# A review on mitigation of greenhouse gases by agronomic practices towards sustainable agriculture

**Abstract:** Agriculture is one among the sources of greenhouse gas emission in the World. Agriculture, being a prominent source of economic sectors in developing countries its impact on environmental climate changes both directly and indirectly through emission of greenhouse gases. To achieve reduced GHGs emissions in agriculture sector, there is a need to adopt climate smart activities and improved food and nutritional security to ensure a climate-smart sustainable agriculture. This short article explores the key ways to mitigate green house gases emissions in agriculture and critically highlights the potential for bacterial nitrogen fixation in soybean which is a recent approach. Symbiotic nitrogen fixation shows a great potential for GHGs mitigation while supporting the agriculture simultaneously. Other agronomic practices include tillage, residue management, rice field management, climate smart agriculture, organic farming and bio energy etc. This will help the farmers and other stakeholders to bring an environmentally friendly agriculture towards more ecological farming approach for future sustainability.

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

## Introduction

“Globally, air pollution has been a major concern towards climate change for the past few decades. Researchers have gained a lot of attention in this issue to help the people for getting a sustainable environment. The world is facing the main curse of elevated green house gases (GHGs) emission in atmosphere by anthropogenic activities such as change in land use pattern, deforestation, industrialization, transportation and cultivation of crops anaerobically leads to global climate shift which is a critical environmental challenges that we are facing today. The concentration of atmospheric $CO_2$ is presently 420 ppm on earth” (NASA, 2023). It is a potent Global Warming Gas (GWG) and increased by 43% approximately since the arrival of industrial revolution and is further expected to increase to 60% in 2100 if the current fashion continues. Another potent GWG is $N_2O$ through which its primary emission takes place by soil bacteria through a process called nitrification under both aerobic and anoxic environment. $N_2O$ has a 298 fold global warming potential than $CO_2$ and also contributes to overall global warming effect approximately 19 %. Globally, it has been estimated that naturally vegetated soils generate 6.6 Tg of $N_2O$ per year and that the oceans provide around 3.8 Tg of $N_2O$ per year to the atmosphere (Laishram *et al.*, 2023 crossref).

Currently, the world is focussing predominantly on direct emissions through agriculture, it is also important to look at indirect ways of carbon emissions that arise from agriculture as well. Indirect emissions such as uses of farm machineries, fertilizer production units and pesticides, etc. The GHGs emissions from agriculture sector is 10–12% (5.1–6.1 Pg), land use 6–17% (5.9 ± 2.9 Pg), agriculture related chemical production/distribution 0.6–1.4% (0.3–0.7 Pg) and other farm operations including irrigation 0.2–1.8% (0.1–0.9 Pg) of total global emissions. Hence, agriculture alone is known to contribute between 16.8% to 32.2% including those land use and direct and indirect emissions. Therefore, it has been a growing interest for climate smart farming with an awareness to the farmers and researchers about agriculture sector impacting the global climate negatively.

"Mitigation strategy such as use of autotrophic microbiota and some microorganisms viz; algae, chemoautotrophic, cyanobacteria and chemolithoautotrophic bacterias having $CO_2$ fixing mechanisms 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 ($N_2$) present in atmosphere abundant, it's a strong covalent triple bonded compound and relatively non reactive molecule in atmosphere. The process called nitrogen fixation converts atmospheric $N_2$ into ammonium ion or other related nitrogenous compounds such as reactive nitrogen, has a critical role in biosphere" (Kuypers *et al*, 2018 ). Being a nutrient element for plants it is also a important limiting factor for normal growth and metabolism in plants. The process called Haber-Bosch which a chemical nitrogen production permitted the huge production of fertilizers at large industrial-scale that supported global need, but simultaneously releases reactive nitrogen to environment.

