Mitigation of green house gasesby agronomic practices towards sustainable agriculture

Abstract: Agriculture is an important source of greenhouse gas emissions. It is one of the economic sectors that impact both directly and indirectly towards climate change which contributes to greenhouse gas emissions. For the agriculture sector to achieve reduced GHG emission, climatesmart activities and improved food security will be needed for this sector to become a climate-smartsustainable agriculture. This article explores the key ways to mitigate green house gas emissions within the agriculturesector andcritically highlights the potential for bacterial nitrogen fixation in soybean and mitigation of greenhouse gas (GHG) emissions. Nitrous oxide (N_2O), a GHG, is mainly emitted from agricultural use of nitrogen fertilizer and symbiotic nitrogen fixation. Thus, symbiotic nitrogen fixation shows potential for GHG mitigation in soybean while simultaneously supporting sustainable agriculture. Other agronomic practices include tillage and residue management, rice field management, climate smart agriculture, organic farming and bio energy etc.

Keywords: *Bradyrhizobium*, methane, nitrogen fixation, nitrous oxide (N_2O), rice

Introduction

Pollution has been a major concern of the world for the past few decades. It has gained a lot of attention of the research world to help people around the globe for getting a sustainable environment to live within. The elevated green house gases (GHGs) emission in atmosphere by anthropogenic activities such as change in land use pattern, industrialization, deforestation, transportation and cultivation of crops leads to global climate shift which is one of the critical environmental challenges that the world is facing today. The atmospheric concentration of CO_2 is presently 408 ppmon earth. As one of the potent Global Warming Gas (GWG), CO_2 has increased by approximately 43% since industrial revolution and is expected to further increase to 60% in 2100 if the current trend continues. The primary cause of N_2O emissions in soil is by the bacteria through nitrification under aerobic conditions and denitrification in anoxic environment. N_2O has a 298 fold greater global warming potential than CO_2 and contributes to around 19 % of the overall global warming effect. Globally, it is estimated that naturally vegetated soils generate 6.6 Tg of N_2O per year and that the oceans provide around 3.8 Tg ofN_2O per year to the atmosphere (Laishram *et al.*, 2023).

Comment [AB1]: The latest value as of March 2023 is 420ppm as per NASA measurements (https://climate.nasa.gov/vital-signs/carbon-dioxide/). The author(s) should include the latest data for all parameters.

While we focus predominantly on the direct agricultural emissions, it is important to also look at indirect carbon emissions, which arise from within agriculture as well and have known to add to the total estimate of global GHG. Indirect emissions come from the use of farm machinery, fertilizer production and use of pesticides and irrigation. Total global GHG emissions from agriculture sector will be agricultural emissions (5.1–6.1 Pg, 10–12% of total global emissions), land use (5.9 ± 2.9 Pg; 6–17% of total), agri related chemical production/distribution (0.3–0.7 Pg, 0.6–1.4%) and farm operations (including irrigation) (0.1–0.9 Pg, 0.2–1.8% of total global emissions). Agriculture alone is known to have contributed between 16.8% and 32.2%, including land use and direct and indirect emissions. There has been a growing interest in the need for climate-specific smart farming with an awareness of the agricultural sector impacting the climate negatively.

Mitigation strategy of GHGs emission by autotrophic biota and some microorganism such as algae, cyanobacteria, chemoautotrophic and chemolithoautotrophic bacteria having CO_2 fixing mechanism supported by key enzyme like Ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO) and facilitated by enzyme like carbonic anhydrase (CA) is one of the promising option (Kumar *et al.*, 2018).

