

The Impact of Nutrition-Sensitive Climate-Smart Agriculture on Global Food Security

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Abstract

Climate-smart agriculture (CSA) is an approach aimed at transforming and reorienting agricultural systems to support food security under the new realities of climate change. Incorporating nutrition-sensitive interventions within CSA frameworks ensures that agricultural practices not only enhance productivity and resilience but also improve the nutritional quality of food. This integrated approach addresses the dual challenges of malnutrition and climate change, promoting sustainable food systems that are capable of feeding a growing global population. By optimizing resource use, enhancing crop diversity, and implementing innovative farming techniques, nutrition-sensitive CSA contributes to a more secure and nutritious food supply. This paper explores the role of nutrition-sensitive CSA in bolstering global food security, examining its benefits, challenges, and potential pathways for broader adoption.

Keywords: *Climate-Smart Agriculture (CSA), Nutrition-Sensitive Agriculture, Global Food Security, Sustainable Food Systems, Agricultural Resilience, Crop Diversity, Malnutrition, Resource Optimization, Innovative Farming Techniques.*

1. Introduction

Global Food Security: A Pressing Challenge

Global food security remains one of the most critical challenges of the 21st century. According to the United Nations, approximately 690 million people were undernourished in 2019, and this number has been exacerbated by the COVID-19 pandemic, climate change, and geopolitical conflicts. The concept of food security encompasses not only the availability of food but also access, utilization, and stability of food systems. Ensuring that all people have access to sufficient, safe, and nutritious food to maintain a healthy and active life is essential for global stability and human well-being(1).

The Role of Agriculture in Food Security

Agriculture is the backbone of global food production, providing the majority of the world's food supply. However, traditional agricultural practices are increasingly under strain due to various factors including population growth, resource depletion, environmental degradation, and, notably, climate change. Modern agriculture must evolve to meet the growing demand for food while also addressing the challenges posed by a changing climate and ensuring sustainability(2).

Climate Change and Agriculture

Climate change poses a critical threat to global food security through impacts on crop yields, livestock productivity, and fisheries due to changing temperatures, precipitation patterns, and extreme weather events(3). According to the Intergovernmental Panel on Climate Change (IPCC), the agricultural sector is both a contributor to and a victim of climate change, accounting for approximately 21% of global greenhouse gas emissions. This dual relationship necessitates an urgent transformation in agricultural practices to mitigate emissions and adapt to changing climatic conditions.

Nutrition-Sensitive Agriculture

Traditional agricultural approaches have often focused on increasing yields without sufficient attention to nutritional outcomes. However, a growing recognition of the importance of nutrition-sensitive agriculture is emerging. This approach aims to maximize the positive impact of the food system on nutrition while minimizing any unintended negative nutritional consequences. It involves the integration of nutritional objectives into agricultural policies, investments, and interventions. By promoting the production and consumption of a diverse range of nutritious foods,

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nutrition-sensitive agriculture seeks to address issues of malnutrition, including both undernutrition and the rising prevalence of obesity and diet-related non-communicable diseases.

Climate-Smart Agriculture (CSA)

Climate-Smart Agriculture (CSA) is an integrative approach that aims to achieve three primary goals: sustainably increasing agricultural productivity and incomes, adapting and building resilience to climate change, and reducing and/or removing greenhouse gas emissions. CSA involves a variety of practices and technologies tailored to specific contexts and aimed at making agricultural systems more resilient and sustainable. This approach is critical for ensuring food security in the face of climate change(4).

The Intersection of Nutrition-Sensitive and Climate-Smart Agriculture

The intersection of nutrition-sensitive and climate-smart agriculture offers a holistic approach to enhancing food security by integrating nutrition outcomes with climate resilience strategies. By integrating nutritional considerations with climate-smart practices, it is possible to develop agricultural systems that are resilient to climate impacts while also promoting better nutritional outcomes. This integrated approach can contribute to the overall goal of sustainable development by addressing economic, social, and environmental dimensions concurrently..