"However, the release of this reactive nitrogen in atmosphere, soil and water has been generated critical environmental issues recently" (Shibata *et al.*, 2015). The anthropogenic source of emission of nitrous oxide ($N_2O$) is increasing from agricultural lands. $N_2O$ is one of the potent greenhouse gas and is also known to deplete ozone-layer in stratosphere. The recent growth of $N_2O$ emissions exceeds highest projected emission scenarios (Tian *et al.* 2020). Hence, nitrifying bacteria possess a significant advantages to mitigate GHGs emission which is environmental friendly need of the hour.

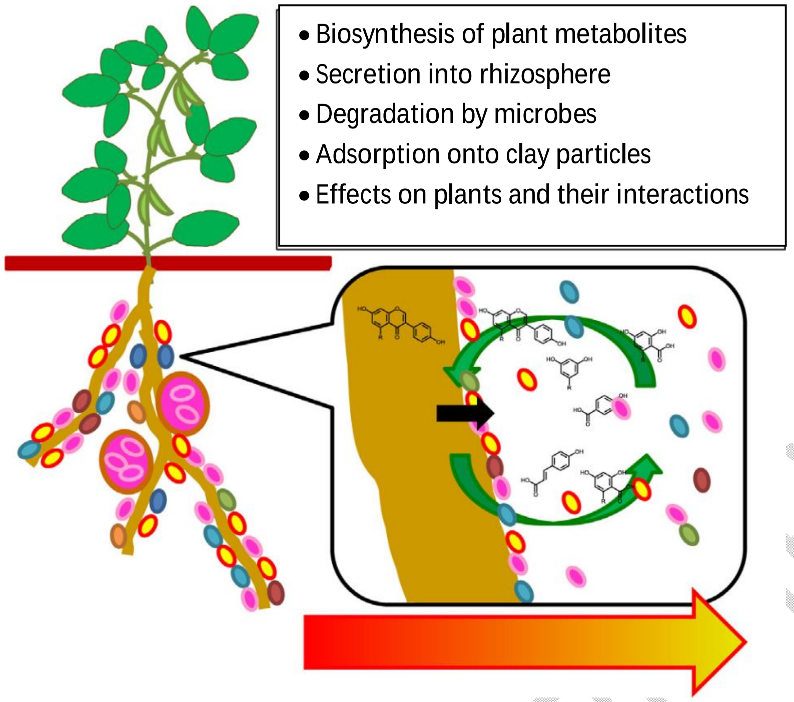
## Emissions from Agriculture

"As of 2015, Paris Agreement has aimed to limit the elevation of global average temperature below 2°C above the pre-industrial levels by 2100. To achieve this aim, equilibrium is needed between anthropogenic GHG emissions and its removals in the 2nd half of this century" (Jantke *et al.,* 2020). "The Agreement hardly mentioned that the agriculture sector contributes around 10–14% global GHG emissions" (Tubiello *et al.,* 2013). "The primary GHG emissions (a) methane from enteric fermentation, (b) carbon dioxide from decomposition of soil organic carbon, and (c) nitrous oxide from manure and synthetic fertilizer. After decades of human neglectance, the international scientific community has been gradually starting to aware about this sector for achievement of the global goal. The potentiality of GHGs from agriculture sector is lesser in developed countries which are around 10% of national GHG inventories" (Suzuki *et al.,* 2018). "However, countries like India, agriculture plays a vital role in national GHG emission. Hence, a critical focus on GHG reduction is on high priority" (Jackson *et al.,* 2018).

## Different agronomic practices to mitigate GHGs

### 1. Soybean nitrogen fixation

Soybean (*Glycine max*), a major oilseed crop with 300 million tonnes production globally contains many proteins and lipids in seeds and various secondary metabolites such as isoflavones and saponins as functional ingredients. The crop establishes well symbiotic relationships with soil rhizobia and arbuscular mycorrhizal fungi (AMF) which requires less fertilizer at early stages for initial start. For this symbiotic association, soil rhizospheric microbes are essential. The term rhizosphere coined by Lorenz Hiltner (1904) is the region that close to plant's roots surface where various interactions occur between them plants roots and soil microbiota. Roots exert some physical and chemical influences such heat generation, secretion of plant derived metabolites. Roots secrete metabolites actively with the utilization of energy from ATP and diffusion passively (Figure 1) (Sugiyama, 2019). At the most initial stage of interactions, rhizobia infect first on roots, elicit root nodules and forms a symbiont thereafter then fixes atmospheric $N_2$ symbiotically.