Although,dinitrogen (N_2) which is abundant inatmosphere is a strong covalent bond and relatively non reactive molecule, the nitrogen fixation process converts N_2 into ammonium or other related nitrogenous compounds such as reactive nitrogen, which is a fundamental component of living organisms and it has a critical role in biosphere (Kuypers*et al.* 2018). It is also a limiting factor for the growth of crop plants. Chemical nitrogen fixation by the Haber-Bosch process permitted fertilizer production at industrial-scale that supported global population growth, but simultaneously it released reactive nitrogen into the environment. Humans have more than doubled the environmental input of natural reactive nitrogen compounds, such as urea and ammonium, mainly through the increasing rates of biological nitrogen fixation by symbiotic rhizobia in leguminous crops and through the use of manufactured fertilizers industrially.

However, the release of reactive nitrogen into the atmosphere, water and soil has generated serious environmental issues recently (Shibata *et al.* 2015). Theanthropogenic emission of nitrous oxide (N_2O) into the atmosphere is increasing from agriculturalfields (Tian *et al.* 2020). N_2O is one of the major greenhouse gas and is also ozone-depleting compound in the stratosphere. The concentration of atmospheric N_2O has increased by >20% from 270(nL/L) in 1750 to 331 (nL/L) in 2018 due to anthropogenic N_2O emission. The recent growth in N_2O emissions exceeds some of the highest projected emission scenarios

Comment [AB2]: New latest data as of 2023 should be included.

(Tian *et al.* 2020). Nitrifying bacteria possess significant advantages for mitigation GHGs emission which have been the main focus of attention today, which environmental friendly

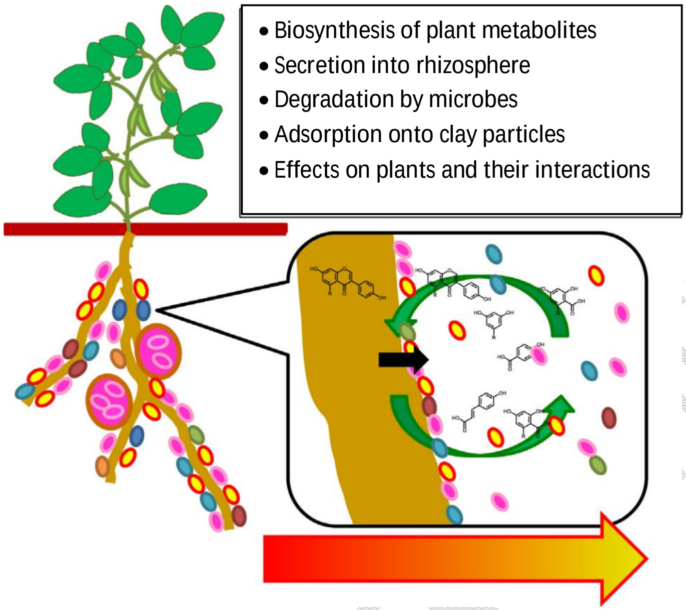
Emissions from Agriculture

In 2015, the Paris Agreement aimed to limit the increment of the global average temperature below 2-degree Celsius above pre-industrial levels by 2100. To achieve this aim, a balance is needed between the anthropogenic GHG emissions by sources and removals by sinks of GHG in the second half of this century (Jantke*et al.*, 2020). The Paris Agreement hardly mentioned the agricultural sector even though it contributes around 10–14% global GHG emissions (Tubiello*et al.*, 2013). After decades of neglect, the international scientific community is gradually starting to understand that this sector is essential for the achievement of the goal mentioned above. The potentiality of GHG mitigation by the contribution of the agriculture sector is less in developed countries, where this sector typically forms around 10% of national GHG inventories (Suzuki *et al.*, 2018). However, there are some developed countries like India, where agriculture relatively plays a vital part in the national GHG emission profile. Agriculture is the second-largest source of GHG emissions in Australia, and it contributes 14% of total GHG emissions. Hence, a focus on GHG reduction is a high priority (Jackson *et al.*, 2018). The primary GHG emissions from agricultural sectors consist of (a) methane from enteric fermentation, (b) carbon dioxide from decomposition of soil organic carbon, and (c) nitrous oxide from manure and synthetic fertilizer.

