

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

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## ABSTRACT

Agriculture is a cornerstone of global food security, which 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<sub>2</sub>O), methane (CH<sub>4</sub>) and carbon dioxide (CO<sub>2</sub>) exacerbate this issue, with N<sub>2</sub>O 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<sub>2</sub>O emissions compared to conventional practices, emphasizing the importance of sustainable agricultural methods. Additionally, conservation tillage and practices like zero-tillage help reduce CO<sub>2</sub> 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<sub>2</sub> 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 and Methane Mitigations*

## 1. INTRODUCTION

Food provisioning especially through agriculture is an important activity and this is highly sensitive to climatic shock. Such things as use of fossil fuel for electricity generation, big industries and transport. The more accumulation of atmospheric greenhouse gases is as a result of agricultural activities: Rice production; Synthetic fertilizer, rearing of livestock; Changing the deforestation; Waste deposited has also played a central role in the emission of greenhouse gases. This accumulation play role of having significant contribution towards climate change that lead to raise in temperature and other stresses (Houghton *et al.*, 1996).

By the year 2050, the global population is expected to reach 9.73 billion, necessarily an 50% increase in agricultural production compared to 2012 levels (FAO, 2017). Agriculture is also to play a crucial role in renewable energy, particularly in reducing greenhouse gas (GHG) emissions from fossil fuel reliance (IEA, 2020). In the U.S., approximately 44% of

domestic corn (*Zea mays* L.) is utilized for ethanol production, with the remaining nutrients repurposed as animal feed. Corn stover, often left in the fields post-harvest, holds significant potential as a biofuel feedstock (Langholtz *et al.*, 2016).

Despite higher crop yields in the U.S. with corn yields 89% above the global average (USDA Foreign Agricultural Service, 2020). The agricultural sector accounted for 9.6% of U.S. GHG emissions in 2019 (U.S. EPA, 2021). Globally, agriculture contributes 21-37% of total GHG emissions (Mbow *et al.*, 2019). Key GHGs include CO<sub>2</sub>, methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O), with respective global warming potentials of 1, 28 and 265 (IPCC AR5, Myhre *et al.*, 2013). In the U.S. agriculture emitted 628.6 Tg CO<sub>2</sub>e per year, with CH<sub>4</sub> and N<sub>2</sub>O as major contributors (U.S. EPA, 2021). Life-cycle analysis (LCA) has emerged as a vital tool for assessing the environmental sustainability of agricultural practices, enabling a comprehensive evaluation of GHG sources and sinks (Sieverding *et al.*, 2020; Singh, 2013).

The agricultural sector is contributing about 13% of man-made greenhouse emission globally, this is equivalent of between 5 to 6 giga tones of CO<sub>2</sub> equivalent per year as estimated by Barker *et al.*, 2007. This was expected to rise by about 40 per cent by 2030 mainly driven by a growing population and enhanced consumption occasions for food, ruminant meat inclusive (Smith *et al.*, 2007). The Global warming potential is for N<sub>2</sub>O is 298 (CO<sub>2</sub> e) and CH<sub>4</sub> is 25 (CO<sub>2</sub> e) compared to 1(CO<sub>2</sub> e) of CO<sub>2</sub> (Forster *et al.*, 2007). Nitrous oxide is released exclusively from inorganic fertilizer and manure, which are spread over the soils. Methane comes primarily from animals and fermentation of feed, rice production and managing manure. Carbon dioxide is released mainly from the microbial decomposition of plant litter and organic matters or soil, and from burning of residues. (Smith, 2004).

Producers and land workers were experiencing harsh impacts of climate change, which is mainly caused by the build-up of greenhouse gases (GHGs) in the atmosphere. Agricultural producers can play a major role in mitigating climate change by reducing greenhouse gas emissions and storing it above or below ground.

### **Agricultural Practices which majorly Contribute to Greenhouse Gas Emissions**

Agriculture was significantly playing a major role in greenhouse gas (GHG) emissions, with a primary GHGs of concern in the United States being (CO<sub>2</sub>), (CH<sub>4</sub>) and (N<sub>2</sub>O). In 2022, these three gases accounted for 97% of total emissions in the country (EPA, 2024a).

CO<sub>2</sub>, comprising 80% of total emissions, primarily from fossil fuel combustion in transportation and power generation. Methane contributes 11%, mainly from waste decomposition in enteric fermentation in livestock and natural gas plants. Nitrous oxide accounts for 6% of emissions, largely due to agricultural soil management, manure management and wastewater treatment.

