# Addressing Climate Change: The Role of Agriculture in Greenhouse Gas Mitigation


**ABSTRACT**

Agriculture, a cornerstone of global food security, is significantly affected by climate change, primarily driven by human activities that increase greenhouse gas (GHG) emissions. Accounting for approximately 13% of global anthropogenic GHG emissions, agricultural practices-such as livestock rearing, rice cultivation and synthetic fertilizer use which contribute substantially to global warming. Emissions from nitrous oxide ($N_2O$), methane ($CH_4$) and carbon dioxide ($CO_2$) exacerbate this issue, with $N_2O$ being particularly concerning due to its high global warming potential. Mitigation strategies within the agricultural sector are essential, including improved nutrient management, the use of nitrification inhibitors and innovative fertilizer application technologies. Organic farming demonstrates lower $N_2O$ emissions compared to conventional practices, emphasizing the importance of sustainable agricultural methods. Additionally, conservation tillage and practices like zero-tillage help reduce $CO_2$ emissions by minimizing soil disturbance and enhancing carbon sequestration. Biochar application further supports soil health and GHG reduction by enhancing carbon storage. To mitigate methane emissions from rice fields, reduced tillage and the introduction of electron acceptors can effectively inhibit methanogenesis. As $CO_2$ constitutes about 72% of total GHG emissions, agricultural practices that increase soil organic carbon (SOC) are critical for effective carbon sequestration. Overall, the agricultural sector holds significant potential for GHG mitigation, with studies suggesting that 89% of the mitigation potential can be achieved through carbon sequestration. Therefore, adopting these strategies is crucial not only for reducing emissions but also for ensuring sustainable agricultural productivity in the face of climate change challenges.



*Keywords: [Climate Change, Greenhouse Gas Emissions, Nitrous Oxide, Carbon Sequestration, Sustainable Practices, Methane Mitigation*


## 1. INTRODUCTION

Agriculture is our primary food source and it is susceptible to climate change. Anthropogenic activities like fossil fuel burning for power generation, industrial manufacturing and transportation, agricultural activities such as rice production, synthetic fertilizer use, livestock rearing and changes in land use patterns such as deforestation as well as waste disposal have contributed to the increased atmospheric concentration of greenhouse gases. This increase is an important contributor to climate change leading to increased global temperature and other stresses (Houghton *et al*., 1996).

The agriculture sector accounts for about 13 per cent (Barker *et al*., 2007) of global anthropogenic greenhouse gas emissions, Therefore, between 5 and 6 giga tonnes (Gt) of $CO_2$ equivalents ($CO_2$ e) per year. This is predicted to rise almost 40 per cent by 2030 largely due to increasing demand from a growing population and changing consumption patterns for food, including increasing demand for ruminant meats (Smith *et al*., 2007). The relative global warming potential (*i.e*., relative amount of warming compared to the same mass of $CO_2$) of N2 $_O$ is 298 ($CO_2$ e) and that of $CH_4$ is 25 (CO2 e) compared to 1($CO_2$ e) of $CO_2$ (Forster *et al*., 2007). Nitrous oxide is emitted mainly from inorganic fertilizer and manure application to soils. Methane is emitted largely from livestock (fermentation in digestion), rice production and manure handling. Carbon dioxide is mainly released from microbial decay of plant litter and soil organic matter, as well as from burning of plant residues (Smith, 2004).

**Mitigation:** The process or result of making something less severe, dangerous or damaging. The agriculture sector also contributes significantly to GHG mitigation by acting as GHG sink for 10% of emissions. Mitigation could be accomplished through intensification and extensification of agriculture. However, it could reduce total land requirement and total agricultural emissions, *i.e*., a reduced carbon footprint per kg of product.

**Nutrient management:**

Efficient use of nitrogenous fertilizers can reduce $N_2O$ emissions from agricultural fields. In addition, by reducing the quantity of application of synthetic fertilizers required, improved management can also reduce $CO_2$ emissions associated with their manufacture.

**Nitrous oxide mitigation in organic agriculture**

Organic agriculture reduces emissions of $N_2O$ due to the ban on use of mineral nitrogen and the reduction of livestock units per hectare. Soils in organic farming are more aerated and have significantly lower mobile nitrogen concentrations, which reduces emissions of $N_2O$. Since organic crop systems are limited by the availability of N, they aim to balance their N inputs and outputs and their N use efficiency. So, emissions are low in organic agriculture when compared to conventional farming (Petersen *et al*., 2006).

