
Greenhouse Gas Emissions From Agriculture: Impacts, Challenges, and Strategies for Protecting the Earth

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Abstract

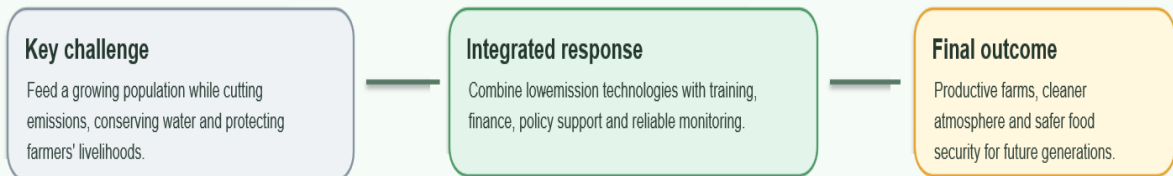
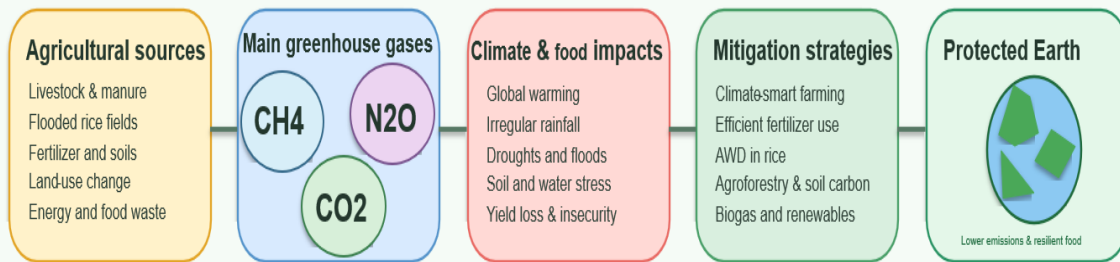
Agriculture plays a central role in global food security, rural livelihoods, and economic development, but it is also a major source of greenhouse gas emissions. The main greenhouse gases linked with agriculture are methane, nitrous oxide, and carbon dioxide. Methane is mainly released from livestock digestion, manure management, and flooded rice fields. Nitrous oxide is largely emitted from the use of synthetic fertilizers, manure application, and soil management practices, while carbon dioxide is associated with land-use change, deforestation, machinery, energy use, and the loss of soil organic carbon. Recent global evidence shows that agri-food systems contribute nearly one-third of total human-caused greenhouse gas emissions. These emissions increase global warming, disturb rainfall patterns, reduce soil and water quality, and threaten long-term food security. This review examines the major sources, impacts, challenges, and mitigation strategies related to greenhouse gas emissions from agriculture. The paper is based on recent global reports and scientific literature published mainly between 2020 and 2025. The findings show that sustainable agricultural practices such as climate-smart agriculture, improved fertilizer management, alternate wetting and drying in rice, conservation agriculture, agroforestry, improved livestock feeding, renewable energy use, and reduction of food loss and waste can significantly reduce emissions. However, adoption remains limited due to financial constraints, lack of awareness, weak policy support, smallholder limitations, and poor access to technology. The paper concludes that protecting the Earth from the harmful effects of agricultural emissions requires a balanced approach that combines productivity, sustainability, farmer support, and strong climate policy.

Keywords: Agriculture, greenhouse gas emissions, climate change, methane, nitrous oxide, climate-smart agriculture, sustainability

Graphical Abstract

Graphical Abstract: Agriculture, Greenhouse Gases and Earth Protection

Agricultural sources → CH₄, N₂O and CO₂ → climate impacts → mitigation pathways



1. Introduction

Agriculture is one of the most essential sectors for human survival because it provides food, fiber, employment, and income for billions of people across the world. However, modern agriculture is also closely connected with climate change. It is not only affected by rising temperatures, irregular rainfall, droughts, floods, heat waves, and pest outbreaks, but it also contributes to climate change through the release of greenhouse gases (GHGs). The major greenhouse gases associated with agriculture are methane (CH₄), nitrous oxide (N₂O), and carbon dioxide (CO₂). These gases trap heat in the atmosphere and intensify global warming, which creates serious risks for food production, natural ecosystems, and human well-being.

