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AGRICULTURAL POLLUTION-DRIVEN CLIMATE CHANGE: IMPLICATIONS FOR FOOD PRODUCTION AND SECURITY

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ABSTRACT Agricultural pollution plays a significant role in climate change, which in turn affects food production and security. Major pollutants include greenhouse gases such as carbon dioxide, methane, and nitrous oxide, released through farming activities like livestock farming, fertilizer application, and soil management. These emissions accelerate global warming, resulting in altered rainfall patterns, rising temperatures, and more frequent extreme weather events, all of which damage crop yields and food supplies. The impact on food security is profound, as climate change can decrease crop productivity and cause food price volatility. This issue is especially critical for key crops like wheat, rice, maize, and soybeans, which are highly sensitive to temperature fluctuations and ozone pollution. Moreover, intensive farming harms soil health and ecosystem services, further threatening long-term food security. Implementing adaptation strategies is crucial to lessen these impacts. Such measures include adopting climate-smart farming techniques, improving crop varieties, and enhancing soil fertility through integrated management. Transitioning to organic farming and reducing chemical fertilizer use can also cut greenhouse gas emissions and boost resilience to climate change. Achieving effective adaptation requires coordinated efforts from policymakers, researchers, and farmers to uphold food production and security amid ongoing climate challenges.

Keywords: *Pollution; Policies; Climate; SDGs; Agriculture*

INTRODUCTION

Agricultural Intensification (AI) refers to increasing agricultural output per unit of input to meet the growing global demand for food and non-food products. Advanced equipment, chemical fertilizers, insecticides, and biocides are frequently used in this procedure, which may have severe negative environmental impacts. AI is required to feed the growing population. Still, it is associated with several environmental problems, including greenhouse gas (GHG) emissions, changes in ecosystem services, eutrophication of water bodies, and loss of biological diversity (Pereira et al., 2025). Global greenhouse gas emissions, such as carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), are primarily caused by agriculture. Manure management, rice paddies, fertilizer application, and cattle enteric fermentation are essential sources. Methane emissions from rice production and animals are especially noteworthy, with livestock making up around 25% of agricultural emissions (Chataut et al., 2023). Overuse of nitrogen and phosphorus fertilizers causes pollution and eutrophication by allowing nutrients to seep into soil, surface water, and groundwater. This excess of nutrients may cause eutrophication of water bodies and reduce plant species diversity (Zhang et al., 2025). Agricultural pesticides have the potential to contaminate non-target areas, impacting ecosystem health and biodiversity. The usage of pesticides is a major contributor to both persistent and volatile organic pollutants in the air (Ge et al., 2021). To eradicate hunger and attain food security, AI seeks to increase food production. However, food security may be threatened by AI contamination, which can compromise food safety and nutritional quality. SDG 13's primary focus is on greenhouse gas emissions, of which agriculture is a significant contributor (Zhao et al., 2025). The goal of sustainable agricultural intensification (SAI) is to balance lower greenhouse gas emissions with higher yields (Pretty et al., 2018). Conservation agriculture and integrated nutrient management are two strategies that can improve carbon sequestration and reduce greenhouse gas emissions (Ravikumar et al., 2021).

Agricultural pollution and its contribution to climate change

Methane emissions from rice paddies are significant due to the anaerobic conditions in flooded fields. Optimizing water management, utilizing rice straw and humic acid-iron complexes, and choosing rice cultivars that have high drought resistance are all effective mitigation techniques (Lee et al., 2024). Manure management and enteric fermentation are the leading causes of methane emissions from livestock. Enhancing feed quality and waste management techniques are examples of effective mitigation (Ramlan et al., 2024). The use of manure and synthetic nitrogen fertilizers is a significant source of nitrous oxide (N2O) emissions. Optimizing fertilization methods, including drip fertigation, slow-release fertilizers, and nitrification inhibitors, can reduce emissions (Wenzhu et al., 2024). N2O emissions can be significantly reduced while crop yields are maintained by implementing the "4R" principles (Right amount, Right type, Right time, Right place) (Nasiro & Mohammednur, 2024). Deforestation increases carbon emissions by reducing carbon sinks. Reforestation and sustainable forest management are essential tactics to reduce these emissions (Afroz et al., 2023). Carbon contained in soil is released as a result of soil deterioration, which is often driven by deforestation and poor farming practices (Villarino et al., 2017). Crop rotation, conservation tillage, and biochar application are methods that can improve soil carbon sequestration. By changing the hydrological cycle and ecosystem functioning, air pollution, which includes greenhouse gases and aerosols, has a substantial effect on climate systems. Reduced water availability and ecosystem production may result from this (Duan et al., 2017). Increased temperatures and intensified weather events driven by climate change worsen water pollution, leading to dangerous algal blooms and deteriorated water quality. It is crucial to implement integrated measures that tackle both climate change and water pollution (Shahady, 2024).