Effects of plants into rhizospheric zone

**Figure 1: Secretion and fate of metabolites in the rhizosphere**

(Source: Sugiyama, 2019)

“Rhizobia provides fixed nitrogen to the host plant while host plant supplies photosynthetically fixed carbon to the bacteria. The soybean rhizosphere is a site of active nitrogen transformations, including the production and consumption of $N_2O$” (Sánchez and Minamisawa, 2019). “Nodule decomposition also emit $N_2O$ in soybean rhizosphere. A $N^{15}$ tracer revealed that $N_2O$ emitted from soybean rhizosphere was almost derived from $N_2$ that had been symbiotically fixed in the nodules” (Inaba *et al.*, 2012 ). “During nodule decomposition, organic nitrogen inside nodules is mineralized to $NH_4^+$ followed by the nitrification and denitrification processes to yield $N_2O$. *Bradyrhizobium diazoefficiens* and other soil microbes generate $N_2O$ during nodule degradation. Howevere, bacteria strains *nosZ* + strains of *B. diazoefficiens* are exclusively able to take up $N_2O$ via $N_2O$ reductase” (Figure 2) ( Inaba *et al.* 2012 ).

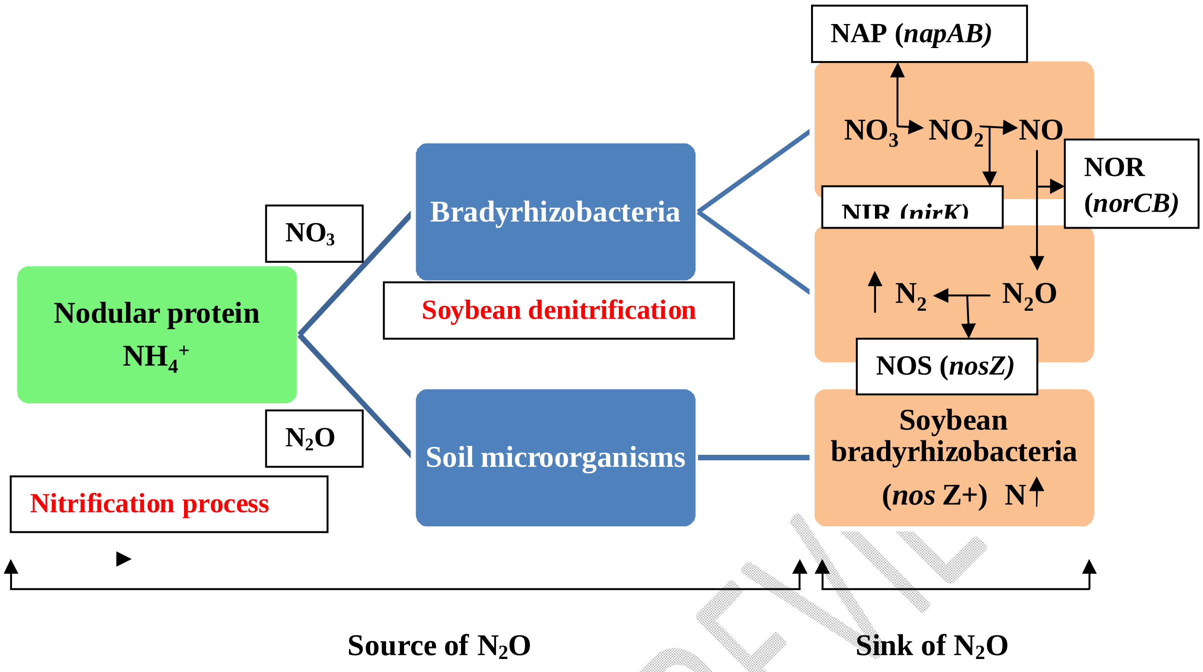


**Figure 2: Schematic representation of $N_2O$ metabolism in the soybean rhizosphere**

"The above figure 2 shows that measurement of $N_2O$ flux from decomposed nodules formed from strain of *Bradyrhizobium diazoefficiens* , *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). In contrast, *B. diazoefficiens* strains carried *nosZ* ( *nosZ* +) exclusively to uptake $N_2O$ which acts as an $N_2O$ sink" (Inaba *et al.