Recent global evidence shows that agriculture and food systems are among the major contributors to greenhouse gas emissions. According to FAO (2024), global agri-food systems emitted approximately 16.2 gigatons of carbon dioxide equivalent (Gt CO₂-eq) in 2022, representing about 29.7% of total human-caused greenhouse gas emissions. Although this share declined from 38% in 2000 to 29.7% in 2022, total agri-food system emissions increased by about 10% during the same period. This indicates that the relative share of agriculture-related emissions has declined mainly because emissions from other sectors have grown faster, not because the agri-food system has fully solved its emission problem.

At the global level, greenhouse gas emissions continue to rise. UNEP (2024) reported that total global greenhouse gas emissions reached a new record of 57.1 Gt CO₂-eq in 2023, showing a 1.3% increase compared with 2022. In this wider context, the agri-food sector remains highly important because nearly one-third of global emissions are connected with food production, land use, processing, transport, consumption, and waste. Therefore, reducing agricultural emissions is necessary for achieving global climate targets and protecting the Earth from further warming.

The Agriculture, Forestry and Other Land Use (AFOLU) sector is also recognized by the IPCC as a major source of greenhouse gas emissions. The IPCC reported that AFOLU accounted for around 13–21% of total global anthropogenic greenhouse gas emissions during 2010–2019. Within this sector, agriculture is a dominant contributor, and IPCC assessments indicate that agriculture accounted for about 91% of AFOLU emissions on average over the assessed period. These figures clearly show that emission reduction in agriculture is not a minor environmental issue but a central part of global climate action.

Greenhouse gas emissions from agriculture originate from multiple activities. Livestock production is one of the largest agricultural sources of methane. Ruminant animals such as cattle, buffalo, sheep, and goats produce methane during digestion through enteric fermentation. Manure storage and decomposition further contribute methane and nitrous oxide emissions. With increasing global demand for meat and dairy products, livestock-related emissions have become a major concern for climate scientists and policymakers. Research suggests that improved animal feeding, better manure handling, animal health management, selective breeding, and biogas production can reduce emissions without reducing livestock productivity.

Crop production is another important source of agricultural greenhouse gases, especially through fertilizer use, soil management, and rice cultivation. Nitrous oxide emissions mainly result from the application of synthetic nitrogen fertilizers and organic manure. When nitrogen is applied in excess or without proper timing, soil microorganisms convert part of it into nitrous oxide, a gas with a much stronger warming effect than carbon dioxide. Recent research has highlighted that precision nutrient management, soil testing, split fertilizer application, nitrification inhibitors, and organic amendments can improve nitrogen-use efficiency and reduce nitrous oxide emissions from agricultural soils.

Rice cultivation has also received special attention in climate research because flooded paddy fields produce methane under oxygen-deficient conditions. This is particularly important for Asia, where rice is a major staple food and large areas are under irrigated paddy cultivation. Studies on water-saving irrigation methods, especially alternate wetting and drying, show promising results in reducing methane emissions while also saving irrigation water. Such practices are important because agriculture already uses a large share of global freshwater resources, and climate change is increasing pressure on water availability.

Land-use change and soil degradation also play a major role in agricultural greenhouse gas emissions. When forests, grasslands, or wetlands are converted into cropland or pasture, large amounts of stored carbon are released into the atmosphere. Intensive tillage, residue burning, and poor soil management reduce soil organic carbon and weaken soil health. Recent studies have shown that conservation agriculture, cover cropping, crop rotation, residue retention, agroforestry, and restoration of degraded lands can increase soil carbon storage and reduce the environmental footprint of agriculture.

The issue of agricultural greenhouse gas emissions is complex because agriculture must meet the food demands of a growing global population while reducing its climate impact. The world population is projected to approach nearly 9.7 billion by 2050, which will increase demand for cereals, vegetables, meat, milk, and other food products. At the same time, climate change is already reducing crop yields, increasing water stress, and affecting rural livelihoods. Therefore, the major challenge is to produce more food with fewer emissions and less damage to natural resources.

