Review Article

Mitigation strategies for greenhouse gases to ensure food security

Anam Amin*, Laiba Tanveer, Emmania Abid, Mahnoor Absar, Mahnoor Tariq

University of Central Punjab, Lahore, Pakistan

***Corresponding author's email:** anam.amin@ucp.edu.pk

Abstract

Global warming and food insecurity are global concerns, with agriculture being a major contributor to greenhouse gas emissions. Greenhouse gases such as carbon dioxide, nitrous oxide, and methane, from agricultural activities significantly impact climate change. Approximately 24% of global greenhouse gas emissions come from agriculture. Nitrous oxide is 300 times stronger than carbon dioxide and is mainly produced from organic manure and fertilizers. Methane, another potent greenhouse gas, is released during fermentation, manure management, and burning of residues. Carbon dioxide, a major contributor to climate change, is emitted through farming practices, fertilizers, pesticides, and deforestation. Climate change affects food security by directly impacting crop production and indirectly affecting food availability, cost, and supply chains. Hunger rates have been increasing globally, emphasizing the need to control global warming to reduce food insecurity. This review highlights various mitigation strategies for controlling greenhouse gases from agriculture with improved crop productivity. Soil characterization techniques, such as X-ray computed tomography, tracer and chamber-based methods, help to understand the soil composition for greenhouse gas mitigation strategies. Soil amendments, like biochar application can effectively reduce emissions by modifying microbial activity and biogeochemical processes. Controlled irrigation practices, minimum and zero tillage, and efficient nitrogen fertilizer usage also contribute to greenhouse gas mitigation and improves crop productivity. Strategies such as slow release of fertilizers and the use of inhibitors help to increase nitrogen usage efficiency and reduce nitrous oxide emissions. Implementing these strategies globally is crucial for mitigating greenhouse gas emissions, reducing global warming, and ensuring food security.

Keywords: Greenhouse gases, Soil amendments, Irrigation, Food insecurity, Crop productivity, Fertilizers.

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Introduction

Global warming and food insecurity are emerging concerns around the globe [1]. One of the potential cause of global warming is the alarming increase in the emission of greenhouse gases [2]. The greenhouse gases emitted from the natural and anthropogenic sources have altered the climate by changing the composition of atmospheric gases [3]. Agriculture sector is one of the major contributors of greenhouse gasses including methane (CH_3), nitrous oxide (N_2O) and carbon dioxide (CO_2) [4].

Agriculture is climate dependent human activity that is both the a victim and a contributor of climate change [5]. Agriculture contributes 24% of Global Greenhouse gas emissions [6]. Total greenhouse emission is projected to increase by approximately 50% by 2030 [7]. According to Intergovernmental Panel on Climate Change (IPCC), greenhouse gases) entraps heat in the atmosphere of earth, resulting in an increase in temperature [8]. Agricultural greenhouse gases are produced as the result of soil and manure management, fermentation, use of both synthetic and organic fertilizers, and consumption of fossil fuels [7]. Animal manure accounts for approximately 37% of greenhouse gas emission [9].

Nitrous oxide traps heat in the atmosphere and contributes to global warming [8, 9]. The emission of nitrous oxide is increasing at a rate of 2% per decade [12]. Nitrous oxide is 300 times stronger than carbon dioxide [13]. About 75% of agricultural nitrous oxide is produced due to increased use of organic manure, nitrogen containing fertilizers and synthetic fertilizers during farming [12-14]. Nitrous oxide is not directly produced by plant tissues [10]. Plant roots absorb nitrous oxide from the soil and release it into the atmosphere [17]. Nitrous oxide depletes the ozone layer and contributes to climate change [16, 17].

Methane gas is another important greenhouse gas which contributes to the global warming [18, 19]. Agriculture activities release approximately 50.63 % of methane gas into the atmosphere [22]. Methane is produced as a result of activities like fermentation, cultivation of rice, management of manure, and the burning of residues [23].

Carbon dioxide is one of the major contributor to global warming, climate change, and disruption in the climate [24]. Approximately 14% of carbon dioxide is released into the atmosphere as a result of agricultural activities [4, 23]. Soil holds a significant amount of organic carbon and approximately 10% of atmospheric carbon dioxide (CO_2) cycles through terrestrial soils annually [26]. Farming, fertilizers, pesticides and agricultural machinery, burning of agricultural residues, and deforestation are the sources of increased atmospheric carbon dioxide [24, 25]. Figure 1 shows the issues associated with Climate change and Global warming.