2.Literature Survey

Nutrition-Sensitive Agriculture

Nutrition-sensitive agriculture has gained increasing attention as a strategy to combat malnutrition and improve food security. Studies have highlighted the significance of aligning agricultural practices with nutritional goals. Ruel and Alderman (2013) emphasized that traditional agriculture often prioritizes yield over nutritional value, leading to calorie-dense but nutrient-poor diets. They argue for a paradigm shift towards diversification of crops, particularly the inclusion of fruits, vegetables, and biofortified crops that can provide essential micronutrients. Additionally, the World Bank (2014) underscores the importance of agricultural policies and programs that explicitly incorporate nutritional objectives, suggesting that such integration can lead to better health outcomes and overall food security(5).

Climate-Smart Agriculture

Climate-Smart Agriculture (CSA) integrates practices like improved crop varieties, agroforestry, conservation agriculture, and integrated water management to enhance productivity, resilience, and reduce greenhouse gas emissions, crucial for addressing climate change impacts on food security (Lipper et al., 2014).The Food and Agriculture Organization (FAO, 2013) provides a comprehensive framework for CSA, stressing the need for context-specific strategies that consider local climatic conditions, resource availability, and socio-economic factors. Empirical studies, such as those by Harvey et al. (2014), demonstrate that CSA practices can significantly enhance farmers' adaptive capacity and mitigate the adverse effects of climate variability.

Integrating Nutrition-Sensitive and Climate-Smart Agriculture

The integration of nutrition-sensitive and climate-smart agriculture presents a holistic approach to achieving food security and sustainable development. Fanzo et al. (2017) discuss the potential synergies between these two approaches, noting that CSA can support nutritional outcomes by promoting diverse and resilient food systems. For example, agroforestry and crop diversification, key components of CSA, can lead to more varied and nutritious diets. Moreover, comprehensive reviews by HLPE (2017) indicate that policies promoting integrated approaches can enhance food security by addressing both climate and nutritional challenges simultaneously. These studies suggest that policy frameworks and agricultural extension services need to be aligned to support farmers in adopting practices that are both climate-smart and nutrition-sensitive(6).

Case Studies and Empirical Evidence

Empirical evidence from various regions illustrates the effectiveness of combining nutrition-sensitive and climate-smart practices. In Sub-Saharan Africa, for instance, projects integrating these approaches have shown promising results. A study by Frelat et al. (2016) found that households practicing diversified cropping and agroforestry had better food security outcomes and dietary diversity. Similarly, in South Asia, experiences documented by Aggarwal et al. (2018) reveal that integrated CSA practices, such as stress-tolerant crop varieties and improved irrigation techniques, can enhance food production and nutritional quality. These case studies highlight the context-specific benefits and challenges of implementing integrated agricultural practices, underscoring the importance of localized adaptation and capacity-building efforts.

3. Existing and Proposed System

The existing agricultural systems globally have traditionally focused on maximizing crop yields to ensure food availability, often at the expense of nutritional quality and environmental sustainability. Conventional agricultural practices emphasize high-yield monoculture farming, the extensive use of chemical fertilizers and pesticides, and mechanization to boost productivity. While these practices have succeeded in significantly increasing food production and reducing hunger, they have led to several adverse outcomes, including nutritional deficiencies, environmental degradation, and substantial greenhouse gas emissions. The emphasis on staple crops like rice, wheat, and maize has resulted in diets that lack essential nutrients, contributing to malnutrition. Additionally, intensive farming practices have degraded soil health, reduced biodiversity, and depleted water resources, undermining the resilience of agricultural systems to climate change(7).