**Mitigation using nitrification inhibitors**

Emission of $N_2O$ can be reduced by using nitrification inhibitors, which slow down the microbial processes leading to $N_2O$ formation (Robertson, 2004). S. benzylisothiouronium butanoate (SBT butanoate) and S. benzylisothiouronium fluroate (SBT fluroate) increased yield of crop plants are some of the nitrification inhibitors used and they reduced emissions of $N_2O$ by 4-5% (Bhatia *et al*., 2010). Nitrification and urease inhibitors were also used to reduce the loss of N as $N_2O$. Dicyandiamide (DCD) and Nitrapyrin applied to grassland reduced the emission of $N_2O$ from $NH_4$ based fertilizers by 64% and 52% respectively (McTaggart *et al*., 1994).

**Slow-release fertilizer application and manipulation technologies**

Fertilizer application technology has a significant impact on nitrous oxide emissions.
The following are the various parameters of this technology:

1. Slow release of urea and $NH_4$ based fertilizers can be achieved by using various coatings, chemical modifications, and changing the size of fertilizer granules.
2. A combination of increasing the pellet size to 1g and adding DCD resulted in very slow nitrification rates, with 30% of the initial N application still present 8 weeks after fertilizer application (Goose and Johnson, 1993).

**Nitrogen management technology**

Practices which are like fertilizer type, timing, placement and rate of fertilizer application, as well as coordinating the time of application with irrigation and rainfall events will influence nitrous oxide emissions.

**Type of fertilizer**

Emissions of $N_2O$ were significantly higher from a soil fertilized with urea compared to $NH_4$ $NO_3$ (Mc Taggart *et al*., 1994). Tenuta and Beauchamp (2003) found that the relative magnitude of total emissions was greater from urea than from ammonium sulphate, which in turn was greater than that from calcium ammonium nitrate. Bouwman *et al* (2002) found that nitrate-based fertiliser resulted in significantly lower emissions of $N_2O$ than ammonium-based fertilizer. Snyder *et al*., (2007) demonstrated that slow, controlled release and stabilized N fertilizer can enhance crop productivity and minimize the $N_2O$ emissions. $NH_4$ $NO_3$ and $NH_4$ $HCO_3$ was found beneficial in reducing the volatilization of $NH_3$ and the emission of $N_2O$.

**Fertilizer N timing:**

Crop nitrogen intake capacity was generally low at the beginning of the growing season and increasing rapidly during vegetative growth and drops sharply as the crop nears maturity. Before planting spring crops results in increased soil nitrogen with poor plant nitrogen uptake, leading to increased $N_2O$ emissions. large emissions of $N_2O$ could potentially be avoided by fertilizing in spring rather than autumn. Hultgreen and Leduc (2003) showed that emissions of $N_2O$ were lower following spring N fertilizer application compared to autumn application.

**Fertiliser N placement:**

Placement of N fertilizer into the soil near the zone of active root uptake may reduce surface N loss and increase plant N use resulting in a reduction in $N_2O$ emissions (CAST, 2004). Hultgreen and Leduc (2003) reported that the $N_2O$ emissions were reduced when urea was broadcast in mid-row rather than side-banded.

**Fertiliser N rate:**

The emission of $N_2O$ correlates well with fertilizer N rate (Drury *et al*., 2008). Millar *et al* (2010) also report that increasing the amount of N applied to soil resulted in increasing emissions of $N_2O$. Miller *et al* (2010) suggested that the incentive for nitrous oxide emission reduction by application of lower nitrogen application rates within an advisable range ultimately could be financially remunerated through a nutrient market.

**Coordination with irrigation and rainfall events:**

Application of fertilizer immediately after rain will increase N use efficiency of plants and mitigate $N_2O$ emissions. Losses of N through leaching, volatilization and denitrification can be decreased through alternate flooding. The exception was when there were mid-season drainage or alternate flooding and drainage cycles, in which case it increased (Pathak, 2010). The N management regime also reduced global warming potential (GWP) by 1 to 9%.

**Tillage/residue management**

Tillage of the soil stimulates microbial decomposition of soil organic matter, which results in emissions of $CO_2$ to the atmosphere. In the last decades advancements in weed control methods and farm machinery now allow many crops to be grown with minimum tillage (Smith *et al*., 2008).

**Conservation tillage $CO_2$ mitigation technology**

Conservation tillage is a tillage system that conserves soil, water and energy resources through the reduction of tillage intensity and retention of crop residue. Conservation tillage involves the planting, growing and harvesting of crops with limited disturbance to the soil surface.

Conservation tillage is any method of soil cultivation that leaves the previous year's crop residue (such as corn stalks or wheat stubble) on fields before and after planting the next crop to reduce soil erosion and runoff, as well as other benefits such as carbon sequestration (MDA, 2011). It also features non-disturbance of the soil. This type of soil tillage is characterized by tillage depth and the percentage of surface area disturbed. Conservation tillage methods include zero-till, strip-till, ridge-till and mulch-till. Zero-tillage is the extreme form of conservation tillage resulting in minimal disturbance to the soil surface.

