Upscaling Potential Sustainable Agricultural Practices as Carbon Sequestration and GHG Emission Reduction Options

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Abstract

According to the World Resources Institute Climate Analysis Indicators Tool (WRI CAIT), India's total Green House Gas (GHG) emissions in 2014 were 3,202 million metric tons of carbon dioxide equivalent (MtCO2e), totalling 6.55 per cent of global GHG emissions. India is the world's fourth-biggest emitter of carbon dioxide after China, the US and the EU. In India, about 68.7 per cent of GHG emissions come from the energy sector, followed by agriculture (19.6%), industrial processes (6%), land-use change and forestry (3.8%), and waste (1.9%). The global technical GHG mitigation potential from agriculture is estimated to be 5.5-6.0 Gt CO2-eq/year, by 2030. This can be achieved by the adoption of the best available management practices related to sustainable land use, good agronomic practices, soil and water management practices, agroforestry, etc. In the COP26 summit held at Glasgow, 2021, India has pledged to adopt a net-zero emissions target by 2070. In this context, academia and research organizations are undertaking research on carbon sequestration and GHG emission mitigation. The results indicate that there are huge opportunities for investment through carbon financing in agriculture to upscale the good practices to reduce the atmospheric greenhouse gas emission through carbon sequestration. This review paper elucidates the important Climate smart Agricultural (CSA) technologies and practices that help in the sequestration of carbon and reducing the emission of GHGs.

Keywords: Carbon Sequestration, GHG emission reduction, CSA technologies, climate change

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Introduction

Agriculture, especially in developing countries, is one of the major contributors to Greenhouse Gases (GHGs). The sector is emitting about 13 per cent of the total global anthropogenic GHG emissions (Wang et al., 2017). India is the world's fourth-biggest emitter of carbon dioxide after China, the US and the EU (The Economic Times, 2021). According to the World Resources Institute Climate Analysis Indicators Tool (WRI CAIT), in 2014, India's total GHG emissions were 3,202 million metric tons of carbon dioxide equivalent (MtCO2e), which was 6.55 per cent of global GHG emissions. In India, about 68.7 per cent of GHG emissions come from the energy sector, followed by agriculture (19.6%), industrial processes (6%), land-use change and forestry (3.8%), and waste (1.9%).

In agriculture, the majority of GHG emissions are generated from the production and use of agricultural inputs such as water, fertilizers and pesticides, farm machinery, soil disturbance, residue management and irrigation (Prasad et al, 2021). GHG emission in India has increased by 161 per cent over 50 years from 14.81 TgCE/year (0.12 tCE ha-1yr-1) in 1960 to 38.71 TgCE/year (0.28 tCE ha-1yr-1)by 2010. Further, in India, the total emissions from major crops, i.e. rice, wheat, maize, cotton and sugarcane (these crops constituted 80% of total crop emission) and livestock, i.e. cattle, buffalo, pig, sheep and goat (constituted 99% of total livestock-related emission) CO2e were 451 Megatonnes (Mt) in 2012. Under the Business As Usual (BAU) scenario with no mitigation, projected GHG emissions from these crops and livestock species would be 489 MtCO2e in 2030, while emissions under the mitigation scenario would be 410 MtCO2e, offering a technical mitigation potential of about 78.67 MtCO2e per year. About 18 per cent of the total emissions from agriculture could be abated by adopting technically feasible mitigation measures (Sapkota et al, 2019). In addition, the intensive cultivation without caring for the sustainability of the system has resulted in the common problem of reduced Soil Organic Content (SOC) stock. The SOC has depleted considerably in the top 20 cm of the Indian soil horizon due to intensive farming practices and unsustainable agricultural approaches (Meena et al, 2020). The SOC of soils in the Indian agroecosystem has depleted severely, ranging from often <1 g kg^{-1} or barely 10 to 15 Mg C ha^{-1} to 40 cm depth (Lal, 2015).

To minimise the GHG emissions, India ratified the Paris Agreement a year after the submission of its Intended National Determined Contribution (INDC). Its NDCs for the period 2021 to 2030 are to reduce the emissions intensity of GDP by 33-35 per cent by 2030 below 2005 levels, to create an additional (cumulative) carbon sink of 2.5-3 billion tonnes of carbon dioxide (CO2) equivalent through additional forest and tree cover by 2030. In the Conference of Parties (COP26) summit held at Glasgow, Scotland in 2021, India has also pledged to adopt a net-zero emissions target by 2070. Further, to achieve net-zero emission by 2070, the country has made five major commitments, such as instalment of non-fossil energy capacity to 500 GW by 2030, ensure economy's carbon intensity down to 45 per cent by 2030, ensure 50 per cent of its energy requirement through renewable energy by 2030 and reduce 1 billion tonnes of carbon emissions from the total projected emissions by 2030 (India Today, 2021 and The Print, 2021).

