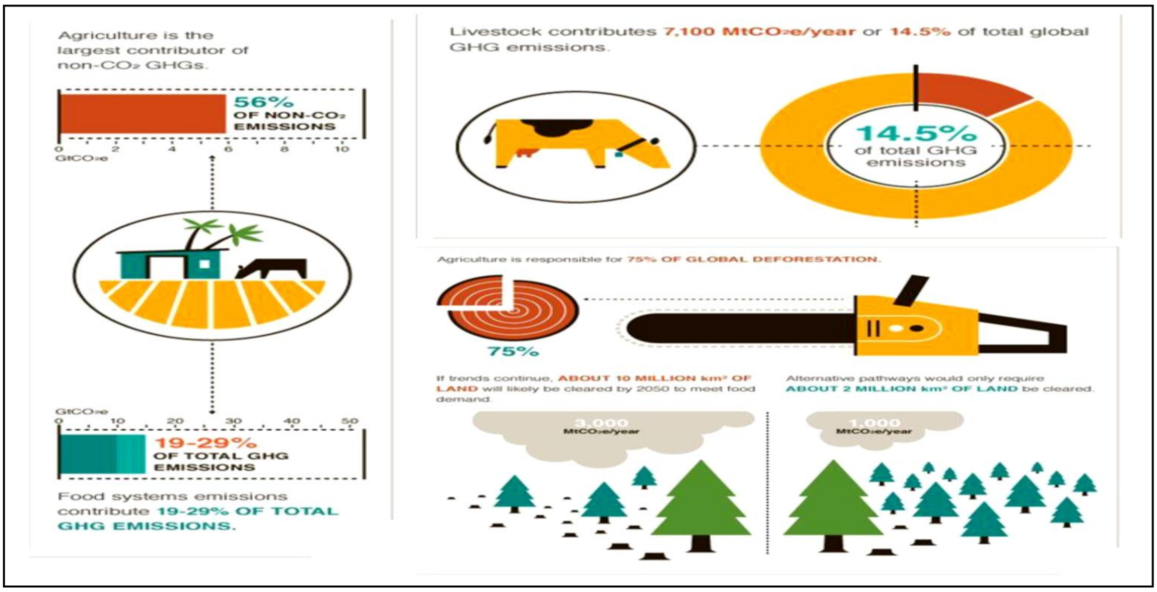

Fig. 3. Agricultural greenhouse gas emission
(https://ccafs.cgiar.org/bigfacts/#theme=food-emissions)

8. INDIAN AGRICULTURE CHALLENGES

Indian agriculture faces several challenges. One of the main issues is the need for enhanced productivity. Farmers encounter obstacles in adopting modern techniques and technologies that can significantly boost yields. Additionally, inadequate infrastructure, such as irrigation facilities and storage capacity, poses a considerable hurdle. Moreover, fluctuating climatic conditions, including unpredictable rainfall and extreme weather events, further complicate the agricultural landscape. This, coupled with the vulnerability of small-scale farmers to market fluctuations, creates a precarious situation. To address these challenges, there is a pressing need for comprehensive policy reforms. Government initiatives should focus on providing farmers with access to advanced farming practices, improving infrastructure, and implementing effective risk mitigation strategies. Strengthening research and development in agriculture can also play a pivotal role in overcoming obstacles and ensuring sustainable growth in the sector." The green revolution has led to socio-economic disparities among the Indian farming community. While it has favored large landholding farmers and agro-based industries, it has negatively impacted small and marginal farming communities, as well as water resources, environment and soil fertility [7]

Therefore, in the post-green revolution era, Indian agriculture is facing the following major challenges:

9. FOOD SECURITY

Food security can be defined as reliable access to a sufficient quantity of nutritious food. However, despite the significant increase in food production following the Green Revolution, which led to a decline in the undernourished population from 18.6% in 1990-92 to as low as 10.9% in 2014-16, many people across the country still face food and nutritional insecurity. Achieving sustainable food security remains a major economic, political, sociological, and scientific challenge in the 21st century.