Climate-Smart Agriculture (CSA) promotes agricultural practices enhancing productivity, resilience, and sustainability to address climate change impacts effectively. Key CSA practices include conservation agriculture, which improves soil health and reduces erosion through techniques such as no-till farming, cover cropping, and crop rotation; agroforestry, which integrates trees into agricultural landscapes to enhance biodiversity, sequester carbon, and provide additional sources of income and nutrition; and efficient water use practices like drip irrigation, which conserve water and improve crop yields. Despite these advances, CSA primarily focuses on productivity and resilience, often overlooking the nutritional quality of the food produced(8).

Nutrition-Sensitive Agriculture (NSA), on the other hand, explicitly aims to improve nutritional outcomes by promoting the production and consumption of diverse, nutrient-rich foods. NSA strategies include biofortification, which involves breeding crops to increase their nutritional value, such as vitamin A-rich sweet potatoes or iron-fortified beans; crop diversification, which encourages the cultivation of a variety of crops including fruits, vegetables, legumes, and nuts to enhance dietary diversity; and community-based approaches that engage local communities in designing and implementing nutrition-sensitive interventions tailored to meet specific dietary needs and preferences. However, NSA initiatives often operate independently of CSA practices, missing the opportunity to create synergistic benefits for food security and nutrition(9).

Proposed System

The proposed system integrates nutrition-sensitive approaches within the CSA framework, creating a holistic strategy known as Nutrition-Sensitive Climate-Smart Agriculture (NSCSA). This integrated approach addresses food security, nutritional quality, and climate resilience simultaneously. NSCSA combines the strengths of CSA and NSA, focusing on practices that enhance agricultural productivity and nutritional outcomes while building resilience to climate change. Key components of the proposed system include promoting the cultivation of biofortified and nutrient-dense crops within CSA practices to ensure that increased productivity also translates to improved nutritional quality; implementing diversified cropping systems that include a mix of cereals, legumes, fruits, and vegetables to enhance dietary diversity and resilience; and utilizing sustainable soil and water management practices alongside NSA strategies to maintain soil fertility and water resources, supporting the growth of nutrient-rich crops.

Education and capacity building are crucial for the successful implementation of NSCSA. Proposed initiatives include providing farmers with access to extension services that offer training on NSCSA practices, emphasizing the benefits of crop diversification and biofortification, and engaging local communities in participatory approaches to identify and address specific nutritional and agricultural challenges. Effective policy support and institutional frameworks are also essential for scaling up NSCSA practices. Key policy recommendations include implementing policies that provide financial incentives and technical support for farmers adopting NSCSA practices, investing in research to develop and disseminate innovative NSCSA technologies and practices tailored to local contexts, and establishing systems to monitor and evaluate the impacts of NSCSA on food security, nutrition, and climate resilience to ensure continuous improvement and adaptation.

In conclusion, the proposed NSCSA system represents a comprehensive approach to addressing the interconnected challenges of food security, nutrition, and climate change. By integrating nutrition-sensitive strategies within the CSA framework, it is possible to create agricultural systems that are more productive, resilient, and capable of providing diverse and nutritious diets. Achieving this vision will require coordinated efforts from farmers,

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researchers, policymakers, and communities worldwide, working together to build a more sustainable and equitable global food system.

4. Enhancing nutritional quality in crops through nutrition-sensitive agriculture practices

Nanofertilizers:

- **Efficient Nutrient Delivery:** Nanofertilizers release nutrients in a controlled manner, ensuring they are available to plants over a longer period.
- **Enhanced Absorption:** Due to their small size, nanoparticles can easily penetrate plant cells, improving nutrient uptake efficiency.
- **Reduction in Fertilizer Use:** By improving nutrient use efficiency, nanofertilizers can reduce the overall amount of fertilizer needed, minimizing environmental impact(10).

Nanosensors:

- **Real-Time Monitoring:** Nanosensors can detect nutrient deficiencies and other stress factors in real-time, allowing for timely interventions.
- **Precision Agriculture:** By providing detailed information about soil health and plant needs, nanosensors enable precise application of fertilizers and water, optimizing crop growth.