These gases like, CO<sub>2</sub> can remain for 1000's of years, while methane lasts around 10 years and nitrous oxide over 100 years. In terms of potency, nitrous oxide is 265 times which is more effective than CO<sub>2</sub>, and methane is 28 times more powerful. This difference underscores the urgency of targeting methane and nitrous oxide for effective climate change mitigation strategies (EPA, 2024b).

### **Agricultural Solutions to Mitigate Climate Change**

Agricultural producers can significantly contribute to mitigating climate change by reducing farm gas emissions and enhancing carbon sequestration in soils and biomass. The USDA's Natural Resources Conservation Service (NRCS) is at first place of these efforts, implementing provisions from the Biden Administration's Inflation Reduction Act, which allocates an additional \$19.5 billion over 5 years for climate change mitigation practices in agriculture. Inflation Reduction Act funds are designed specifically for activities that support climate change mitigation, emphasizing the role of agriculture in addressing environmental challenges (EPA, 2024b).

**Mitigation:** The act of reducing the severity, risk or harm associated with a situation/ Calming down of the intensity. Possible measures of mitigation are intensive and extensive agriculture. Nonetheless, it could slash the overall land construed and overall agricultural emission, or per unit carbon footprint.

**Nutrient management:**

Application of nitrogenous fertilizers should also be optimally done to help minimize the emission of N<sub>2</sub>O from agricultural fields. Secondly, through improving management practices it is also possible to decrease the application frequency of synthetic fertilizers and, therefore, possibly decrease CO<sub>2</sub> emissions connected with their production.

### **N<sub>2</sub>O mitigation strategies in organic agriculture**

Organic agriculture slows down N<sub>2</sub>O emissions because use of mineral nitrogen is prohibited and population of the livestock per hectare is minimized. The investigated soils in organic farming showed increased aeration and lower mobile nitrogen contents which leads to enhancement of N<sub>2</sub>O emissions. Since OM systems are N-limited, they would like to have simple inputs/outputs N balance and high N utilization efficiency. (Petersen *et al.*, 2006).

### **Mitigation strategies using nitrification inhibitors**

N<sub>2</sub>O emissions can be minimized by the use of nitrification inhibitors, since their application would slow the microbial activity which results to N<sub>2</sub>O production (Robertson, 2004). S. benzylisothiuronium butanoate and S. benzylisothiuronium fluoroate improved yield crops some of the N inhibitors used are assistance in reducing emissions by N<sub>2</sub>O by 4-5% (Bhatia *et al.*, 2010). Of these compounds, the major uses of nitrification and urease inhibitors were in reduction of loss of N as N<sub>2</sub>O. The herbicides Dicyandiamide (DCD) and Nitrapyrin when applied to grassland also reduced the emissions of N<sub>2</sub>O and from NH<sub>4</sub> based fertilizers by 64% and 52% respectively (McTaggart *et al.*, 1994).

### **Slow-releasing fertilizer application and its manipulation techniques**

Fertilizer application technology plays a significant impact on nitrous oxide emission.

The following are the major various parameters of this technology:

1. Slow releasing urea and NH<sub>4</sub> based fertilizers can be improved by using various coatings, chemical modifications, and changing the size of fertilizer granules.
2. Attempts to increase the size of the pellet up to 1g and the incorporation of DCD, led to poor nitrification rates being recorded at 30% Nitrogen up to 8 weeks after the fertilizer was applied (Goose and Johnson, 1993).

### **Nitrogen management technology**

Practices which are mentioned 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.

#### **Fertilizer types**

Total emission of N<sub>2</sub>O was found to be relatively greater from soil treated with urea rather than from that treated with NH<sub>4</sub> NO<sub>3</sub> parallel with the finding of Mc Taggart *et al.* (1994). The comparative analysis of the results obtained by Tenuta and Beauchamp (2003) has shown that the relative amount of all emissions was greater in the case of urea compared to ammonium sulphate which, in its turn, was more than that from calcium ammonium nitrate. Bouwman *et al.*, (2002) came to understand that nitrate-based fertilizer reduced the emission of N<sub>2</sub>O by 45% as compared to the ammonium based-fertilizer. Snyder *et al.*, (2007) have established that slow, controlled release, and stable utilization of N fertilizer can help to increase crop yields, and reduce the N<sub>2</sub>O emissions.