10. DEPLETION OF WATER SUPPLIES

Indian agriculture is predominantly dependent on the monsoon, leading to uncertainty in water availability for agricultural production. Canal and well irrigation systems have played a crucial role in addressing this challenge within the Indian context. Over the last 50 years, advancements in canal and well irrigation systems have contributed to a twofold increase in the irrigated cropped area.

11. DEGRADATION OF THE QUALITY OF SOIL

Therefore, resource-intensive agriculture has impeded the continuous availability of freshwater in the present changing climate scenario. Water scarcity significantly influences crop yields compared to other challenges, and the continuous exploitation of water resources is likely to result in rising food prices, food shortages, and increased food imports by third-world countries [8]. The injudicious use of water resources has also led to increased water logging and intensified soil salinization. Consequently, policymakers should pay proper attention to proper irrigation water management and the judicious use of water resources.

12. AVAILABILITY OF NUTRIENTS

According to Sathya et al. in [9] crop plants require 17 different nutrient elements for proper growth and development. These nutrient elements are categorized as either macro or micronutrients depending on the needs of the crop plant. The macro-nutrients are divided into primary and secondary nutrients, with primary nutrients being quickly consumed by plants compared to the secondary nutrients. As a result, primary nutrients are supplied by straight fertilizers, while other nutrients are obtained through organic manures, biological nitrogen fixation, and plant residues, As highlighted by Sankar Ganesh et al, [10]) study (Shukla et al., 2015) have emphasized that the mobility of micronutrients is influenced by several factors such as organic matter, pH, the chemical makeup of these micronutrients, their concentration, and their interaction with soil, plants and microbes. As a result, achieving sustainable crop production requires a judicious and integrated approach that involves using synthetic fertilizers and manure, adopting efficient crop varieties, implementing improved agronomic management practices, and fostering proper soil-plant-microbes interaction.

13. DIFFERENCES IN SOCIOECONOMIC STATUS AMONG FARMERS

According to Nath et al. [11]) small and marginal farmers dominate Indian agriculture, accounting for 88% of the total farming community in India. This category is mostly made up of Schedule tribe and Schedule caste categories. In addition, small and marginal landholders cultivate 72Mha of land and contribute approximately 56-60% of India's total food requirements. However, their land holdings are among the most climatically and ecologically vulnerable lands. As highlighted by (Srivastava et al., 2016). The current climate scenario necessitates the development of ecologically sound technologies that require low external inputs and incorporate traditional knowledge. Such technologies are urgently needed to address climate change and its impacts.

14. SUSTAINABLE AGRICULTURE

Research studies conducted across different regions of India and the world have demonstrated the adverse effects of the green revolution on soil microbial biodiversity. Additionally, stagnation in crop yields has been observed in the Indo-Gangatic plains, where the green revolution technology was adopted. The excessive and indiscriminate use of agro-chemicals has resulted in the emission of greenhouse gases from the agricultural sector, contributing to global warming and climate change. As a result, agriculture research has shifted its focus towards holistic natural resource management to achieve long-term crop productivity and ensure food security, as emphasized by (Sathya et al., [9] According to (Corwin et al., [12] Sustainable agriculture is characterized by a delicate balance of maximum crop productivity and economic stability while minimizing the utilization of finite natural resources and detrimental environmental impacts. Tilman et al., [13] define sustainable agriculture as practices that meet current and future societal needs for food and fiber, ecosystem services, and healthy lives by maximizing the net benefit to society when all costs and benefits of the practices are considered. The need and basis of sustainable agriculture can be better understood through the Fig 4.

Sustainable agriculture encompasses a comprehensive range of soil, pest, and nutrient management technologies, including the use of crop residues, dung, biological nitrogen fixation, crop rotations, mixed cropping, and others [15] These measures not only promote biological diversity but also enhance soil quality, nutrient pools, and ecosystem restoration. Additionally