Climate change due to high levels of greenhouse gas emissions have risked the food security among various countries [29]. Food security is a rising concern associated with global warming [30]. A documentary by Food and Agriculture Organization (FAO) presented that climate change has a direct impact on agriculture-based food systems because the crops and the conditions for growing crops are altered [31]. Approximately 3.1% to 7.4% reduction in crop yield is expected for each degree Celsius increase in temperature [32]. Food and Agriculture Organization (FAO), WHO and UNICEF reported the trend of increased hunger globally since 2014 and 25.9% population around the globe was influenced by hunger [31].

Both the climate change and the food system are interlinked and either has a positive or a negative effect on each other [33]. Climate change has exacerbated the alarming food shortage crisis as it has direct impact on the crop production and indirectly impacts the cost, food availability and supply chain, increasing the hunger rates globally [34]. Figure 1 gives an overview of how climate changes impact the society and other factors including natural resources. Therefore, control of Global warming is necessary to reduce food insecurity around the globe by agriculture on climate change and to improve food security [35]. Climate smart Agriculture (CSA) can increase food production while reducing greenhouse gas emission [36].

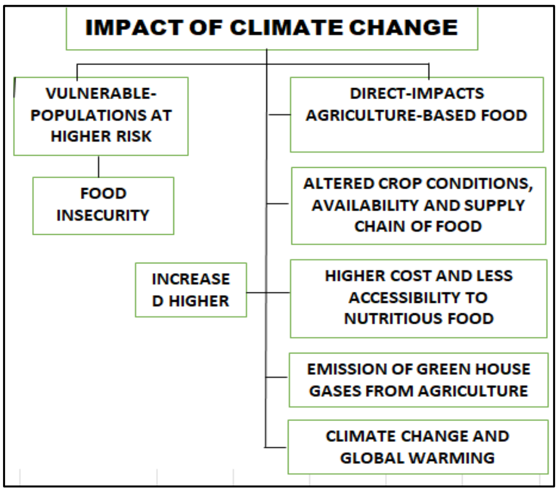

Figure 1: Vulnerable and direct relationship of climate change with food security

This review highlights the potential solutions for mitigating greenhouse gas emission from agriculture which includes improved soil amendments, optimized irrigation practices, and better fertilizer techniques. Soil characterization techniques such as X-ray computed tomography, chamber-based techniques, and tracer methods help to understand the composition of soil. Such characterization techniques can help to develop effective greenhouse gas mitigation strategies. Soil amendments like biochar application, controlled irrigation practices, minimum tillage, and efficient use of nitrogen fertilizer reduces greenhouse gas emission and improves soil fertility, and crop yield [37]. These mitigation techniques can also contribute to a more sustainable and secure food system.

Soil characterization for greenhouse gas mitigation

Agricultural greenhouse gas mitigation requires detailed soil characterization for detailed analysis of soil contents, composition and texture [38]. X-ray computed tomography is an important soil analysis technique which helps to study the hydro-physical characteristics of soil like soil texture, structure and pore size [34]. X-ray computed tomography is a non-destructive technique for the study of interaction between soil microbial community and soil contents [40].

Nuclear techniques offer significant benefits over traditional methods for assessing the impact of climate change. Nitrogen-15 tracer method enables the examination of nitrogen-containing fertilizer uptake pathway in the plant [36,37]. Nitrogen-15 tracer technique can also pinpoint the sources of nitrous oxide production which is crucial for developing strategies to reduce greenhouse gas emission. Nitrogen-15 tracer technique is used in combination with mass spectroscopy which helps in qualitative and quantitative analysis of soil nitrogen content [43].Carbon-13 tracer method allows the determination of soil quality and carbon sequestration in the soil [44].This method assists in identifying the optimal combinations of tillage, crop rotation and ground cover to increase crop yield and to improve the efficient use of scarce resources [45].

Chamber based greenhouse gas flux measurement technique is another method that is widely being used for estimating the flux of methane, carbon dioxide, and nitrous oxide between the soil, crops, and the atmosphere [46].