Nanopesticides:

- **Targeted Pest Control:** Nanopesticides can be designed to specifically target pests without affecting beneficial organisms, reducing chemical residues in crops.
- **Reduced Chemical Use:** Effective at lower concentrations, nanopesticides can decrease the overall amount of chemicals used, promoting a healthier environment.

Biofortification:

- **Enhanced Nutrient Content:** Nanoparticles can be used to fortify crops with essential micronutrients (e.g., iron, zinc) during growth, improving their nutritional profile.
- **Improved Bioavailability:** Nanotechnology can enhance the bioavailability of these nutrients, making them more easily absorbed by the human body.

Soil Health Improvement:

- **Microbial Activity:** Nanomaterials can enhance the activity of beneficial soil microbes, which play a critical role in nutrient cycling and soil fertility(11).
- **Soil Structure:** Nanomaterials can improve soil structure and water retention, supporting healthy plant growth.

Stress Resistance:

- **Drought and Salinity Tolerance:** Nanoparticles can help plants better withstand abiotic stresses such as drought and high salinity, ensuring consistent crop yields.
- **Disease Resistance:** Nanotechnology can be used to develop disease-resistant crop varieties by enhancing the plant's immune response.

Environmental Impact:

- **Reduction in Runoff:** Controlled release of nutrients and pesticides reduces runoff, preventing water pollution.
- **Sustainable Practices:** By improving efficiency and reducing chemical use, nanotechnology supports more sustainable agricultural practices.

5. Accelerating the Rate of Climate Change Adaptation and Fortitude to Ensure the Security of food and Nutrition

Climate change poses significant threats to global food and nutrition security, affecting agricultural productivity, food availability, and nutritional quality. Enhancing climate change adaptation and resilience within agricultural systems is crucial for safeguarding food and nutrition security, particularly for vulnerable populations. This involves implementing strategies and practices that improve the ability of agricultural systems to withstand and recover from climate-related shocks while ensuring the provision of diverse and nutritious food(12).

1. Diversified Cropping Systems

Diversified cropping systems enhance resilience by reducing dependence on a single crop, thereby spreading risk and ensuring food availability even when certain crops fail due to extreme weather events or pest outbreaks. Integrating a variety of crops, including cereals, legumes, fruits, and vegetables, can improve soil health, reduce pest and disease incidence, and enhance dietary diversity. Crop rotation and intercropping practices are examples of diversification strategies that contribute to more resilient and sustainable farming systems.

2. Climate-Resilient Crop Varieties

Developing and adopting climate-resilient crop varieties is essential for maintaining productivity under changing climatic conditions. These varieties are bred for traits such as drought tolerance, heat resistance, and pest and disease resistance. Biofortified crops that are enhanced with essential nutrients can also address both climate resilience and nutritional deficiencies. Research and development efforts should focus on making these resilient and nutritious crop varieties accessible to farmers, particularly smallholders in vulnerable regions.

3. Sustainable Water Management

Effective water management practices are critical for adapting to climate change and ensuring food and nutrition security. Techniques such as rainwater harvesting, drip irrigation, and the use of drought-tolerant crops help optimize water use and improve agricultural productivity. Conservation agriculture practices, including minimum tillage and mulching, can enhance soil moisture retention and reduce water requirements. Integrated water resource management approaches can help balance water use among agricultural, domestic, and industrial needs, promoting sustainability and resilience.

4. Agroforestry and Sustainable Land Management

Agroforestry, the integration of trees into agricultural landscapes, enhances resilience by providing multiple benefits, including improved soil fertility, increased biodiversity, and additional sources of food and income. Trees can act as windbreaks, reduce soil erosion, and improve water infiltration. Sustainable land management practices, such as contour farming and terracing, help prevent land degradation and maintain productive agricultural land. These practices contribute to more stable and resilient agricultural systems capable of supporting food and nutrition security.