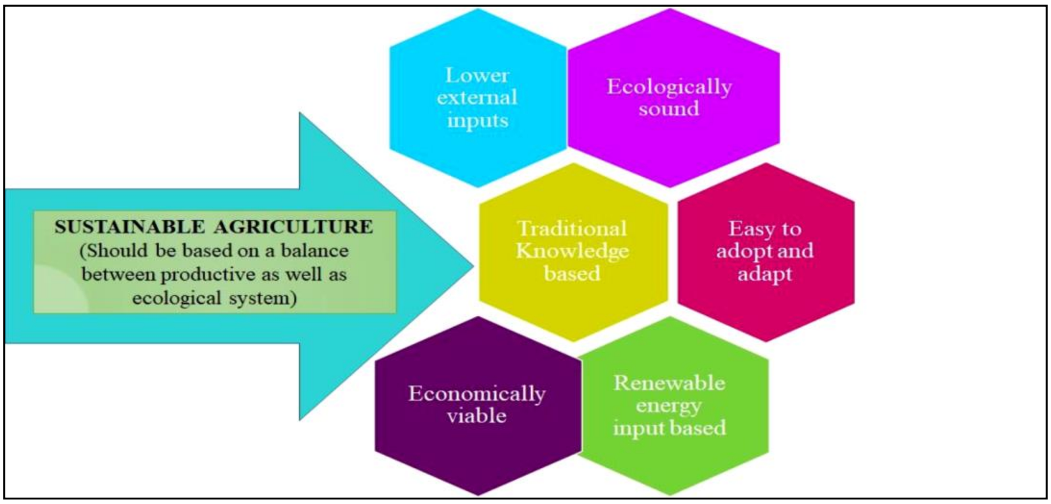

Fig. 4. Need and basis of the sustainable agriculture
Source: Singh et al.,[14]

they contribute to increased climate resilience by reducing soil degradation, all while improving the socio-economic status of farmers [16-33].

However, the subsidized rate of synthetic fertilizers and the limited availability of organic nutrient sources present significant obstacles to the transition towards a sustainable agroecosystem.

15. CONCLUSION

This comprehensive review provides an in-depth analysis of sustainable and climate-smart agriculture, exploring the complex principles and practical applications that underpin these approaches. Additionally, the review highlights the challenges that must be addressed to ensure the success of sustainable and Climate smart agriculture. By emphasizing soil health, biodiversity preservation, adept water management, and the reduction of chemical inputs, sustainable agriculture emerges as a critical strategy in addressing current food production demands while safeguarding essential resources for the prosperity of future generations.

The review underscores the holistic nature of sustainable agriculture, recognizing its potential to strike a harmonious balance between productivity and environmental stewardship. The deliberate focus on soil health and biodiversity not only enhances agricultural resilience but also promotes long-term ecosystem vitality. Water management practices contribute to efficient resource utilization, ensuring that water, a finite and vital resource, is conserved for both agricultural and broader ecological needs.

Moreover, the conscientious reduction of chemical inputs aligns with the broader global movement towards environmentally friendly and sustainable agricultural practices. This strategic shift not only minimizes the ecological footprint of farming activities but also fosters healthier ecosystems and reduces the potential negative impacts on human health.

In essence, the insights gleaned from this review illuminate the pivotal role of sustainable and climate-smart agricultural practices in shaping a resilient and responsible future for food production. By integrating these principles into agricultural policies and practices, we can strive towards a more sustainable and equitable global food system that meets the needs of the present without compromising the well-being of future generations.

While the Green Revolution has significantly contributed to fulfilling the role of providing food to a large population, the excessive reliance on external inputs such as synthetic fertilizers and agrochemicals has resulted in the degradation of natural resources and the environment. The Indian government has formulated numerous plans and strategies to address the issue of climate change. However, the effective implementation of these plans remains a challenge. It is crucial to create and diligently execute appropriate strategies and regulations for climate change in the long run, given its significant impact on agricultural production. Therefore, there is an urgent need to prioritize and implement sustainable practices for the benefit of farmers, the environment, and food security. "In the current changing climate scenario, sustainable agriculture has emerged as a viable alternative. Its significance is evident not only in maintaining long-term crop productivity and soil health but also in contributing to the reduction of greenhouse gas emissions from the agriculture and allied sectors. Sustainable agriculture operates in a manner that aims to meet both current and future societal needs for food and fiber, as well as for ecosystem services and healthy lives. This is achieved by maximizing the net benefit to society.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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