**Zero-till farming system**

In zero-tillage, crops are planted with minimum disturbance to the soil by planting the seeds in an un-ploughed field with no other land preparation. A typical zero-tillage machine is a heavy implement that can sow seed in slits 2-3cm wide and 4-7cm deep and also apply fertiliser in one operation (CIMMYT, 2010). It can be described as ridge-till farming system and mulch-till farming system.

**Ridge-till farming system:** Ridge-till involves planting seeds in the valleys between carefully molded ridges of soil. The previous crop's residue is cleared off ridges tops into adjacent furrows to make way for the new crop being planted on ridges. Maintaining the ridges is essential and requires modified or specialized equipment (MDA, 2011).

**Mulch-till farming system:** Mulch-till is another method of reduced tillage system in which residue is partially incorporated using chisels, sweeps, field cultivators, or similar farming implements that leaves at least one third of the soil surface covered with crop residue (MDA, 2011).

### Biochar - a potential technique for carbon sequestration

Crop residues can be carbonized by partial combustion to a highly stable carbon compound known as 'biochar' or biomass-derived black carbon. The main quality of biochar is its carbon-rich fine-grained, highly porous structure and increased surface area which makes it an ideal soil amendment for carbon sequestration (Lehmann, 2007; Newsletter, CRIDA, 2010). Biochar also acts as a soil conditioner that enhances plant growth, retains nutrients and improves soil properties (Lehman and Rondon, 2005; Lehman *et al*., 2006; Glaser *et al*., 2002). Biochar applications to soil sequester carbon and reduce emissions of non-$CO_2$ greenhouse gases. It also provides a habitat for micro-organisms, which can increase soil microbial diversity. A low-cost charring kiln has been developed to produce biochar from cotton, maize, and castor bean stalks on a small scale to study the production of biochar at different loading rates and partial combustion periods (Lehman *et al*., 2006). When biomass is exposed to moderate temperatures, between about 400 and 500°C (a low-temperature pyrolysis) under complete or partial exclusion of oxygen, biomass undergoes exothermic processes and releases gases, heat and biochar. Such pyrolysis produces biochar, a carbon-rich, fine-grained, porous substance and solid byproduct, similar in its appearance to charcoal, which, when returned to soil, creates a range of environmental benefits, such as enhanced soil carbon sequestration and soil fertility improvement. This is a novel approach to sequester carbon in terrestrial ecosystems that creates environmental benefits and produces several useful products in the process of its manufacture (Lehmann, 2007).

### Methane mitigation using reduced tillage technology

Reduced tillage technology for paddy rice involves planting or transplanting directly into the soil with minimal prior tillage in the residues of the preceding crop. Methane emissions at the tilling stage of rice field preparation account for more than 80% of total annual emissions (US EPA, 1991). Wet-land tillage compared to dry-land zero-tillage results in an earlier onset of methanogenesis and therefore, contributes to greater to methane production during the growing season. Zero-tillage results in the lowest methane emissions and is a practice which utilizes crop residues in place of compost or mulch. This is often done by hand transplanting, but mechanical rice trans planters that can transplant small seedlings into flooded soil are becoming popular in developed countries like Japan and South Korea (e.g., http://en.wikipedia.org/wiki/Rice_transplanter). Following about a week after an herbicide application, broadcasting of pre-germinated seeds into the flood water is also done (Huang *et al*., 2012).

### Change to methanogenic activity using electron acceptors

Addition of electron acceptors, such as ferrihydrite, to paddy fields can stimulate microbial populations that compete with and slow the activity of methanogens, thereby reducing emissions of methane. According to Lueders and Friedrich (2002), methane emissions from paddy fields can be reduced by the addition of electron acceptors to stimulate microbial populations that compete with methanogens. Methanogenesis can be suppressed by the supplementation of alternative electron acceptors such as Fe (III) or sulfate, when electron donors for respiratory processes become limiting (Achtnich *et al*., 2005). This mitigation strategy is based on the thermodynamic theory which predicts that the energetically more favorable electron acceptor will be utilised first under substrate limiting conditions (Zehnder and Stumm, 1988).

Functional shifts can occur within a rice field soil microbial community by supplementing alternative electron acceptors in the form of ferrihydrite and gypsum, and thereby respiratory processes other than methanogenesis are promoted. Under gypsum addition, hydrogen was rapidly consumed to low levels (~0.4 Pa), indicating the presence of a competitive population of hydrogenotrophic sulfate-reducing bacteria (SRB). This was paralleled by a suppressed activity of the hydrogenotrophic RC-I methanogens as indicated by the lowest SSU rRNA quantities. Full inhibition of methanogenesis only became apparent when acetate was depleted to non-permissive thresholds (<5 µM) after 10 days.