Climate-smart agriculture has emerged as an important approach to address this challenge. It aims to increase agricultural productivity, strengthen adaptation to climate change, and reduce greenhouse gas emissions where possible. Practices such as efficient fertilizer use, improved irrigation, low-emission livestock systems, agroforestry, conservation agriculture, renewable energy use, and reduction of food loss and waste can help protect the Earth from the hazardous effects of agricultural emissions. However, the adoption of these practices remains limited in many developing countries due to lack of awareness, financial constraints, weak extension services, poor access to technology, and insufficient policy support.

Therefore, understanding the sources, impacts, challenges, and mitigation strategies of agricultural greenhouse gas emissions is essential for developing sustainable food systems. This review aims to examine recent research on greenhouse gas emissions from agriculture, discuss their harmful effects on climate and food security, identify key barriers to emission reduction, and highlight practical strategies for protecting the Earth through sustainable and climate-smart agricultural practices.

Materials and Methods

This paper is based on a review of recent global literature, reports, and scientific studies related to greenhouse gas emissions from agriculture. The review focused mainly on publications from 2020 to 2025, with priority given to recent international reports and peer-reviewed research articles.

Relevant literature was searched using keywords such as “greenhouse gas emissions from agriculture,” “agriculture and climate change,” “methane emissions from livestock,” “nitrous oxide from fertilizer,” “rice methane emissions,” “climate-smart agriculture,” “agricultural mitigation strategies,” and “food systems emissions.” Sources included reports from international organizations such as the Food and Agriculture Organization of the United Nations, the Intergovernmental Panel on Climate Change, and the United Nations Environment Programme, along with recent research articles published in scientific journals.

The selected literature was reviewed under four main themes: sources of agricultural greenhouse gas emissions, impacts of emissions on climate and food security, challenges in emission reduction, and mitigation strategies for sustainable agriculture. Studies were selected on the basis of relevance, recent publication date, scientific credibility, and direct connection with agriculture and climate change.

Results and Discussion

Sources of Greenhouse Gas Emissions from Agriculture

Agriculture contributes to greenhouse gas emissions through several direct and indirect pathways. The major direct sources include livestock production, rice cultivation, fertilizer application, manure management, soil disturbance, and residue burning. Indirect emissions are linked with land-use change, deforestation, energy use in farm machinery, irrigation, processing, transportation, storage, packaging, and food waste. These sources show that agricultural emissions are not limited to field production only, but are connected with the wider agri-food system.

Livestock production is one of the leading sources of agricultural methane emissions. Ruminant animals such as cattle, buffalo, sheep, and goats produce methane during digestion through a process known as enteric fermentation. This methane is mainly released through belching. In addition, manure storage and decomposition release both methane and nitrous oxide, especially when manure is kept in wet or poorly managed conditions. With increasing global demand for

meat, milk, and dairy products, livestock-related emissions have become a major concern for climate change mitigation.

Rice cultivation is another important source of methane emissions. Flooded paddy fields create anaerobic conditions, where the soil has little or no oxygen. Under such conditions, methane-producing microorganisms become active and release methane into the atmosphere. This issue is particularly important in Asia, where rice is a major staple crop and large areas are cultivated under flooded conditions. Poor water management in rice fields can increase methane emissions and reduce the overall climate efficiency of rice production.

Fertilizer use is a major source of nitrous oxide emissions from agricultural soils. Nitrous oxide is a highly powerful greenhouse gas and has a much stronger warming effect than carbon dioxide over a long period. When nitrogen fertilizers or organic manures are applied in excess, or at unsuitable times, soil microorganisms convert part of the nitrogen into nitrous oxide. Therefore, inefficient fertilizer use not only increases environmental pollution but also raises production costs for farmers.

Carbon dioxide emissions from agriculture are mainly associated with land-use change, deforestation, fossil fuel use, and soil carbon loss. When forests, grasslands, or wetlands are converted into cropland or pasture, large amounts of stored carbon are released into the atmosphere. Intensive tillage, residue burning, and poor soil management further reduce soil organic carbon. Farm machinery, tube wells, irrigation pumps, transport vehicles, cold storage, and food processing units also contribute to carbon dioxide emissions through the use of fossil fuels.