* 2012 ). Then the net $N_2O$ flux is determined by the balance between $N_2O$ sources and sinks. Thus, the inoculation of soybeans with strains from denitrifying group (*B. diazoefficiens*) has great potential to reduce $N_2O$ emission in rhizosphere. Almost all ecosystem processes depends on soil microbes, therefore microbial activity and their abundance determine the sustainable productivity of agricultural lands, deterioration of resources, ecosystem resisting to nutrient mining and GHG emissions. Methanotrophs or methaneoxidizing bacteria (MOB), present in aerobic soils are also potential biological sink to mitigate $CH_4$ emission to the atmosphere (Laishram *et al.*, 2023). Thus, the usage of industrial nitrogenous fertilizers can be lowered by biological reduction symbiotic $N_2$ fixation process which is crucial for sustainable agriculture today.

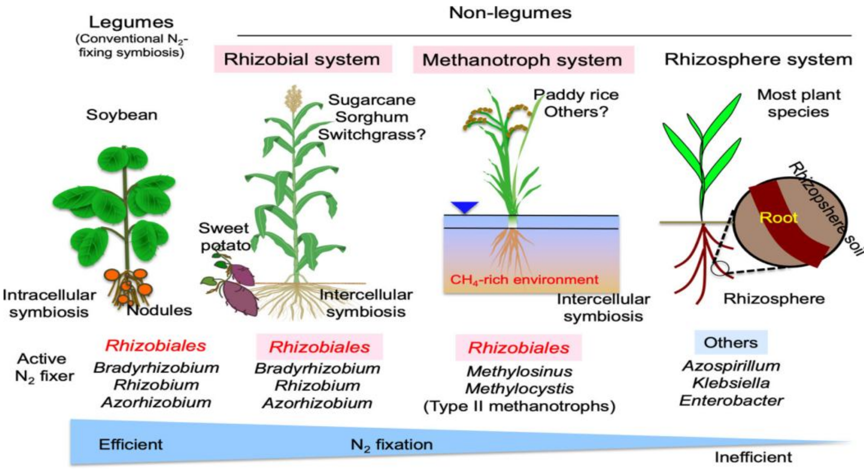


**Figure 3**. Hypothetical categories of N2-fixing bacteria associated with plants. Pink-colored "Rhizobia system" and "Methanotroph system" are new categories of $N_2$- fixing symbiosis with non-legumes, which are different from classical "Rhizosphere system."

(Source: Minamisawa, 2023)