#### **Time of N fertilizer:**

Crop nitrogen has ability to assimilate very small amount of N in the initial period of most growing seasons but it increases drastically during the period of vegetation growth, and declines very sharply as the crop attains its maturity. Prior to planting spring season crops where may result in increased soil N with poor plant nitrogen uptake increasing the rate of N<sub>2</sub>O emissions. Other seventeen percent of N<sub>2</sub>O emissions might be prevented by applying fertilizers in spring instead of in autumn. Hultgreen and Leduc (2003) also observed that N<sub>2</sub>O emissions were lower where N fertilizer was applied in spring rather in autumn.

#### **Placement of N fertilizer:**

Application of N fertilizer to the soil within the zone of active root uptake and may minimize surface N loss, enhance plant N utilization and therefore decreases N<sub>2</sub>O emission as noted by CAST (2004). Hultgreen and Leduc (2003) were found that the N<sub>2</sub>O emissions reduction if urea was broadcast in mid-row rather than side-banded.

#### **Fertilizer N rate:**

The N<sub>2</sub>O emissions coincide with the effect of N fertilizer rate (Drury *et al.*, 2008). Luo *et al.*, (2010) also observed that emissions of N<sub>2</sub>O were positive related to the amount of N applied to the soil. Miller *et al.*, (2010) opined that the crushing motivator of nitrous oxide reduction through applying of lower nitrogen application rates within an advisable range could be financially rewarded through a nutrient market.

### **Correlation strategies with irrigation and rainfall events:**

Use of fertilizers soon after rain fall will enhance N uptake by plant and also reduce on emission of N<sub>2</sub>O. Reduction in losses of N can supplementarily be eased by method of alternate flooding. The only time it did so was when there was mid-season drainage or when there was alternate flooding and drainage cycles (Pathak, 2010).

### **Residue/ Tillage management**

It enhances microbial turnover of soil organic residues releasing CO<sub>2</sub> to the atmosphere since residues of the soil boost microbial decomposition in the amount of soil. Now in the last decades of enhancements in weed control strategies and farm implements many crops are produced with minimum tillage (Smith *et al.*, 2008).

### **Conservation tillage strategies helps in CO<sub>2</sub> mitigation technology**

Conservation tillage that conserves soil, water and energy by lowering the degree of tillage and retaining residues of harvested crops. This conservation tillage which entails the process of planting, growing and harvesting crops with minimal invasion of the soil structure. This is the practice of tilling that involves leaving the previous year's produced residue on the fields before and after planting the next crop for an enhanced control of soil erosion and run off, Carbon credits among other advantages (MDA, 2011). It also provides an idea of non-interference of the ground. These tillage methods include which mainly include zero tillage system, strip tillage system, ridge tillage system and mulch tillage system. Therefore, zero tillage is an extreme form of conservation tillage that creates least disturbance on the soils.

### **Zero-till farming system**

Zero-tillage means planting crops that are done by planting seeds in the field that has not been ploughed and has had no other treatment. The common zero tillage machinery is a heave tool that can sow seed in slits of 2-3cm width and depths below range from 4-7 cm also it assists in applying fertilizer at one go (CIMMYT, 2010).

**Ridge-till farming system:** Ridge-till in particular mostly requires placing seeds into the space of low levee between carefully constructed ridges of soil. It is very important to maintain the ridges, this necessarily takes modified or specialised equipment (MDA, 2011).

**Mulch-till farming system:** The other case of RTT is the mulch till where residue is partly incorporated using chisels, sweeps, field cultivators or other farming tools more than one third of the soil surface in Ikeogu (MDA, 2011).

### **Biochar – technique strategies for carbon sequestration**

Organic wastes will be pyrolyzed and converted into bio-char or biomass derived black carbon from crop residues through partial combustion, since biochar has highly stable carbon contents, fine-grained, porous nature with high surface area that make it most suitable for soil amendments for carbon sequestration according to Lehmann (2007) and Newsletter, CRIDA (2010). Biochar, which in addition to being a fertilizer also has properties of a soil conditioner which accelerates plant growth, stabilizes nutrients and has an impact on physical and chemical properties of soil (Lehman & Rondon, 2005; Lehman *et al.*, 2006; Glaser *et al.*, 2002). Its uses in sequestering carbon in soils and in curbing other greenhouse gases excluding CO<sub>2</sub>. It also offers a right environment to host micro-organisms that enhances soil microbial densities. This is a low-cost charring kiln used in the making of biochar from cotton, maize and castor beans stalks for small-scale production and also to research on the effects of different loading rates and different partial combustion durations on the production of biochar (Lehman *et al* 2006). If biomass is subjected to moderate temperate, between about 400°C and 500°C at substantially O<sub>2</sub> or biomass is involved in exothermic reactions and gives out gas, heat and biochar. This is one of the innovative strategies to fix carbon in terrestrial ecosystems that results in positive impacts on environment while others produce several useful outputs in their production process (Lehmann, 2007).