Table 1 Latest Evidence on Major Sources of Greenhouse Gas Emissions from Agriculture

Source of emissions	Major greenhouse gas	Latest numerical evidence	Main explanation	Reference
Agri-food systems	CO ₂ , N ₂ O, CH ₄	16.2 Gt CO ₂ -eq in 2022	Includes farm production, land-use change, processing, transport, retail, consumption, and food waste.	FAO, 2024
Share of agri-food systems in global emissions	CO ₂ , N ₂ O, CH ₄	29.7% of total global anthropogenic emissions in 2022	Nearly one-third of global emissions are linked with food systems.	FAO, 2024
Farm-gate agriculture	CH ₄ , N ₂ O, CO ₂	Farm-gate emissions increased by 15% between 2000 and 2022	Farm-gate emissions mainly come from crop and livestock production activities.	FAO, 2024
Livestock production	Mainly CH ₄ and N ₂ O	Around 54% of farm-gate emissions	Major sources include enteric fermentation, manure storage, and manure application.	FAO, 2024
Enteric fermentation and manure	CH ₄	Over 32% of global anthropogenic methane emissions	Ruminants release methane during digestion, while manure produces methane under poor storage conditions.	FAO, 2024
Rice cultivation	CH ₄	Major methane source in flooded paddy systems	Flooded rice fields create anaerobic conditions that support methane-producing microorganisms.	IPCC, 2022
Fertilizer and manure use	N ₂ O	Major source of agricultural nitrous oxide emissions	Excessive or poorly timed nitrogen application increases soil N ₂ O emissions.	IPCC, 2022; Basheer et al., 2024
Land-use change and deforestation	CO ₂	AFOLU emitted about 13–21% of global anthropogenic GHGs during 2010–2019	Conversion of forests, grasslands, and wetlands releases stored carbon.	IPCC, 2022

Source note: Adapted from FAO (2024), IPCC (2022), and Basheer et al. (2024).

Overall, the results show that agricultural greenhouse gas emissions come from many interconnected activities. Livestock and rice systems mainly contribute methane, fertilizer and manure use mainly produce nitrous oxide, while land-use change and energy use contribute carbon dioxide. This means that reducing agricultural emissions requires a complete food-system approach rather than focusing on a single source.

Impacts of Agricultural Greenhouse Gas Emissions

Greenhouse gas emissions from agriculture contribute significantly to global warming and climate instability. Rising temperatures affect both crop and livestock production. In crops, heat stress can reduce seed germination, flowering, pollination, grain filling, and final yield. In livestock, high temperatures reduce feed intake, milk production, fertility, growth rate, and disease resistance. These effects directly reduce agricultural productivity and farm income.

Climate change also disturbs rainfall patterns and increases the frequency of extreme weather events. Some regions experience longer droughts, while others face heavy rainfall, floods, and waterlogging. Drought reduces water availability for crops and animals, while floods damage standing crops, destroy farm infrastructure, wash away nutrients, and increase soil erosion. These conditions make agricultural production more uncertain and increase the vulnerability of farmers. Agricultural greenhouse gas emissions also affect soil, water, and biodiversity. Excessive fertilizer use can pollute groundwater and surface water through nitrate leaching and runoff. This may cause eutrophication in rivers, lakes, and reservoirs. Deforestation and land conversion reduce natural habitats and biodiversity. Soil degradation reduces soil fertility, water-holding capacity, and long-term productivity. As soil quality declines, farmers often become more dependent on external inputs, which may further increase emissions.

Food security is one of the most serious areas affected by agricultural emissions and climate change. Climate-related yield losses can reduce food availability, increase food prices, and disturb food supply chains. Poor and smallholder farmers are especially vulnerable because they often have limited access to irrigation, credit, technology, insurance, and climate information. Therefore, reducing agricultural emissions is not only an environmental issue but also a social, economic, and food-security priority.