## 2. Biochar

"Biochar application in different forms is followed by farmers since agriculture evolution. In traditional farming practices like jhum and shifting cultivation which are predominant in NE hilly regions of India, clear agricultural lands after crop cultivation which results in addition of biochar in the soil unconsciously. The algal biochar addition  in soil increase the retention time of manyl limiting nutrients which enhances soil fertility and crop production economical" (Purakayastha *et al.*, 2019). In all agricultural activities, rice soil is the main culprit of $CH_4$ emission to atmosphere and its mitigation can play a significant role in reducing the global warming and current climate change. Feng *et al.*, (2012) studied "the effects of $CH_4$ emission on biochar application to rice soil in field experiment and observed that a significant reduction in total $CH_4$ emission. It reason being the reduction was due to the biochar doesn't inhibit the microbial activity of methanogens ($CH_4$ production bacteria) but significantly increased the abundance of methanotrophs ($CH_4$ oxidizing bacteria) in rice soil which resulted in total $CH_4$ mitigation". Wu *et al.* (2019) also investigated "the effect of 6 years old aged and fresh biochar on $CH_4$ oxidation in soil and observed that ammonium and nitrate content in soil enhanced the $CH_4$ oxidation by promoting the population of methanotrophs and methanotrophs under biochar amendments applied. The biochar is produced at higher pyrolysis temperature have potential of more $CH_4$ inhibition as compared to lower pyrolysis temperature". "Biochar application enhance the secure storage of carbon i.e. carbon sequestration and thus lower in emissions of $CH_4$ to atmosphere. The contradictory studies have reported by application of biochar stimulates $CH_4$ emissions from rice" (Shaukat *et al.,* 2019). "Application of biochar with lager surface area enhances iron reducting bacterial populations in soil which results in lower production of $CH_4$ as these microbes compete with methanogenic bacteria" (Wang *et al.,* 2017). "$CH_4$ emission dynamics under biochar made from feedstocks such as wheat straw, rice, corn, wood has been documented" (Wang *et al.*, 2017; Shaukat *et al.*, 2019).

## 3. Smart farming and climate smart agriculture

"The recent smart farming based precision agriculture aimed to improve overall productivity by increasing crop profitability and yield while reducing the environmental footprint such as GHGs emission by utilizing different agro-techniques such as efficient irrigation (Islam *et al.*, 2020), precise and targeted use of chemical pesticides and fertilizers etc". "In addition, Internet of Things (IoT) enables the reduction of inherent environmental impact by performing real time detection of weeds or other pest infestations (Islam *et al.*, 2021) monitoring region wise weather conditions, soil conditions etc., which ultimately reduce and allows adequate use of inputs such as nutrient, water, pesticides or any other agro-chemicals" (Alam *et al.*, 2021). The smart technologies application in agriculture includes:

- **Field Monitoring:** Smart farming helps to reduce spoilage of crop with better provision through monitoring timely, accurate data collection and management of crop land (Prathibha *et al.,* 2017). It promotes the efficient application of nutrients, provide optimum water timely.
- **Livestock Farming:** It helps to monitor the grazing of animal in open pastures or other location in big stables. It also helps in detecting and maintaining air quality within, ventilation in farms and detecting and reducing GHG emission.
- **Green Houses:** Smart farming helps crops, fruits and vegetables by controlling their micro-climate thus maximizing the production as well as quality in protected green house condition.
- **Compost management:** Smart technologies controls in moderating temperature and humidity thus preventing from fungus and/or other microbial contaminants in hay, straw, etc.

## Climate Smart Agriculture

"Climate Smart Agriculture (CSA) is a promising technique in agriculture where integration of traditional farming practices along with recent technology towards agricultural productivity considering climatic constraints by reducing GHGs emissions. Hence, CSA comprises sustainable agricultural practices which contribute to increase crop productivity and gross revenue, adaptation and more resilience to climate change and reduction of GHGs emission as much as possible" (McNunn *et al.,* 2020). "Many farm level studies suggested that adoption of CSA technologies has been proven to improve and increase productivity and quality, net income, efficacy usage of inputs and most importantly reduced GHGs emissions" (Sapkota *et al.,* 2014). "Some widely used CSA practices which help to improve crop productivity, enhance resilience and reduce GHGs emission" (Panchasar *et al.,* 2021) are as follows:

a. Carbon smart practices focused on reducing GHGs emission. Examples include

- Integrated Pest Management designed to minimize the use of chemicals in the farm.
- Agro Forestry and Fodder management emphasises on sustainable land management and carbon reductions.
- Concentrate Feeding for livestock aims to reduce nutrient losses from feed, hence reduces the feed requirement for livestock.

b. Retention of organic matters in the soil by reducing energy consumption at the time of land preparation.

c. Weather-smart practices utilize better technology to aware the farmers about weather and climatic conditions. Besides, they also offer income security.