Agricultural practices to mitigate GHGs

1. Soybean nitrogen fixation

Soybean (*Glycine max*) is a major oilseed crop with over 300 million tonnes production globally. Soybean seeds contain many proteins and lipids which make it particularly nutritious. It also contains various secondary metabolites such as isoflavones and saponins, as their functional ingredients. The crop establishes symbiotic relationships with rhizobia and arbuscular mycorrhizal fungi (AMF) and requires less fertilizer at initial stage. For this association rhizosphere microbes are necessary.The term “rhizosphere”was coined by Lorenz Hiltner (1904). It is the region close to plant’s roots surface where various interactions occur between them. Roots exert both physical influences, such as by root structure or heat generation, and chemical influences, such as by the secretion of a wide variety of plantderived metabolites. Plant roots secrete metabolites into the rhizosphere actively using the energy from ATP and passively through diffusion (Figure 1) (Sugiyama, 2019).At the initial stage of interaction, rhizobia first infect roots, elicit root nodules and forms a symbiont thereafter fix atmospheric N_2symbiotically.



Effects of plants into rhizospheric zone

Figure 1: Secretion and fate of metabolites in the rhizosphere

(Source: Sugiyama, 2019)

The usage of industrial N fertilizers can be leveraged by symbiotic N_2 fixation process which is biological reduction is an ecologically crucial process for sustainable agriculture. Rhizobia provides fixed N to the host plant and in return the host plant supplies photosynthetically fixed carbon to the bacteria. The soybean rhizosphere is a site of active N transformations, including the production and consumption of N_2O (Sánchez and Minamisawa, 2019). Major source of N_2O is nodule decomposition. A N ^{15} tracer experiment revealed that the N_2O emitted from the soybean rhizosphere was almost entirely derived from N_2 that had been symbiotically fixed in the nodules (Inaba *et al.* 2012) . During nodule organic N inside nodules is mineralized to NH_4^+followed by subsequent nitrification and denitrification processes occur to yield N_2O. *Bradyrhizobiumdiazoefficiens*and other soil microbes generate N_2O during nodule degradation. *nosZ*+ strains of *B. diazoefficiens*are exclusively able to take up N_2O via N $_2$O reductase (Figure2)(Inaba*et al.* 2012).