The discussion indicates that agricultural emissions create a harmful cycle. Agriculture emits greenhouse gases, these gases intensify climate change, and climate change then reduces agricultural productivity. Breaking this cycle requires sustainable practices that reduce emissions while protecting food production and farmer livelihoods.

Table 2 Latest Data on Impacts of Agricultural Greenhouse Gas Emissions

Impact area	Latest numerical evidence	Explanation	Reference
Global greenhouse gas burden	57.1 Gt CO ₂ -eq in 2023	Global GHG emissions reached a record level, increasing pressure on climate-sensitive sectors such as agriculture.	UNEP, 2024
Increase in global emissions	1.3% increase from 2022 to 2023	Continued increase in emissions makes climate targets more difficult to achieve.	UNEP, 2024
Agri-food contribution to global emissions	29.7% in 2022	Agriculture and food systems remain major contributors to global warming.	FAO, 2024
Agri-food emission increase	10% increase between 2000 and 2022	Although the percentage share declined, total agri-food emissions still increased.	FAO, 2024
Climate warming risk	Current policies may lead to about 3.1°C warming by 2100	Higher warming would increase droughts, floods, heat stress, and crop-yield instability.	UNEP, 2024
Land and food-system vulnerability	AFOLU accounts for 13–21% of global anthropogenic GHG emissions	Agriculture is both a source of emissions and a sector highly exposed to climate impacts.	IPCC, 2022
Future food demand pressure	World population projected near 9.7 billion by 2050	More food will be required, increasing pressure on land, water, livestock, and fertilizer use.	United Nations, 2022
Smallholder vulnerability	Smallholders are highly exposed to climate shocks	Limited finance, irrigation, insurance, and technology reduce their adaptive capacity.	IPCC, 2022

Source: UNEP (2024), FAO (2024), IPCC (2022), and United Nations (2022).

Challenges in Reducing Agricultural Emissions

Reducing greenhouse gas emissions from agriculture is challenging because agriculture must continue to produce enough food for a growing global population. Unlike some industrial sectors, agriculture cannot simply reduce activity because it is directly linked with food security and human survival. The main challenge is to produce more food with fewer emissions, less water use, and lower pressure on natural resources.

A major barrier is the limited capacity of smallholder farmers. Many farmers, particularly in developing countries, have limited access to finance, modern technology, training, extension services, and climate information. Although sustainable practices may be beneficial in the long term, their initial cost can be high. Farmers may also be reluctant to adopt new practices if they fear yield reduction or financial risk.

Another challenge is the diversity of agricultural systems. Farming practices differ according to climate, soil type, water availability, crop variety, livestock breed, farm size, and market

conditions. A mitigation practice that works well in one region may not be suitable in another. For example, alternate wetting and drying can reduce methane emissions in rice, but it requires proper irrigation control and farmer training. Similarly, improved livestock feed can reduce methane emissions, but it may not be affordable or easily available for small farmers.

Policy and institutional weaknesses also slow down emission reduction. In many countries, agricultural policies still focus mainly on increasing production rather than reducing environmental impacts. Subsidies may sometimes encourage excessive use of fertilizers, water, or energy. Weak extension systems, poor monitoring, limited research funding, and lack of farmer incentives further reduce the adoption of climate-smart agriculture.

Measurement and monitoring of agricultural emissions is another important challenge. Emissions vary according to soil type, climate, crop system, fertilizer rate, livestock type, manure management, and field conditions. Many developing countries do not have strong data systems to measure agricultural emissions accurately. Without reliable data, it becomes difficult to design effective mitigation plans, evaluate progress, and develop evidence-based policies.