5. Community-Based Adaptation

Community-based adaptation involves engaging local communities in identifying and implementing adaptation strategies that are tailored to their specific needs and contexts. This participatory approach ensures that adaptation measures are culturally appropriate, locally relevant, and more likely to be adopted and sustained. Community-based adaptation can include activities such as establishing seed banks, promoting local food systems, and implementing early warning systems for climate-related hazards. Building the capacity of local communities to adapt to climate change is crucial for long-term resilience and food security.

6. Policy Support and Institutional Frameworks

Strong policy support and institutional frameworks are necessary to facilitate the widespread adoption of adaptation and resilience strategies. Governments should implement policies that incentivize sustainable agricultural practices, support research and development of climate-resilient crops, and provide financial and technical assistance to farmers. Institutional frameworks should promote coordination among various stakeholders, including government agencies, research institutions, non-governmental organizations, and local communities. Effective policies and institutions can create an enabling environment for scaling up adaptation efforts and achieving food and nutrition security.

7. Monitoring and evaluation of program effectiveness and impact

Monitoring and evaluation systems are essential for assessing the effectiveness of adaptation strategies and facilitating necessary adjustments. These systems should track changes in agricultural productivity, food availability, and nutritional outcomes in response to climate change and adaptation interventions. Data collected through monitoring and evaluation can inform policy decisions, guide resource allocation, and improve the design and implementation of adaptation strategies. Continuous learning and adaptation are crucial for enhancing resilience and ensuring food and nutrition security in the face of climate change.

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6. Smallholder farmers will gain a great deal from the implementation of nscsa

Increased Crop Yields:

- Efficient Nutrient Use: Nanofertilizers ensure that nutrients are delivered directly to plant roots in a controlled manner, leading to better crop growth and higher yields.
- Improved Pest and Disease Management: Nanopesticides and nanosensors help in timely and effective pest control, reducing crop losses.

Cost Reduction:

- Reduced Input Costs: With more efficient use of fertilizers and pesticides, farmers can reduce the amount of these inputs, lowering their overall costs.
- Lower Water Usage: Precision agriculture enabled by nanosensors can optimize irrigation, reducing water consumption and related costs.

Enhanced Crop Quality:

- Nutrient Fortification: Nanotechnology can improve the nutritional content of crops, producing healthier food that can fetch higher market prices.
- Consistent Crop Performance: Improved resistance to stresses such as drought and disease ensures more reliable crop quality and yield.

Sustainable Practices:

- Environmental Protection: Reduced chemical runoff and better soil health contribute to a more sustainable farming environment.
- Long-Term Soil Fertility: Nanomaterials can enhance soil structure and fertility, ensuring long-term agricultural productivity.

Real-Time Monitoring and Precision Farming:

- Nanosensors: These provide real-time data on soil health, nutrient levels, and plant stress, allowing farmers to make informed decisions quickly.
- Precision Application: With accurate data, farmers can apply fertilizers and pesticides only where needed, reducing waste and environmental impact.

Resilience to Climate Change:

- Stress Resistance: Nanotechnology can help crops withstand extreme weather conditions, such as droughts and floods, which are becoming more common due to climate change.
- Adaptive Farming Practices: Real-time monitoring allows farmers to quickly adapt their practices to changing climatic conditions.

Economic Empowerment:

- Higher Market Value: Nutritionally fortified and high-quality crops can command better prices in the market.
- Increased Profit Margins: With reduced input costs and higher yields, smallholder farmers can enjoy better profit margins.

Knowledge and Skill Enhancement:

- Access to Technology: Training and support in using nanotechnology can enhance farmers' skills and knowledge, making them more competitive.
- Collaborative Networks: Adoption of advanced technologies can connect farmers to larger networks and markets, fostering collaboration and growth.