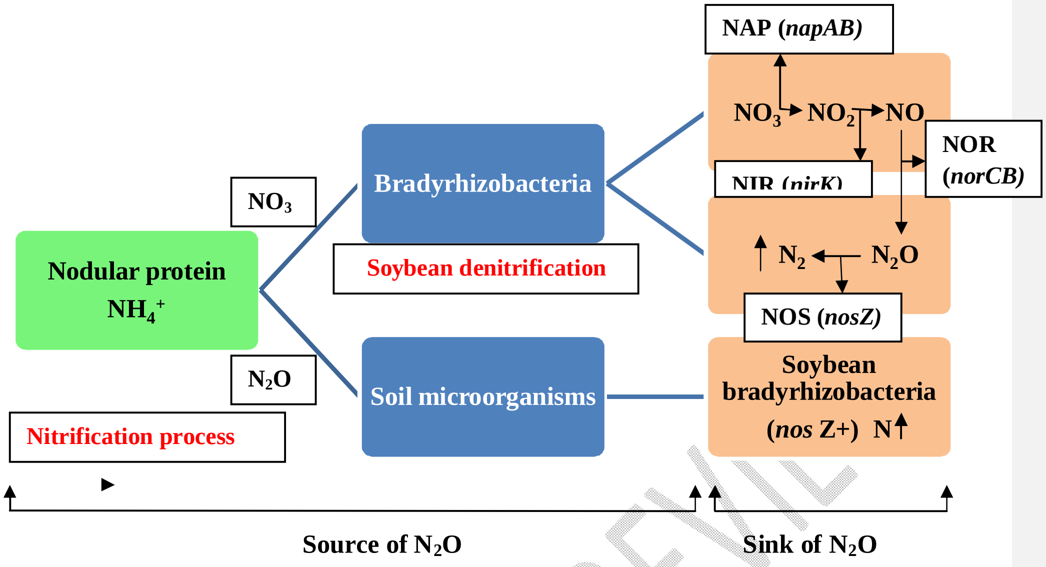


Figure 2: Schematic representation of N_2O metabolism in the soybean rhizosphere

Measurement of the N_2O flux from decomposed nodules formed with the wild-type strain of *Bradyrhizobiumdiazoefficiens*,*nirK*mutant, and *nirK/nosZ*double mutant showed that *B. diazoefficiens*are one of the players in N_2O emission via denitrification (41% of the total N_2O produced) (Inaba *et al.* 2012) In contrast, *B. diazoefficiens*strains carrying *nosZ*(*nosZ*+) exclusively uptake N_2O, acting as an N_2O sink (Inaba *et al.* 2012). The net N_2O flux in the soybean rhizosphere is determined by the balance between N_2O sources and sinks (Figure 1) . Thus, inoculation of soybeans with strains from the complete denitrifying group (*B. diazoefficiens*) has the potential to reduce N_2O emission in the soybean rhizosphere.Almost all ecosystem processes depend on soil microbes; therefore microbial activity and abundance are what determine the sustainable productivity of agricultural lands, ecosystem resistance to nutrient mining, deterioration of soil and water resources, and GHG emissions. Methanotrophs or methaneoxidizing bacteria (MOB), present in aerobic soils, are potential biological sink to mitigate methane emission to the atmosphere (Laishram *et al.*, 2023).

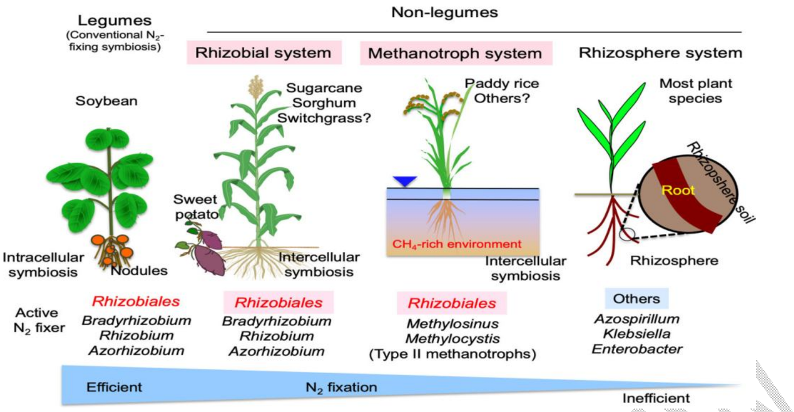


Figure 3. Hypothetical categories of N2-fixing bacteria associated with plants. Pink-colored "Rhizobia system" and "Methanotroph system" are new categories of N_2- fixing symbiosis with non-legumes, which are different from classical "Rhizosphere system."

(Source: Minamisawa, 2023)