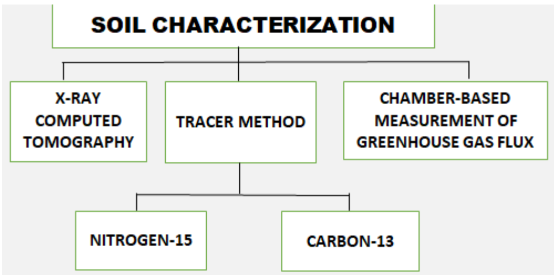

Figure 2: Summary of methods of soil characterization for identification of soil characteristics.

These chambers could be fully automated offering higher frequency of measurement and more accurate measurement of greenhouse gas emission. The conditions of such chambers could be standardized to generate high quality transferable data [47].

Methods for greenhouse gas mitigation

Control of greenhouse gases from the thoroughly analyzed agricultural soil is important in order to control Global warming [4]. In order to achieve climate control objectives, different national and international authorities should work on identifying the strategies for the control of greenhouse gases [48]. Agriculture is responsible for 21% to 37% of global warming [49].

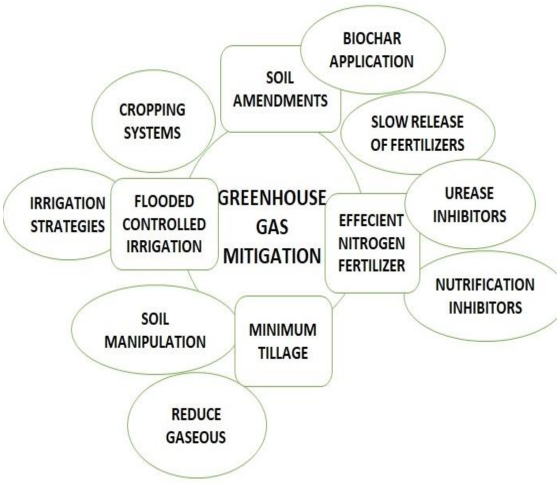

Figure 3: Commonly used methods for greenhouse gas mitigation from agriculture for climate control.

Soil amendments

Soil contains minerals, organic matter, gases, and water [50]. Soil amendments is the most suitable method to reduce the greenhouse gas emission from agricultural land [51]. Balanced use of fertilizer, water and soil in the agricultural crops helps in reducing greenhouse gas emissions [52]. Carbon dioxide emission can be reduced to 0.6 g/h/m2 by making bone meal amendment in the soil [53]. Bone meal is prepared by utilizing the waste if meat like bones which carries variety of nutrients [54]. Bone meal fertilizer is actually rich in nitrogen, calcium and phosphorous which makes it a useful fertilizer for crop as it does not increase the emission of nitrous oxide [55].

The use of appropriate fertilizers and manure in the agriculture can minimize the release of N_2O [56]. Application of reduced amount of animal manure can reduce nitrous oxide emission from the sweet potato plant along with increasing the yield of the crop [57]. Altering the microbial communities in the soil using different nitrogen stabilizers can reduce greenhouse gas emission from the crops [58]. Covering rice paddy with thin plastic film can reduce methane and NO3 production by 80% [51, 52]. According to some studies, use of inorganic fertilizers can improve soil fertility and reduce carbon dioxide emission [61].

Soil amendments play an important role in the improvement of the crop yield and other quality of the crops [62]. According to [63] soil amendments have a long term positive impact on nutritional value of crops. Further studies showed that improvement in yield of crops varies according to the soil composition and crop type [64]. In 2020, Larkin indicated that making changes in the soil improves the yield of zucchini and beans, and protects the crops from weed attacks. Soil cracking also improved the crop productivity in Vertisols [66]. A comparative study indicated that organic amendments in soil improved the yield of crops significantly [67].