Table 3 Challenges in Reducing Agricultural Greenhouse Gas Emissions

Challenge	Supporting data or evidence	Why it matters	Reference
Rising food-system emissions	Agri-food emissions increased by 10% from 2000 to 2022	Emissions are still increasing despite climate policies and awareness.	FAO, 2024
Increasing farm-level emissions	Farm-gate emissions increased by 15% between 2000 and 2022	Direct agricultural production remains difficult to decarbonize.	FAO, 2024
Livestock dependency	Livestock contributes around 54% of farm-gate emissions	Reducing livestock emissions is difficult because livestock supports food, income, and livelihoods.	FAO, 2024
Regional variation	Agricultural share of AFOLU emissions ranged from 66% in Africa to almost 100% in the Middle East during 1990–2019	Mitigation strategies must be region-specific rather than uniform.	IPCC, 2022
Methane management difficulty	Enteric methane and manure account for over 32% of anthropogenic methane emissions	Methane reduction requires changes in feeding, breeding, manure handling, and policy support.	FAO, 2024
Limited farmer resources	Smallholder farmers often lack finance, technology, and extension support	Adoption of low-emission practices may remain low without incentives.	IPCC, 2022
Measurement gaps	Emissions vary by soil, crop, climate, fertilizer rate, and livestock system	Weak data systems make accurate monitoring and mitigation planning difficult.	IPCC, 2022
Policy barriers	Many agricultural policies still prioritize production over emission reduction	Poor incentives can encourage excessive fertilizer, water, or energy use.	OECD, 2025

Source: FAO (2024), IPCC (2022), and OECD (2025).

Therefore, emission reduction in agriculture requires more than technical solutions. It needs farmer-friendly policies, financial support, training, research, strong institutions, and reliable monitoring systems. Without these support mechanisms, even scientifically proven mitigation practices may remain limited in practical adoption.

Strategies for Protecting the Earth from Agricultural Emissions

Climate-smart agriculture is one of the most effective approaches for reducing agricultural emissions while maintaining food production. It focuses on three major goals: increasing productivity, improving resilience against climate change, and reducing greenhouse gas emissions where possible. This approach is important because it does not treat climate protection and food security as separate goals, but connects them through sustainable farming practices.

Improved fertilizer management can significantly reduce nitrous oxide emissions. Farmers should apply fertilizers according to the right source, right rate, right time, and right place. Soil testing, split fertilizer application, balanced nutrient management, organic amendments, composting, precision farming, and nitrification inhibitors can improve nitrogen-use efficiency. These practices reduce nitrogen losses, lower input costs, and decrease nitrous oxide emissions from soils.

In rice production, alternate wetting and drying is an important methane-reduction strategy. Instead of keeping rice fields continuously flooded, fields are allowed to dry for short periods before being irrigated again. This reduces anaerobic conditions and limits methane formation. In addition to lowering methane emissions, this method can also save irrigation water. However, its success depends on proper water control, farmer awareness, and field-level technical support.

Livestock emissions can be reduced through improved feeding, better animal health, selective breeding, manure management, and biogas production. Better-quality feed can improve digestion and reduce methane emissions per unit of milk or meat. Improved animal health and productivity also reduce emissions intensity because healthier animals produce more output with fewer resources. Manure can be managed through composting or converted into biogas, which provides renewable energy and reduces methane release from open manure storage.

Conservation agriculture is another important mitigation strategy. It includes minimum soil disturbance, crop residue retention, and crop rotation. These practices improve soil organic matter, reduce erosion, save fuel, increase soil moisture, and enhance carbon storage in soils. Cover crops and legumes can improve soil fertility and reduce dependence on synthetic fertilizers. Conservation agriculture also improves resilience against drought and heavy rainfall. Agroforestry can help protect the Earth by storing carbon in trees and soils while supporting biodiversity and farm income. Trees planted on farms provide shade, reduce wind erosion, improve microclimate, recycle nutrients, and provide fruits, fodder, fuelwood, and timber. Agroforestry is especially useful in areas facing soil degradation, heat stress, and declining biodiversity.

Reducing food loss and waste is also an essential climate strategy. A large amount of food is lost during harvesting, storage, transportation, processing, retail, and consumption. When food is wasted, the land, water, energy, fertilizer, labor, and emissions used to produce that food are also wasted. Better storage facilities, cold chains, processing technologies, market access, awareness campaigns, and improved supply-chain management can reduce unnecessary emissions.