2. Biochar

The application of biochar in different forms in agricultural ecosystems is followed by farmers since agricultural evaluation. In jhum and shifting cultivation, forests are burned to clear agricultural land which results in addition of biochar in soil unconsciously. The addition of algal biochar in soil increased the retention time of several limiting nutrient which enhanced soil fertility and crop economical production (Purakayastha*et al.*, 2019). In agriculture, rice soil is the main source of CH_4 emission to atmosphere and its mitigation can play significant role in reducing global warming. There are contradictory reports for CH_4 emission from rice under biochar application which was hard to do interpretations. Feng *et al.*, (2012) studied the effects of biochar application on CH_4 emission from rice soil in field experiment and observed significant reduction in total CH_4 emission. The amendment of biochar in to rice soil doesn't inhibit the microbial activity of CH_4 production bacteria (methanogens) but significantly increased the abundance of CH_4 oxidizing bacteria (methanotrophs) in rice soil which resulted in CH_4mitigation. Wu *et al.* (2019) investigated the effect of six years old aged and fresh biochar on CH_4 oxidation in soil and found that ammonium and nitrate content in soil enhanced the CH_4 oxidation by promoting the population of methanotrophs type I and methanotrophs type II, respectively under biochar amendments. The biochar produced at higher pyrolysis temperature have more CH_4 production inhibition potential as compared to the biochar produced at lower pyrolysis temperature. Application of biochar in agricultural soil enhanced the storage of carbon in the form of carbon sequestration and thus results in lower emissions of CH_4 gas to atmosphere. The contradictory studies reporting application of biochar stimulates CH_4 emissions from rice soil were also documented (Shaukat *et al.*,2019). Application of biochar having lager surface area enhances iron reduction bacterial population in soil which results in lower production of CH_4 as they compet with methanogenic bacteria (Wang *et al.,* 2017). CH_4 emission dynamic under biochar production from feedstocks such as wheat straw, rice, corn, wood, has been documented (Wang *et al.,* 2017; Shaukat *et al.,*2019), however the effect of biochar production from algal feedstock is lacking and required, which can help in combating CH_4 emission from agricultural soil.

3. Smart farming

The recent advancement of smart technologies has enabled the vision of smart farming (alternatively known as smart agriculture) based precision agriculture. The aim of smart farming is to improve productivity by increasing crop yields and profitability, and reduce the environmental footprint such as GHG emission by utilizing different techniques such as efficient irrigation (Islam *et al.,* 2020), targeted and precise use of pesticides and fertilizers for crops etc. In addition, IoT enables the reduction of the inherent environmental impact by performing real-time detection of weeds or infestations (Islam *et al.,* 2021) monitoring weather conditions, soil condition etc., which consequently reduces and allows adequate use of inputs such as water, pesticides or agro-chemicals (Alam*et al.,* 2021). The application of smart technologies in agriculture includes, but is not limited to:

- **Field Monitoring:** Smart farming helps to reduce spoilage and crop waste with the provision of better monitoring, accurate data collection, and management of the agriculture fields (Prathibha*et al.,* 2017). For instance, smart farming promotes the efficient application of fertilizers, electricity and water.
- **Green Houses:** Smart farming helps to maximize the production and quality of fruits and vegetables by controlling micro-climate conditions of a green house.
- **Compost management:** Smart technologies prevent fungus and other microbial contaminants in hay, alfalfa, straw, etc. by controlling temperature and humidity.
- **Livestock Farming:** Smart livestock farming helps to monitor animal grazing in open pastures or location in big stables. Smart farming also helps in detecting and maintaining air quality, ventilation in farms and detecting and reducing GHG emission from farms.
- **Offspring Care:** Smart farming helps in monitoring and controlling offspring in animal farms to ensure their survival, growth and health

4. Climate Smart Agriculture

Climate Smart Agriculture (CSA) is a promising innovation in agriculture which integrates traditional farming practices with technology towards the aimof increasing agricultural productivity considering climate constraints while reducing GHG emissions. Hence, CSA comprises sustainable agricultural systems which contribute to increased crop yields, productivity and revenue; more resilience and adaptation to climate change of food systems; and reduction of greenhouse gas emission as much as possible (McNunn*et al.*, 2020). Several farm level studies presented in the research literature suggest that adoption of CSA technologies has proven to improve and increase quality and amount of crop yields, net income, efficient usage of input materials and most importantly has reduced GHG emissions (Sapkota *et al.*, 2014).Some widely used CSA practices and technologies which help to improve crop yields and productivity, enhance resilience and reduce GHG emission (Panchasar*et al.*, 2021).

a. Carbon-smart practices, which are focused on reducing GHG emission. Examples include
   - Integrated Pest Management (IPM), which is designed to minimize the use of chemicals.
   - Agro Forestry (AF) and Fodder management (FM). They emphasise on sustainable land management and carbon reduction.
   - Concentrate Feeding (CF) for Livestock, which aims to reduce nutrient losses, hence reduces the food requirement for livestock.

b. Retention of organic matters by reducing energy consumption during land preparation

c. Weather-smart practices: these CSA practices utilize technology to make the farmers aware about weather conditions. Besides, they offer income security related services.