To better adapt to climate change, there is a need for investment in sectors vulnerable to climate change, particularly agriculture, water resources, the Himalayan region, coastal regions, health and disaster management (Sah and Devakumar, 2018).

The global technical GHG mitigation potential from agriculture by 2030 is estimated to be 5.5-6.0 Gt CO2-eq/year. This can be achieved by the adoption of the best available management practices related to land use and soil. Sustainable land and water management practices provide opportunities for carbon sequestration. This can be done through adopting good agronomic practices, nutrient and water management, land use practices etc.

To make agriculture carbon smart, the adoption of climate-smart agricultural/livestock technologies and good practices is essential. It will also help to (1) sustainably increase agricultural productivity and incomes to meet national food security and development goals, (2) build resilience and the capacity of agricultural and food systems to adapt to climate change, and (3) create opportunities to mitigate emissions of Greenhouse Gases (GHGs) and increase carbon sequestration. These three conditions (food security, adaptation, and mitigation) are referred to as the "triple win" of overall Climate Resilient Agriculture (CRA) (Rao et al, 2016). The "technical potential" of agricultural soil to absorb carbon ranges from 3 to 8 gigatons (billion metric tons) of CO2 equivalent a year for 20 to 30 years, enough to close the gap between what is achievable with emissions reductions and what is necessary to stabilize the climate (Das and Avasthe, 2015). Research studies indicate that agriculture provides ample opportunities for sequestration of carbon and minimising the emissions of GHGs.

The review was carried out with the following objectives.

- To identify the good agricultural technologies and practices that help in the sequestration of carbon and reducing the emission of GHGs.
- To assess the potential of these technologies and practices in terms of carbon sequestration and GHG emission reduction potential.
- To suggest the way forward for upscaling of potential carbon sequestration and GHGs emission reduction technologies and practices in agriculture.

Materials and Methods

Data Collection Method

The data and information relating to Climate Smart Agricultural Technologies and practices that played a major role in Carbon Sequestration and reducing GHG emissions were collected through a literature review. A total of 30 published materials including research papers, reports and online news articles were reviewed.

Geographical context

The research papers reviewed on carbon sequestration and GHG emission reduction were restricted to India as the major objective of this review paper is to assess the CSA technologies and practices that played a major role in carbon sequestration and GHG emission reduction in agriculture in India.

The following theme areas were used for literature review such as Zero tillage, Crop Residue Burning, Carbon Farming, Soil Health Management, Bio Char, Integrated Farming System, Organic Amendment, Organic Agriculture, Crop Production, Climate Resilient Village and COP26.

Results and Discussion

The present review has identified a total of 13 most important agricultural innovations, technologies and practices to reduce GHG emissions and enhance carbon sequestration in India.

1. Precision Nutrient Management Technologies (PNMTs)

It is found that agriculture in India consumes high N. Adoption of precision nutrient management technologies by farmers has the potential mitigation of 17.5 MtCO2e per year and cost-saving of Rs. 6500 per tCO2e. However, the results vary from state to state, for example, Uttar Pradesh has GHC mitigation of 3.15 MtCO2e per year by adopting PNMTs, followed by Andhra Pradesh (2.04 MtCO2e), Maharashtra (1.72 MtCO2e) and Punjab (1.5 MtCO2e). States such as Gujarat, Karnataka, Madhya Pradesh, Haryana, Bihar, Rajasthan, West Bengal and Tamil Nadu have GHC mitigation between 0.7 and 1 MtCO2e per year, and it is less than 0.5 MtCO2e per year in other states (Sapkota et al. 2019).

2. Use of legumes for long term

As there is low organic content in the Indian soil, the possibility of on-farm generation of legume biomass (horse gram; Macrotyloma uniflorum (Lam.) by using off-season rainfall and incorporating them in the soil was examined in two field experiments involving sorghum and sunflower from 1994 to 2003. The effects of this incorporation were assessed on crop yields and soil properties for 10 years, together with fertilizer application. Horsegram biomass ranging from 3.03-4.28 t ha-1 year-1 (fresh weight) was produced and incorporated in situ under different levels of fertilizer application. With biomass incorporation, mean organic carbon content improved by 24 per cent over fallow. Microbial biomass carbon improved by 28 per cent. Long-term biomass incorporation and fertilizer application resulted in the build-up of soil nutrients compared with the fallow plots (Venkateswarlu et al. 2007). The above practices would reduce the external application of inorganic fertiliser and thereby mitigate the GHG emission.