Biochar application

Biochar has been under focused research during recent years because of its significant properties like oxygen-containing surface functional groups, high adsorption capacity, high structural stability, improved mineral and trace element contents [59, 60]. Biochar is a beneficial soil amendment for reducing 41% of greenhouse gas emission from agriculture [60-62]. Biochar is a charcoal-like, carbon rich organic fertilizer obtained from various biological materials such as rice structures, roughage, and residue of other agricultural elements [73]. Biochar is manufactured by pyrolysis which converts the carbon into more stable form [74]. Biochar controls greenhouse gas emission by three main methods; by changing the activity of soil microbes, by changing the soil pH and by modifying the biogeochemical processes of the soil [65-67]. Control of Greenhouse gas emission varies according to the soil composition and conditions of agricultural land [64, 68, 69]. A recent study reported that pig manure increases methane emission by 88% and nitrous oxide emission by 79% while CO2 emission was reduced by 5% [80]. However, biochar application reduced the emission of methane, nitrous oxide and CO2 by 37%, 25% and 5%. The application of biochar in soils can reduce the carbon dioxide emission which reduces global warming by 43% [60, 70, 71]. Biochar also results in the decrease of nitrous oxide emission by 30.92% from the crops [72]. Biochar application in dry calcareous soil and cropland reduced methane emission by 33% [72, 73]. Biochar application in alkaline soils of corn field reduces nitrous oxide emission by 26.9% and carbon dioxide emission by 11.8% [85]. Biochar application on irrigated land had significant reduced the methane emission by 40%, CO2 by 4% and NO2 emission by 9% [80]. Biochar application on rainfed land did not affect the NO2 emission and reduced methane production by 38% and CO2 emission by 17%. Biochar application controls greenhouse gas emission from periodically flooded rice fields but not from nonperiodically flooded rice [75, 76].

Biochar application increased grain yield by 13% and 10% in fine and coarse textured soils respectively [80]. Rice is one of the major crops being consumed around the globe [93]. 40 Tons/Hectar biochar application raises the rice yield by 3-16% [94]. The increase in rice yield due to biochar application is also linked with the soil fertility [95]. Wheat is the staple food for most of the people in Pakistan [85, 86]. Biochar application enhanced the productivity of wheat up to 42% [98]. Biochar application improved the maize yield along with significant reduction in nitrous oxide production [69, 88]. Biochar application can increase in the yield of pepper plant by stimulating microbial composition [100]. Biochar improves the yield of crops that are grown in nutrient deficient soils [94] .Biochar application improved soil nutrient content which significantly increased the yield of cherry tomatoes by 64% [101]. Crops such as maize, soybean and mustard do not show the increase in their productivity immediately after biochar application but significant increase in their productivity after some time have been observed [90, 91]. Biochar application controls Greenhouse gas emission from turnip field but has a neutral impact on yield of the crop [104].

Table 1**.** Effect of swine manure biochar and woody biochar on Nitrous Oxide emission

Biochar	**Type**	**N2O Emission Reduction**	**References**
Swine manure biochar	Aerobic	17.8 – 19.2 %	[88]
Woody biochar	Anaerobic	50%	[78, 79]
Low temperature Sugarcane bagasse biochar	Anaerobic	15%	[80, 81]

Flooded and controlled irrigation

Emission of greenhouse gases is greatly influenced by irrigation practices [105]. Irrigation controls microbial activity in soil and provides the substrate [106]. A report by *Global Warming Potential* has demonstrated that water saving irrigation can reduce the effect of greenhouse gas emissions up to 54% [104, 105].

Numerous cropping systems have been examined globally to determine the impact of irrigation on nitrous oxide emission [106, 107]. Plants produce nitrous oxide through nitrification and denitrification of nitrogen content of the soil [111]. Irrigation strategies alter nitrification and denitrification mechanism in soil which affects nitrous oxide emission [109-111]. Controlled irrigation resulted in low nitrous oxide emission than flooded rice and wheat fields [112, 113]. Other studies demonstrated that continuous irrigation of wheat fields contributes reduced emission of nitrous oxide [114, 115]. During the drought of 2013 in China, different irrigation strategies showed reduced carbon dioxide and methane emission from rice fields without affecting their yield [119]. Most of the studies demonstrate that the average emission of carbon dioxide has increased up to 27% with reduced irrigation strategies than with continuous irrigation [117-119]. Few studies showed that intermittent irrigation can control the emission of carbon dioxide by 6.6% [123]. Controlled irrigation is more effective in controlling the emission of methane gas as compared to flooded irrigation [124]. [125] demonstrated the reduction in methane fluxed to 7.6 mg C/m2/h. However, [126] reported that methane emission was higher in flooded field as compared to controlled irrigated field.

Reduced and controlled irrigation system also helps to increase wheat yield up to 7.5% and reduces Greenhouse gas emission up to 9.8% [127, 128]. Controlled irrigation can increase the yield of maize crop up to 13% along with mitigation of Greenhouse gas [129]. Controlled irrigation can reduce methane emission from rice field without reducing crop yield [130]. Flooded irrigation is preferred in rice paddies because water saving irrigation strategy like sprinkler irrigation reduces crop yield [127, 128].