- Weather based Crop Agro(CA) advisory, where technology is used to do weather forecasting, gather relevant information on climate condition and advises the farmers accordingly
- Climate Smart Housing (CSH) for livestock uses technologies to help farmers take timely and specific decisions to protect animals from extreme heat or cold stresses
- Crop Insurance (CI) offers crop-specific insurance to farmers in order to compensate the losses due harms caused by weather variation or natural disasters.

d. Nutrient-smart practices, which are focused on improving efficient use of nutrients, include:

• Site Specific Integrated Nutrient Management (SINM), which optimizes the supply of soil nutrients according to space, season and type of crops.

- Nano-fertilizers provide the nutrients in available form to plants, thus increasing nutrient uptake and boost the production with appropriate deliver of nutrients which are cost effective and sustainable sources of nutrients thus migitaiting the environmental pollution (Devi *et al.,* 2023b).

• Leaf Color Charts (LCC), which are used to detect nitrogen deficiency in crops, such as wheat and maize, by quantifying the required amount of nitrogen based on the greenness of crops. They are also used for split dose applications in rice fields

• Green Manuring (GM) and Intercropping with Legumes (ICL). Both of these practices are used to improve quality of soil and nitrogen supply. The first one uses cultivation of legumes in cropping systems, while the former one uses the same with other main crops in alternative rows of the field

e. Knowledge-smart practices, which improves productivity and helps in reducing environmental footprints by using local knowledge and technology, include:

• Improved Crop Varieties (ICV) provide knowledge about varieties of crops which are more tolerant to weather variation such as floods, drought, cold/heat stresses etc.

• Contingent Crop Planning (CC) provides risk management plan to be prepared for different weather conditions such as flood, drought and cold/heat stresses

• Seed and Fodder Banks (SFB) are another part of the risk management plan, which provides information on the conservation mechanism of seeds and fodders.

5. Water management

About 18% of the world’s croplands now receive supplementary water through irrigation (Millennium Ecosystem Assessment 2005). Expanding this area or using more effective irrigation measures can enhance C storage in soils through enhanced yields and residue returns (Lal 2004). But some of these gains may be offset by CO_2 from energy used to deliver the water or from N_2O emissions from higher moisture and fertilizer N inputs, though the latter effect has not been widely measured. Drainage of agricultural lands in humid regions can promote productivity (and hence soil C) and perhaps also suppress N2O emissions by improving aeration. Any nitrogen lost through drainage, however, may be susceptible to loss as N2O.

6. Rice management

Cultivated wetland rice soils emit significant quantities of methane. Emissions during the growing season can be reduced by many. For example, draining the wetland rice once or several times during the growing season effectively reduces CH_4 emissions (Smith and Conen 2004), although this benefit may be partly offset by higher N_2O emissions, and the practice may be constrained by water supply. Rice cultivars with low exudation rates could offer an important methane mitigation option. In the off-rice season, methane emissions can be reduced by improved water management, especially by keeping the soil as dry as possible and avoiding waterlogging. Methane emissions can also be reduced by adjusting the timing of organic residue additions (e.g. incorporating organic materials in the dry period rather than in flooded periods composting the residues before incorporation or producing biogas for use as fuel for energy production.

7. Grazing land management and pasture improvement

Grazing lands occupy much larger areas than croplands but are usually managed less intensively. The following list provides some examples of practices to reduce GHG emissions and enhance removals. The effects are inconsistent, however, owing to the many types of grazing practices employed and the diversity of plant species, soils and climates involved. The influence of grazing intensity on emission of non-CO_2 gases is not well established, apart from the indirect effects from adjustments in livestock numbers.