The enhanced activity of FRB (Ferric iron reducing bacteria) and SRB (sulfate reducing bacteria) resulted in almost total inhibition of methanogenesis under conditions of limiting substrate and non-limiting electron acceptor availability. Considering the electron uptake potential of eight electrons per $CO_2$ and $SO_4^{2+}$, and one electron per $Fe^{3+}$, only the amount of sulfate reduced perfectly matched the quantity of methane which was not produced under inhibition. FRB also participate in the oxidation of electron donors other than acetate and $H_2$, thus limits its properties of reduction in methanogenesis. This may be another reason for the lower efficiency of inhibition of methanogenesis under ferrihydrite amendment. It was also demonstrated by Lueders & Friedrich (2002) that although the mitigating agent such as gypsum is added in the soil about one-tenth that of the ferrihydrite amendment, but still the mitigation effects were comparable up to 69% and 85% methane reduction, respectively.

**$CO_2$ mitigation**

Carbon dioxide contributes around 72% of total greenhouse gas emissions (Houghton *et al*., 1996). Fossil fuel burning in power stations is the largest source category (29.50 %) of $CO_2$ emissions. Other source categories are industrial processes (20.60%); transport fuel (19.20%); residential and commercial activity (12.90%); land use change and biomass burning (9.12%); fossil fuel retrieval, processing and destruction (8.40%). (Raupach *et al*., 2007).

As per IPCC, 2007 reports; Human activities such as burning fossil fuels and deforestation are causing the concentration of atmospheric $CO_2$ to increase at a rate of 1.8 parts per million per year. It is projected to reach 550 parts per million by 2050. Currently, the level of $CO_2$ in the atmosphere is higher than it has been in the past 65,000 years.

Fossil fuel burning contributes 5.7 gigatons and deforestation adds 2.3 gigatons of $CO_2$ to the atmosphere, totalling about 8.0 gigatons of carbon per year. Soil organic carbon (SOC) has decreased by 50% over the past 40 years due to climate change-induced soil degradation (Lal, 2004). The decline in SOC has become most severe in recent years and is closely linked to decreased productivity of several agricultural crops. Consequently, it is crucial to conserve carbon in the soil with minimal release of $CO_2$ into the atmosphere.

**Carbon sequestration mitigation technologies for $CO_2$**

Carbon sequestration in biological systems is commonly seen as a way to conserve carbon. There are many other technologies that convert atmospheric $CO_2$ to other chemicals, such as methanol and similar organic substrates. However, carbon sequestration in the agricultural system is related to the productivity of crop plants and is considered one of the best ways to store carbon in the biological system. It is defined as the storage of carbon in a stable solid form through the direct or indirect fixation of atmospheric carbon dioxide. $CO_2$ sequestration for carbon capture is a scientific and technical approach to mitigate $CO_2$ in the atmosphere. In the global carbon cycle, carbon continuously moves between the soil and the atmosphere. It enters the soil through photosynthesis in plant leaves and plant-derived organic matter ($CO_2$ influx), and it exit from the respiration of plant roots and soil microorganisms during the decomposition of the organic matter ($CO_2$ outflux). According to Conant *et al*. (2001), converting cropland to fallow land sequesters 0.1 to 1 metric ton C $ha^{-1}yr^{-1}$, depending on the type of biome, with maximum sequestration occurring in native grassland and woodland and other management practices include fertilization, which can sequester 0.3 metric ton C $ha^{-1}yr^{-1}$, and irrigation, which can sequester 0.2 metric ton C $ha^{-1}yr^{-1}$. Barker *et al*. (2007) estimated that 89 percent of the potential for GHG mitigation in the agriculture sector could be achieved through carbon sequestration, while the remaining 11 percent of the mitigation potential is achievable through reducing nitrous oxide and methane emissions.

## 4. CONCLUSION

Agriculture sector accounts for approximately 13% of global anthropogenic emissions, driven by practices such as synthetic fertilizer use, livestock rearing and land-use changes. However, through efficient nutrient management, adoption of organic practices and innovative technologies like nitrification inhibitors and conservation tillage, agriculture can substantially reduce emissions. Strategies such as carbon sequestration in soils and the implementation of reduced tillage can enhance carbon storage while improving soil health and productivity. As the global population grows, the urgency for sustainable agricultural practices becomes increasingly critical. Mitigating greenhouse gas emissions in agriculture not only addresses climate change but also ensures food security and environmental sustainability. Therefore, a concerted effort involving farmers, policymakers and researchers is essential to adopt and promote these mitigation strategies, paving the way for a more resilient agricultural future amidst changing climatic conditions.

## CONSENT (WHERE EVER APPLICABLE)

Authors may use the following wordings for this section: "All authors declare that 'written informed consent was obtained from the patient (or other approved parties) for publication of this case report and accompanying images. A copy of the written consent is available for review by the Editorial office/Chief Editor/Editorial Board members of this journal."

## ETHICAL APPROVAL

This article does not contain any studies with human participants or animals performed by any of the authors

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