Table 4 Strategies for Protecting the Earth from Agricultural Greenhouse Gas Emissions

Strategy	Target emission/source	Expected benefit	Latest research-based evidence	Reference
Climate-smart agriculture	CO ₂ , CH ₄ , N ₂ O	Improves productivity, adaptation, and mitigation	Climate-smart practices combine productivity with emission reduction and resilience.	FAO, 2024; IPCC, 2022
Improved fertilizer management	N ₂ O from soils	Reduces nitrogen loss and production cost	Soil testing, split application, precision nutrient use, and nitrification inhibitors reduce unnecessary nitrogen losses.	Basheer et al., 2024
Alternate wetting and drying in rice	CH ₄ from flooded rice	Reduces methane and saves irrigation water	Intermittent irrigation reduces anaerobic conditions responsible for methane formation.	Loaiza et al., 2025
Improved livestock feeding	CH ₄ from enteric fermentation	Reduces methane per unit of milk or meat	Better-quality feed and improved animal productivity can reduce emission intensity.	FAO, 2024; Nugrahaeningtyas et al., 2024
Manure management and biogas	CH ₄ and N ₂ O from manure	Converts waste into renewable energy	Biogas systems reduce methane from open manure storage and provide clean energy.	FAO, 2024
Conservation agriculture	CO ₂ and N ₂ O from soils	Increases soil carbon and improves soil health	Minimum tillage, residue retention, and crop rotation improve soil organic matter.	IPCC, 2022; Basheer et al., 2024
Agroforestry	CO ₂ from land-use change	Stores carbon in trees and soils	Trees on farms improve carbon storage, biodiversity, microclimate, and farm resilience.	IPCC, 2022
Food loss and waste reduction	Whole food-system emissions	Reduces wasted land, water, fertilizer, energy, and emissions	Reducing food loss lowers emissions already embedded in food production and supply chains.	FAO, 2024
Renewable energy in agriculture	CO ₂ from fossil fuels	Reduces diesel and electricity-related emissions	Solar irrigation, biogas, and efficient machinery reduce fossil fuel dependence.	OECD, 2025

Source: FAO (2024), IPCC (2022), Basheer et al. (2024), Loaiza et al. (2025), Nugrahaeningtyas et al. (2024), and OECD (2025).

Renewable energy use in agriculture can also reduce carbon dioxide emissions. Solar-powered irrigation pumps, biogas plants, energy-efficient machinery, improved drying systems, and renewable-powered cold storage can reduce dependence on fossil fuels. These technologies are especially important in rural areas where energy access is limited and diesel-based systems are common.

Overall, the results show that no single strategy can solve the problem of agricultural greenhouse gas emissions. A combination of practices is required, including better nutrient management, improved livestock systems, water-saving rice production, conservation agriculture, agroforestry, renewable energy, and food-waste reduction. The most effective approach is to combine emission reduction with productivity improvement and farmer support.

Conclusion

Agriculture is both a victim and a contributor to climate change. It produces greenhouse gases mainly through livestock production, rice cultivation, fertilizer use, manure management, land-use change, soil degradation, and energy consumption. These emissions contribute to global warming, irregular rainfall, water stress, soil degradation, biodiversity loss, and threats to food security. At the same time, climate change reduces agricultural productivity and increases the vulnerability of farmers, especially smallholders in developing countries.

The review shows that practical and scientifically supported solutions are available. Climate-smart agriculture, efficient fertilizer management, improved livestock feeding, better manure handling, alternate wetting and drying in rice, conservation agriculture, agroforestry, renewable energy use, and reduction of food loss and waste can help reduce agricultural emissions. These practices can also improve soil health, water-use efficiency, farm productivity, and climate resilience.

However, successful adoption requires more than technical recommendations. Farmers need access to training, finance, affordable technology, climate information, extension services, and supportive policies. Governments, researchers, private organizations, and development institutions must work together to make low-emission agriculture practical and profitable for farmers.

Protecting the Earth from the hazardous effects of agricultural greenhouse gas emissions requires urgent and coordinated action. Sustainable agriculture should not be viewed as an optional choice, but as a necessary pathway for climate protection, food security, environmental sustainability, and the well-being of future generations.

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