Minimum tillage

Minimum tillage refers to sowing the crop seeds directly without working the soil which helps to retain the water and carbon which reduces soil erosion [133]. Minimum tillage reduces gaseous exchange by decreasing the number of macro pores which mitigates emission of greenhouse gases [134-136].. Minimum tillage causes the decomposition of organic matter and produces CO2 upon oxidation of carbon [137]. Reduced tillage has the potential to reduced methane and nitrous oxide emission by 6.6% [138, 139]. It has been estimated that reduced or no-tillage practices can mitigate greenhouse gas emission from approximately 57 million hectares of cropland [140]. Zero tillage retains the soil characteristics by holding the soil organic carbon which increases soil fertility and improves crop production [141]. Zero tillage has reduced global warming potential by 10.8% in barley, 13.7% in maize, 22.5% in rice and 30.1% in soybean [142]. In North China Plain, no tillage reduced nitrous oxide emission in winter-wheat and improved methane adsorption in summer-maize [143]. However, numerous studies have reported an increase in the emission of CO2 and nitrous oxide because of minimum and zero tillage [142-145]. Therefore, global research is required to identify uniform trends in the effect of tillage on greenhouse gas emission [142]. Different tillage systems are used for different crop fields [148].

Table 2. Effectiveness of zero tillage and strip tillage in controlling greenhouse gas production.

Tillage Type	Definition	GHG Mitigation	References
Zero tillage	Plants are seeded directly into undisturbed soil	20%	[144]
Strip tillage	Alternate bands of soils are tilled with rest of the bands of undisturbed soils	16%	[149]

Soil tillage is useful for improving the soil health by retaining carbon in the soil which improves the crop yield [150] [151]. Reduced tillage increases the production of wheat by 26.6% [152]. Conservation tillage has the potential to improve aroma, yield and quality of rice [153]. Zero tillage in rice-based cropping system increases wheat yield up to 11%, rice yield up to 8% and maize yield up to 10% [154]. Minimum tillage does not have any positive or negative impact on maize yield [155]. Zero tillage have been reported to increase maize crop production by 12.9% [156]. Zero tillage in wheat-mungbean-T. aman cropping system has also been identified most suited for improving yield and reducing greenhouse gas emission [150].

Efficient nitrogen fertilizer usage

Nitrogen fertilizers are an important component for agriculture as they improve crop production by 50% [157]. The overuse of nitrogen containing fertilizers leads to increase greenhouse gas emission which results in drastic climate changes [158]. Nitrogen fertilizers contribute to Global warming as it is responsible for the emission of 80% anthropogenic nitrous oxide [52]. In 2019, nitrogenous fertilizer usage accounted for 8.3% of agricultural greenhouse gas production [159]. Controlled use of nitrogen containing fertilizers allows reduced greenhouse gas emission along with improved agronomy [160]. Different strategies for the control of nitrous oxide emission from agricultural lands have been used which include slow release of fertilizers, urease inhibitors and nitrification inhibitors [97-99] . Slow application of nitrogenous fertilizers has the ability to reduce nitrous oxide emission. Urea fertilizers reduce nitrous oxide emission upto 58% while increasing the paddy rice yield upto 23% [164]. The use of biological nitrification inhibitors is an effective approach to ensure nitrogen usage efficiency. The inhibitors of urease and nitrification have been reported to significantly reduce the emission of nitrous oxide upto 65%as they block the active sites [99, 101].

Conclusion

Agriculture is a major contributor to greenhouse gas emissions, including carbon dioxide, methane, and nitrous oxide. These gases contribute to global warming and climate change which in turn have significant impacts on food security worldwide. It is important to control greenhouse gas emission from agricultural activities for controlling the effects of global warming and improving crop production. Soil characterization and strategies to control greenhouse gas emission have the potential to reduce greenhouse gas emissions, improve soil fertility, and increase crop yields, contributing to both climate change mitigation and food security. Extensive studies are required for development of improved strategies for control of Global warming with improved crop production in order to address food security.

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Conflicts of interest

Declare conflicts of interest or state "The authors declare no conflict of interest." Authors must identify and declare any personal circumstances or interest that may be perceived as inappropriately influencing the representation or interpretation of reported research results. Any role of the funders in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript, or in the decision to publish the results must be declared in this section. If there is no role, please state "The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results".

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