7. Trade-offs and synergies between nsa and csa methods in various agricultural scenarios

Nanotechnology in Sustainable Agriculture (NSA) and Climate-Smart Agriculture (CSA) practices offer complementary benefits but also present certain trade-offs across various agricultural contexts. Synergistically, NSA enhances resource efficiency through precise nutrient delivery and pest control, aligning with CSA's emphasis on precision agriculture to optimize input use and improve crop resilience against climate variability. NSA's contributions to soil health through nanomaterials can further complement CSA's soil management practices, leading to sustainable long-term productivity. However, trade-offs arise primarily due to the high costs and specialized knowledge required for NSA, which can limit accessibility for smallholder farmers compared to the more locally

adapted and cost-effective CSA practices. Additionally, while CSA focuses on minimizing environmental impacts, the long-term effects of nanomaterials on ecosystems remain uncertain, necessitating careful management to avoid potential soil and water contamination. Balancing these approaches requires context-specific strategies: in developed regions with more resources, NSA can be more readily integrated with CSA, whereas in developing regions, CSA might be more immediately feasible, with NSA adoption growing gradually as capacities build. Overall, successfully combining NSA and CSA practices involves navigating these synergies and trade-offs to enhance agricultural sustainability and resilience in diverse settings.

8. Conclusion and Future work

Nutrition-sensitive climate-smart agriculture (NSCSA) represents a promising approach to addressing the interconnected challenges of food security, nutrition, and climate change on a global scale. By integrating nutrition-sensitive practices into climate-smart agricultural strategies, NSCSA not only enhances agricultural productivity and resilience but also improves the nutritional quality and diversity of food produced. This has significant implications for combating malnutrition, particularly in vulnerable populations.

The adoption of NSCSA has the potential to positively impact global food security in several ways:

1. **Improved Nutritional Quality:** NSCSA promotes the production of nutrient-dense crops, diversified farming systems, and dietary diversity, addressing micro and macro-nutrient deficiencies prevalent in many regions.
2. **Enhanced Resilience:** Climate-smart agricultural practices such as agroforestry, conservation agriculture, and water management techniques increase the resilience of farming systems to climate variability and extremes, safeguarding food production against adverse weather events.
3. **Sustainable Resource Use:** NSCSA emphasizes sustainable resource management practices, including soil conservation, efficient water use, and reduced reliance on chemical inputs, promoting the long-term viability of agricultural systems.
4. **Income Generation:** By diversifying crops and income sources, NSCSA can contribute to poverty reduction and economic empowerment, particularly for smallholder farmers and marginalized communities.
5. **Environmental Benefits:** Climate-smart agricultural practices mitigate greenhouse gas emissions, conserve biodiversity, and protect ecosystem services, contributing to broader environmental sustainability goals.

Future Work:

While NSCSA holds significant promise for enhancing global food security, several avenues for future research and action are worth exploring:

1. **Scaling Up Adoption:** Efforts to scale up the adoption of NSCSA practices among smallholder farmers and in vulnerable regions are essential. This requires tailored extension services, access to finance, and supportive policies that incentivize sustainable agricultural practices.
2. **Research and Innovation:** To develop and adapt climate-smart agriculture technology and practices to a variety of agroecological environments, more research and innovation are required. This entails developing soil fertility management techniques, cultivating crop types resistant to climate change, and incorporating agroecological ideas into conventional agricultural systems..
3. **Policy Support:** Policy frameworks at national and international levels should prioritize investments in NSCSA, aligning agricultural development strategies with nutrition, climate, and sustainability objectives. This includes incentivizing farmers to adopt climate-smart practices, strengthening social safety nets, and promoting market access for nutritious foods.
4. **Capacity Building:** Building the capacity of farmers, extension agents, policymakers, and other stakeholders is crucial for the successful implementation of NSCSA. Training programs, knowledge sharing platforms, and south-south cooperation can facilitate the exchange of best practices and lessons learned.
5. **Monitoring and Evaluation:** Robust monitoring and evaluation mechanisms are needed to track the impact of NSCSA interventions on food security, nutrition outcomes, climate resilience, and sustainability indicators. This will inform evidence-based decision-making and enable adaptive management approaches.

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Conflicts of interest

The authors have no conflicts of interest to declare

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