8. Management of organic soils

Organic soils contain high densities of C, accumulated over many centuries, because decomposition is suppressed by absence of oxygen under flooded conditions. To be used for agriculture, these soils are drained, which aerates the soil, favouring decomposition and therefore high fluxes of CO_2 and N_2O. Methane emissions are usually suppressed after draining, but this effect is far outweighed by pronounced increases in N_2O and CO_2(Kasimir-Klemedtsson*et al.* 1997). Emissions on drained organic soils can be reduced to some extent by practices such as avoiding row crops and tubers, avoiding deep ploughing and maintaining a more shallow water table, but the most important mitigation practice, probably, is avoiding the drainage of these soils in the first place, or re-establishing a high water table where GHG emissions are still high. Also organic soils contain more number of microbes than tilled soil. Soil microbes play a pivotal role in different soil processes as they are the major components in nutrient cycling by promoting the decomposition of complex organic materials to simpler ones and also take part in soil carbon sequestration. Soil can be supplemented with microbial inoculums like Panchagavya, Beejamruth, Jeevamruth and Kunapajala to hasten the soil micro flora propagation and as soil enrichment where plant can sequestered the carbon effectively. Hence organic or natural farming is considered to be agroecology based diversified farming system, that drastically cut down chemical fertilisers with locally made products like Panchagavya, Beejamruth,Jeevamruth and Kunapajala, *etc.* which are more sustainable (Devi *et al.*, 2023a).

9. Bioenergy

Increasingly, agricultural crops and residues are seen as sources of feedstocks for energy to displace fossil fuels. A wide range of materials have been proposed for use, including grain, crop residue, cellulosic crops (e.g. switchgrass, sugarcane) and various tree species. These products can be burned directly, but often are processed further to generate liquid fuels such as ethanol or diesel fuel (Richter 2004). These fuels release CO_2 when burned, but this CO_2 is of recent atmospheric origin (via photosynthesis) and displaces CO_2 which otherwise would have come from fossil C. The net benefit to atmospheric CO_2, however, depends on energy used in growing and processing the bioenergy feedstock. The interactions of an expanding bioenergy sector with other land uses, and impacts on agro-ecosystem services such as food production, biodiversity, soil and nature conservation, and carbon sequestration have not yet been adequately studied, but bottom up approaches and integrated assessment modelling offer opportunities to improve understanding.

10. Tillage and residue management

West and Post (2002) found that a change from conventional tillage to no-tillage (NT) sequestered 0.57 0.14 Mg C/ha/yr. If sampled below 30 cm, the evidence for soil C sequestration under conservation tillage could be challenged, because of greater variability in detecting differences. Tillage redistributes and mixes plant material and SOC throughout the profile. Tillage or the lack there-of had a larger impact on the placement of C rather than the amount of total C in the profile when sampled below 30 cm. At least in the short term, tillage induces CO_2 emission proportional to the volume of soil disturbed. The impact of NT management on C sequestration and GWP was significant at the end of 20 years, but not earlier (Six *et al.*, 2004). Collectively, these results suggest that C sequestration due to NT or conservation/reduced tillage depends on depth of soil sampling, crop management, and duration of continuous low-intensity tillage system. There are many benefits in reducing tillage beyond C sequestration.

Conclusions

Agriculture based land-usage is arguably one of the contributing factors towardsGHG emissions globally. Reviewing efficient ways to reduce GHG emissions via the application of smartfarming technology and other farming techniques have been part of the study as well.The article also captures any possible sources within smart farming that may contributetowards carbon emissions and suggest ways to reduce the resulting GHG emissions. Asan example of low GHG emission practices, we have elaborately discussed soybean nitrogen fixation by bacteria and how it helps in reducing GHG emissions. This article will help the farmersand other stakeholders to take an environmentally friendly agricultural decision towardsthe aim of building a more ecological farming approach with futuresustainability

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