- Weather based Crop Agro advisory technology is used to forecast weather, gather relevant information on climatic condition and provide the data to farmers accordingly.
- Climate Smart Housing for livestock help the farmers to take timely and specific decisions to protect their animals from various extreme heat or cold stresses.
- Crop Insurance offers the crop specific insurance to farmers to compensate the losses, due harms caused by the weather variations or natural disasters.

d. Nutrient-smart practices focuses on improving the efficient use of nutrients which include:

- Site Specific Integrated Nutrient Management optimizes the nutrient supply of soil according to spatially, season and type of crops grown.
- 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 mitigating the environmental pollution (Devi *et al.,* 2023a).
- Leaf Color Charts (LCC) detects nitrogen deficiency in crops on time such as in wheat and maize by quantifying the required dose of nitrogen based on greenness of crops. They can be also used for split dose fertilizer applications in rice.

- Both Green manuring and intercropping with legumes practices improve quality of soil nitrogen supply. The former is through the inclusion of legumes in cropping sequence, while the later uses the same land with main crops in alternative rows.

e. Knowledge smart practices improve land productivity and help to reduce the environmental footprints by using local knowledge and technologies as follows:

- Improved Crop Varieties (ICV) provide knowledge about varieties of crops regarding tolerant to weather variation such as drought, floods, cold/heat stresses etc.
- Contingent crop planning provides risk management plan/strategies to be prepared in advance for different aberrant weather conditions such as drought, flood and cold/heat stresses.
- Seed and Fodder Banks (SFB) also risk management plan that can provides information on the conservation mechanism of seeds and fodders.

### 4. Water management

About 18% of the world's cropland are now receiving the supplementary water through irrigation (Millennium Ecosystem Assessment 2005). Expanding this irrigated area or using more effective irrigation measures can enhance long term carbon storage in soils by enhancing yield and residue returns (Lal 2004). But some of these may be offset by the $CO_2$ from energy used to deliver the water or from $N_2O$ emissions from higher moisture and fertilizer nitrogen inputs, though the latter effect has not been widely measured. Drainage of agricultural lands in humid regions can promote productivity and hence more soil carbon capture and also suppress $N_2O$ emissions by improving the aeration.

### 5. Rice cultivation management

Cultivating rice in wetland condition emit significant quantities of methane. During the growing season, emissions can be reduced by many ways. For example, drainage in wetland rice once or several times during growing season effectively reduced $CH_4$ emissions (Smith and Conen 2004), though this advantage may be offset partly by higher $N_2O$ emissions and the this practice may be constrained by more water supply. Rice cultivars having low exudation rates could provide an important $CH_4$ mitigating option. During the off season, $CH_4$ emissions can be reduced by improving water management especially by keeping the soil as dry as possible and avoiding waterlogging. It can also be done by adjusting the timing of application of organic residue (incorporation of organic matter during dry period rather than in wet flooded periods that can help in composting the residues well before incorporation or producing biogas for use as fuel for energy production.

### 6. Grazing management and pasture improvement

Grazing lands occupied a larger areas than the crop-lands but usually managed less intensively. These effects are inconsistent however owing to types of grazing practices employed in the field and diversity of plants, soils and climates involved. However, the influence of grazing intensity on emission of non GHGs is not well understood, apart from those indirect effects from livestock numbers.