3. Zero tillage (ZT)

Zero tillage has both climate change mitigation and economic benefits. Adoption of zero tillage in rice, wheat, maize, cotton and sugarcane would provide abatement of about 15

MtCO2e per year in India and also save Rs.4200 per tonne of CO2e abated (Sapkota et al. 2019). In Haryana, ZT based wheat production reduces GHG emission by 1.5 Mg CO2-eq ha-1 season-1. Farmers can save approximately USD 79 ha-1 (20%) in terms of total production costs and increase net revenue by about USD 97.5 ha-1 (28%) under ZT compared to Conventional Tillage (CT). ZT based wheat production has the mitigation benefits of 1.5 Mg ha-1 season-1 as this reduces CO2 emission. This means adopting ZT to about 1 million ha under wheat production in Haryana will reduce GHG emission of about 1.5 million tonnes of CO2 equivalent in a season and it would save about USD 79 million per wheat season through a reduction in the cost of production. This will bring approximately USD 97.5 million additional net revenue to wheat farmers in Haryana (Aryal et al, 2015). Considering the research results, if the Zero Tillage is scaled to all the wheat-producing areas (i.e. around 29 million ha), it has the potential to reduce 43.5 million tonnes of CO2 equivalent in one season.

Further, with the conversion of rice-wheat systems of India to no-tillage, the C sequestration potential is estimated to be 44.1 Mt C over 20 years. Similarly, adopting no-tillage practices in maize-wheat and cotton-wheat production systems would yield an additional 6.6 Mt C. This offset is equivalent to 9.6 per cent of India's annual greenhouse gas emissions (519 Mt C) from all sectors (excluding land-use change and forestry) (Grace et al, 2012). Zero tillage may further help farmers to save 70 to 90 litres of diesel per ha, thereby helping them save USD 40-50 per ha (Wang et al, 2016).

4. Water management

Improved water management in rice in India offered mitigation of ca. 12 MtCO2e per year with a cost saving of Rs. 770 per tonne of CO2e saved. There is also a regional variation, in the case of water management in rice. The highest mitigation potential was found in Andhra Pradesh (3.81 MtCO2e) followed by Tamil Nadu (1.81 MtCO2e), Orissa (1.54 MtCO2e) and West Bengal (1.23 MtCO2e). In Karnataka, Uttar Pradesh, Assam, Punjab and Bihar, this option would have the potential to save between 0.42 and 0.84 MtCO2e emissions, whilst the remaining states would deliver less than 0.25 MtCO2e savings (Sapkota et al. 2019).

5. Micro irrigation and Laser levelling

Other water management options such as sprinkler, or micro-sprinkler irrigation and fertigation together, offered a technical mitigation potential of ca. 5.5 Mt CO2e. However, these measures require large capital investment by farmers and cost more than Rs. 27000 per t CO2e abated (Sapkota et al. 2019). Adoption of laser levelling in rice-wheat areas would result in mitigation of ca. 4 MtCO2e per year at a nominal cost of Rs. 1940 per t of CO2e saved without considering additional yield benefits, and Rs. 21947 saving per t CO2e abated when additional yield benefits were considered.

6. Stopping residue burning

Around 500 Mt of crop residue is generated in India every year. Most of the burning takes place in the states of Uttar Pradesh, Punjab and Haryana. About 25 per cent of the crop residue is burned on the farm. Burning of 98.4 Mt of crop residue has resulted in the emission of nearly 8.57 Mt of CO, 141.15 Mt of CO2, 0.037 Mt of SOx, 0.23 Mt of NOx, 0.12 Mt of NH3 and 1.46 Mt NMVOC, 0.65 Mt of NMHC, 1.21 Mt of PM during 2008-2009, of which, CO2 is 91.6 per cent of the total emissions. The remaining 8.43 per cent consists of 66 per cent CO, 2.2 per cent NO, 5 per cent NMHC and 11 per cent NMVOC (Jain et al, 2015). There is an alarming increase in air pollution in Delhi and nearby cities due to crop burning in Uttar Pradesh, Haryana and Punjab state, in addition to the deteriorating soil fertility year on year. Crop residue burning touches many sectors such as the environment, agriculture, economy, social aspects, education and energy. Rice and wheat contribute 70 per cent of the crop residue. The labour shortage and short time availability between two consequent crops lead to the burning of crop residues (Bhuvaneshwari et al, 2019). About 2 Mt CO2e could be abated every year by stopping residue burning at a small cost of Rs. 680 per t CO2 for residue management.