### **Reduced tillage technology used for Methane mitigation**

Conservation tillage technology for rice is the planting or transplanting of rice without or with least tilling into the soil among the residue of the previous crop. Methane conc emissions at tilling stage of pre-preparation of rice field contribute to more than 80% of total annual production (US EPA, 1991). Methane production enhanced in wetland tilling compared to the dry-land zero-tillage is because wet-land tilling will earlier producer of methanogenesis therefore increases methane production during the growing season. Zero-tillage produce the least amount of methane emissions and it is a tillage that means using crop residues as opposed to compost or mulch. This is often done by hand transplanting, but mechanical rice trans planters that can transplant small seedlings into flooded soil are become popular in developed countries like Japan and South Korea (e.g., [http:>\(wikimedia commons,2017 Rice transplanter;https://en.wikipedia.org/wiki/Rice\\_transplanter\)](http://(wikimedia commons,2017 Rice transplanter;https://en.wikipedia.org/wiki/Rice_transplanter)

The other method utilized is the broadcasting of pre-germinated seeds into the flood water, which is done approximately one week after an application of herbicide by flooding (Huang *et al.*, 2012).

### **Change of methanogenic activity by using electron acceptors**

Incorporation of electron acceptors that are primarily ferrihydrite, to rice fields where they activate microbial activities that inhibit and limit the functioning of methanogens, consequently reducing the release of methane. As mentioned by Lueders and Friedrich (2002), methane emissions from rice fields that could be shortened by the application of electron acceptors in order to increase the microbial activity that displaces methanogens. Methanogenesis can also be inhibited by such means as addition of other electron acceptors such as Fe (III) or sulfate; these are normally present while the electron donors for respiratory processes are present (Achnich *et al.*, 2005). This mitigation strategy was mainly based on the thermodynamic theory wherein it has been anticipated that under substrate limiting condition, the more energetic electron acceptor will be favored (Zehnder and Stumm, 1988).

The result is that functional changes that could take place within the rice field soil microbial community by supporting multiple electron acceptors in ferrihydrite and gypsum forms and other respiratory activity rather than methanogenesis is encouraged. With gypsum addition, H was rapidly reduced down to very low levels (~0.4 Pa) and that there are a competing population of hydrogenotrophic sulfate-reducing bacteria. Given electron uptake capacity of 8 electrons per CO<sub>2</sub> & SO<sub>4</sub>, 2-, and 1 electron per Fe<sup>3+</sup>, only the amount of sulfate reduced was ideal and in proportion to the amount of methane which was not produced prior with inhibition. FRB is also participated in oxidation of electron donors other than acetate and H<sub>2</sub>, thus limitation of reduction in methanogenesis. This may also be another reason for the lower efficiency in inhibition of methanogenesis under ferrihydrite amendment. This the work of Lueders & Friedrich (2002) also shown that though the ferrihydrite mitigation agent is added in this soil mount 1/10 times of its weight with gypsum as mitigating agent is still mitigating and effective up to 69% & 85% of methane reduction respectively.

### **CO<sub>2</sub> mitigation**

CO<sub>2</sub> is considered accounted for approximately 72 percent of the general greenhouse gases emissions (Houghton *et al.*, 1996). The largest source is the burning of fossil fuel in power stations, which is contributing 29.50 % of CO<sub>2</sub> emissions, other source categories include industrial processes (20.60%); transport fuel (19.20%); residential and commercial activity (12.90%); land use changes through burning and biomass burning (9.12%); retrieval, processing, and destruction of fossil fuels (8.40 %), (Raupach *et al.*, 2007 IPCC; burning of fossil fuels transportation and deforestation is having the result of raising the concentration of CO<sub>2</sub> in atmosphere at a rate of 1.8 part quiver per year and it is expected to reach an average of 550 part quiver in the year 2050. Right now, the CO<sub>2</sub> concentration in the atmosphere is higher than that of the last 65 thousand years.

## **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."

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

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