### 7. Management of organic soils

"Organic soil contains high densities of carbon which accumulated over centuries since decomposition is suppressed by absence of oxygen under flooded conditions. For agriculture management soils are drained that aerates the soil provide favourable conditions for decomposition and therefore high fluxes of $CO_2$ and $N_2O$. Methane emissions are suppressed after draining however this effect is outweighed by more pronounced increases in $N_2O$ and $CO_2$" (Kasimir-Klemedtsson *et al.,* 1997). Emissions can be reduced to some extent by avoiding row crops and tubers thus avoids deep ploughing and maintains more shallow water table but one of the most important mitigation practice is probably avoiding the drainage of these soils at first place or re establishing a high water table where GHGs emissions are high. Also organic soils contain more number of microbes than tilled soil. Soil microbes can play a pivotal role in the different soil processes as they involved in components in nutrient cycling by promoting the decomposition of complex organic to simpler ones and take part in soil carbon sequestration. Soil can be supplemented with various microbial inoculums like Beejamruth, Panchagavya, Jeevamruth and Kunapajala depends on choice to hasten the soil micro flora and soil enrichment where the plant can sequestered the atmospheric carbon effectively. Hence organic or natural farming is considered to be agro-ecology based diversified farming system that drastically cut down chemical fertilisers with locally made products like Panchagavya, Jeevamruth Beejamruth, and Kunapajala, *etc.* which are more sustainable (Devi *et al.,* 2023b).

### 8. Bioenergy

"Agricultural crops and their residues are adopted as sources of feed stocks for energy to displace fossil fuels nowadays. A wide range of materials have been proposed for this purpose such as grains, crop residue, cellulosic crops (switchgrass, sugarcane) and other various tree species. These products can be burned down directly but are often processed further to generate the liquid fuels such as ethanol or diesel" (Richter 2004). These fuels again release $CO_2$ when burned down, but this is of recent atmospheric origin via photosynthesis and displaced $CO_2$ which otherwise would have come from fossil carbon. However, the net benefit to atmospheric $CO_2$ depends on energy used in the growing and processing of bioenergy feedstocks. The interactions of expanding bio-energy sector with other land uses and impacts on agroecosystem services such as food production, soil and nature conservation, biodiversity and carbon sequestration have not yet been adequately studied, but bottom up approaches and integrated assessment modelling offer opportunities to improve understanding.

## 9. Tillage and residue management

"West and Post (2002) found a changed from conventional tillage to no tillage (NT) sequestered 0.57-0.14 MgC/ha/yr. If the soil is sampled below 30 cm the evidence for soil carbon sequestration under the conservation tillage could be a challenged because of greater variability in detecting the differences. Tillage operations re-distribute and mixed the plant material and soil organic carbon throughout the soil profile. Tillage had a larger impact on the placement of carbon rather than the amount of total carbon in the soil when sampled below 30 cm. In the short term, tillage induces $CO_2$ emission which is proportional to the volume of soil disturbed. The impact of NT management on carbon sequestration and GWP was significant at the end of 20 years, but not in earlier" (Six *et al.*, 2004). Collectively, these results suggest that carbon sequestration due to NT or conservation/reduced tillage depends on depth of soil sampling, duration of low-intensity tillage system and crop management.

## Conclusions

Agriculture based land usage is arguably one of the major contributing factors towards GHGs emissions globally. Reviewing the various efficient ways to reduce GHGs emissions via the application of smart farming and other agro techniques have been useful part. This article also captures any possible sources of smart farming that may contribute towards carbon emissions and suggest strategic ways to reduce it. As an example of low GHGs emission practices, we have elaborately discussed soybean nitrogen fixation by bacteria and how it helps in reducing GHG emissions. This article will help the farmers and other stakeholders to adopt an environmentally friendly agricultural decision towards the aim of building a more ecological farming approach with future sustainability.

## Future approaches

For marginal and sub marginal dominated farmers like in India, the most efficient way to improve the sustainability is through improvement in their knowledge and skills and also their access to the necessary equipment to finance. Hence, there is a particular need for setting up a community based programmes that can provide a wide range of services to overcome the current barriers that are facing today by most of the farmers. This may include proper education within the climate friendly farming, micro credits for financial investments in new techniques, agricultural extension services, management of wood lands or grazing lands to avoid over degradation and establishing good market access for public products that may also be certified by agency. Such approaches should also be supported through the agricultural policy or targeted by NGOs.

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