Climate change impacts on food security

Significant changes in rainfall patterns brought forth by climate change have increased the frequency and severity of droughts and floods. These developments significantly impact food security and agricultural productivity (Szám et al., 2025). Due to their reliance on rain-fed agriculture, regions such as South/Southeast Asia and Sub-Saharan Africa are particularly susceptible to climate variability (Britto et al., 2024). Maintaining agricultural output depends on soil health. Reduced crop yields result from climate change's exacerbation of soil degradation, including increased salinity, nitrogen depletion, and erosion. Reduced tillage, crop rotation, and the application of organic fertilizers are among the techniques that can lessen soil deterioration and enhance soil health (Alvi et al., 2025). All aspects of food security, availability, accessibility, utilization, and stability are impacted by climate change. As a result, food output declines, food costs rise, and food quality declines. Temperature and CO2 variations driven by climate change affect crop nutritional quality by altering the levels of essential nutrients in food (Giulia et al., 2020).

Case Studies

South/Southeast Asia

Unpredictable rainfall patterns have had a significant negative impact on agriculture in the Janjigir-Champa district of Chhattisgarh, India, pushing farmers to adopt coping mechanisms such as migration and requesting government aid (Murali & Afifi, 2014). Farmers in Angat, Bulacan, Philippines, have been severely impacted by floods and droughts, which have reduced crop yields and raised the prevalence of water-borne illnesses (Agbay et al., 2023).

Sub-Saharan Africa

The region's reliance on rain-fed agriculture makes it highly vulnerable to climate change. Crop losses, decreased food grain yields, and increasing food insecurity are all consequences of climate change (Ghosh et al., 2025). Climate change has negatively affected food security, child nutrition, and agricultural productivity in Ethiopia, underscoring the need for improved water management and climate-resilient farming practices (Bouteska et al., 2024). More details are provided in Table 1.

Table 1: Impact of climate change globally

Impact	Region	Details	References
Altered Rainfall Patterns	Global	Increased frequency/intensity of floods and droughts	(Guan et al., 2021)
Reduced Soil Health	Global	Soil degradation, nutrient depletion, erosion	(Alvi et al., 2025)
Food Security Decline	Global	Decreased production, higher prices, reduced nutritional quality	(Omokpariola et al., 2025)
South/Southeast Asia	India, Philippines	Erratic rainfall, decreased crop production, and migration	(Agbay et al., 2023)
Sub-Saharan Africa	Ethiopia, SSA	Reduced yields, food insecurity, and child nutrition	(Omotoso et al., 2023)

Mitigation and adaptation strategies

The goal of climate-smart agriculture (CSA) is to refocus and restructure agricultural systems to maintain food security amid climate change. It combines three primary goals: lowering greenhouse gas emissions, adapting to and strengthening resilience to climate change, and raising agricultural output and incomes. To improve fertilizer application and ensure nutrients are delivered in a controlled manner that meets plant requirements, precision nutrient management uses cutting-edge technologies, including remote sensing, data analytics, and unmanned aerial vehicles (UAVs) (Mikula et al., 2020). By increasing soil biodiversity and nutrient availability, biofertilizers, including microbial inoculants such as arbuscular mycorrhizal fungi (AMF), play a critical role in CSA and support sustainable agriculture (Anusha et al., 2024). IPM, or integrated pest management, is a sustainable strategy that minimizes environmental effects while controlling pest populations below economic damage thresholds. IPM techniques include the use of resistant crop cultivars, cultural methods, and biological control (Green et al., 2020). IPM is enhanced by organic farming, which promotes biodiversity and ecological balance by eschewing artificial fertilizers and pesticides (Panday et al., 2024). By recycling nutrients and organic matter back into the farming system, the circular economy (CE) in agriculture aims to reduce waste and maximize resource utilization. This covers techniques such as carbon farming, converting waste into fertilizer, and using biochar to improve soil health and store carbon. These methods reduce the need for artificial fertilizers and their negative environmental impacts (Rosemarin et al., 2020). Digital tools and biotechnology are essential to advancing CSA. Biotechnology, including genetic engineering and the development of biofertilizers, offers new approaches to enhancing crop resilience and reducing reliance on chemical inputs (Anusha et al., 2024). The Internet of Things (IoT), robotics, and remote sensing are examples of digital tools that enable precise monitoring and management of agricultural activities, increasing sustainability and efficiency (Adamides, 2020). Outcomes through CSA are demonstrated in Fig. 1.

Policy and governance for pollution control

FAO and IPCC alignment

Through several initiatives, such as the Codex Alimentarius Commission, which establishes international food standards, the Food and Agriculture Organization (FAO) significantly contributes to food safety and quality worldwide. Additionally, the FAO works with the World Health Organization (WHO) and other organizations to address problems like antimicrobial resistance and zoonotic diseases (Lee et al., 2021). The UN Framework Convention on Climate Change (UN-FCCC) is one of the climate change conventions in which the FAO participates (Sanz & Perea Blazquez, 2025).

Sustainable Development Goals (SDGs)

The FAO's initiatives align with the SDGs by promoting sustainable agricultural practices and addressing food security and environmental sustainability (Islam, 2025).

Incentives for low-emission farming and green technologies

Government incentives

Through financial incentives such as tax rebates and subsidies for low-carbon farming methods, governments can promote the adoption of green technologies (Zhang et al., 2025). For instance, participation in agricultural cooperatives greatly increases adoption rates, even when the Chinese government has laws supporting green technologies (Dong et al., 2023).

Economic instruments

Reducing emissions and promoting sustainable practices can be achieved through financial incentives, such as green funding and green technology subsidies. The nature of these incentives and the extent of the funding determine their effectiveness (Chen & Li, 2023).

Contract farming

By offering profitable services and financial incentives, contract farming can help smallholder farmers implement green technologies more effectively (Li & Wang, 2025).

Importance of education, extension, and farmer training

Agricultural extension services

To ensure sustainable food security, extension services are vital in providing farmers with information and technologies (Raidimi & Kabiti, 2019). Good extension initiatives can encourage eco-friendly practices and reduce the use of hazardous inputs such as chemical fertilizers (Hua et al., 2017).

Training and capacity building

To equip farmers with the skills to adopt new technologies and techniques, ongoing education and training are essential. Both formal education at universities and informal training via extension services fall under this category. The effectiveness of training programs can be increased and conventional obstacles overcome through modern distance learning (Moumenihelali & Amooghli-Tabari, 2025).

Peer learning

Farmer-to-farmer training and social learning are also practical in spreading knowledge and practices, as seen in the case of rice farmers in Côte d'Ivoire (Takahashi et al., 2019)

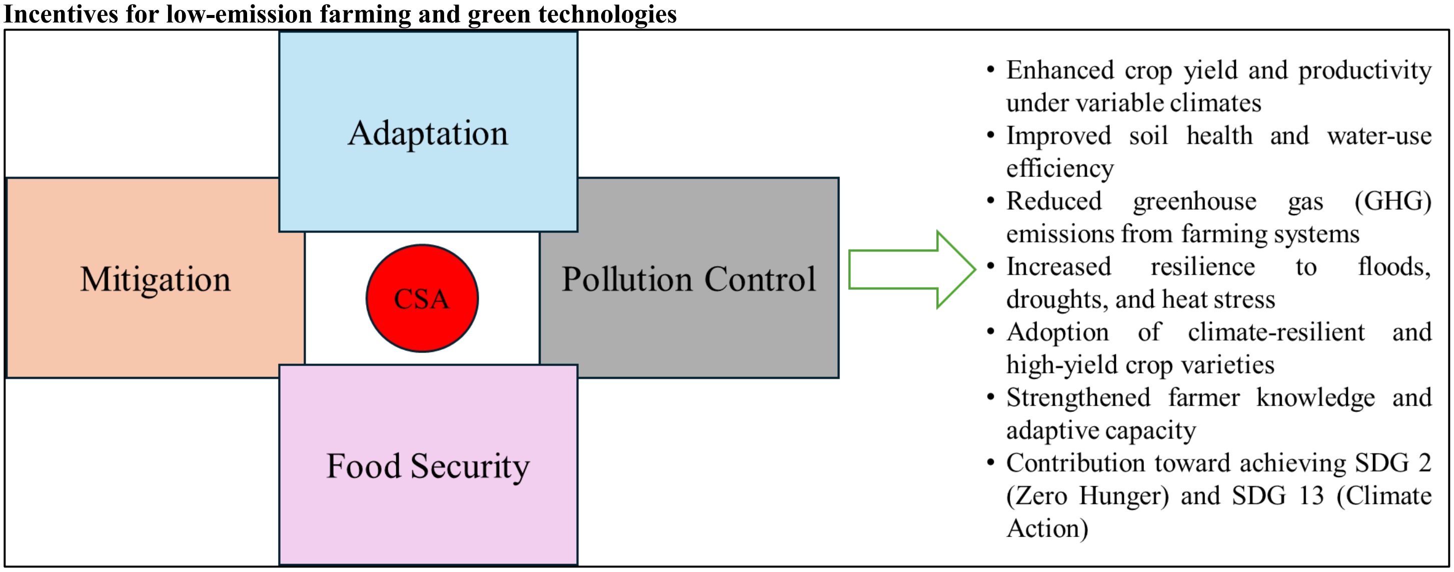

Figure 1: Key components and outcomes of Climate-Smart Agriculture (CSA)

CONCLUSION

Global food security faces significant threats from agricultural pollution, a key yet often overlooked factor in climate change. In addition to speeding up greenhouse gas emissions, pollutants from fertilizers, livestock, and land-use changes also damage soil and water resources that are critical for ongoing food production. SDG 2 (Zero Hunger) and SDG 13 (Climate Action) are deeply impacted by a feedback loop where pollution accelerates climate change, which then heightens agricultural stress. Climate-smart and pollution-reduction strategies, such as precision farming, organic amendments, biofertilizers, and efficient irrigation systems, should be integrated to build greater future resilience. Initial efforts need to focus on strengthening policy frameworks, encouraging farmer education, and funding the development of low-emission technologies. Additionally, biotechnology and digital tools like AI-based climate forecasting and remote sensing can improve early detection and adaptive responses. To break the cycle of pollution, climate change, and food insecurity, and ensure a sustainable, secure food future, global cooperation that balances agricultural productivity with environmental protection is essential.

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