7. Biogas production

Improved manure management through the establishment of large biogas plants has the potential to save 9.3 MtCO2e per year. This option involved large capital investment.

8. Organic farming

Most of the areas in India are under rainfed agriculture (70%) where a limited amount of inorganic fertiliser is used for crop production. Only 0.77 million ha of land is fully under organic farming (Patle et al, 2014). Organic farming uses 20 to 50 per cent less energy than conventional agriculture. Organic farming has great potential to improve soil carbon storage. Niggli et al. (2009) estimated that the global average sequestration potential of organic farming is about 0.9-2.4 Gt CO2 year-1, which is equivalent to an average sequestration potential of about 200 to 400 kg C ha-1 year-1 for all crop-lands. Results of twelve-year long term experiments of ICAR Research Complex for NEH Region, Umiam indicated that long term adoption of organic production practices significantly increases the soil organic carbon and carbon stock and reduces the bulk density as compared to an inorganically managed field. For example, the carbon sequestration of Rice-Carrot was 0.55 Mg ha-1year-1, Rice-Potato 0.61 Mg ha-1year-1, Rice-French bean 0.65 Mg ha-1year-1, Rice-Tomato 0.63 Mg ha-1year-1 (Dutta et al. 2017).

9. Biochar

Application of biochar has also been reported to reduce a considerable amount of methane and nitrous oxide emission from the agricultural field due to its priming effect on the soil. Most of the reported benefits are confined to laboratory and field trials at the institute level; widespread adoption of biochar on farmer's fields is still lacking (Gupta et al, 2020). Biochar production and application to soil have several benefits such as improvement of soil physical properties, improved retention and availability of soil nutrients, improved biological activity and mitigation of emission of GHGs.

The estimated biochar production potential from different crop and woody residues in India is 162 and 32.7 Mt yr-1, respectively and the combined C sequestration potential by incorporation of biochar produced from crop and woody residues into the soil is 95.0 Mt yr-1. ICAR-Central Research Institute for Dryland Agriculture (CRIDA) has developed a biochar kiln with operational procedures and standardization of biochar production protocols from different residues and biochar characterization methods and their properties. On average, the production cost of one kg of biochar from castor and cotton stalk was estimated to be Rs. 14.0 and Rs.13.0, respectively. The results of the field trials of Pigeonpea (PRG 158) showed that the alternate year application of either pigeon pea stalk biochar @ 6 t ha-1 with the recommended dose of fertilizers (50-20-00 kg N, P2O5, K2O ha-1) or cotton stalk biochar @ 3 t ha-1 with the recommended dose of fertilizers produced a higher pigeon pea grain yield of 1484 and 1400 kg ha-1, respectively, compared to control (454 kg ha-1). Moreover, CRIDA has estimated that 7.8 Mt of biochar could be produced annually from castor, cotton and pigeon pea crop residue by using CRIDA biochar kiln. Based on the total carbon percentage in the respective biochar, it is estimated that its application can sequester about 4.6 Mt of total carbon annually in soil, making it a carbon sequestering process (Venkatesh et al. 2018). Further, it is estimated that the mitigation potential of biochar is up to 12 per cent of current anthropogenic CO2 emissions (net emissions of GHGs could be reduced by 1.8 Gt CO2 -C equivalents yr-1) (Woolf et al. 2010).

10. Farmyard manure in rice-wheat cultivation

Continuous cultivation of rice and wheat, without application of organic inputs, significantly depleted total C content (by 39-43%) compared with treatments involving the addition of organic amendments. For example, application of farmyard manure (FYM @ 7.5 t ha-1), paddy straw (PS @ 10 t ha-1) and green manure (GM @ 8 t ha-1) along with inorganic fertilizer resulted in a significant increase in the non-labile C fraction resulting from both organic and inorganic amendments. In addition, an increase in the yield of kharif rice was observed as a result of the addition of these organic amendments. The amount of C sequestered under NPK and FYM was 2.47 Mg per ha after 25 years of cropping pattern of rice-wheat cultivation. Also, in the untreated cropping system, there was a loss of 5.6 C after 25 years. Application of FYM, paddy straw and Green Manure as a supplement with NPK increased organic C and uptake of plant C (Ghosh et al, 2012). In India, about 10 million ha of area is under rice-wheat cultivation i.e. rice is planted with wheat after the rice harvest (Shahane et al. 2020). Hence, there is a huge potential to have maximum carbon sequestration through the application of FYM, Paddy straw and Green Manure along with inorganic amendments in the rice-wheat cropping system of about 10 million ha.

11. Agroforestry

As per the Forest Survey of India (FSI), in 2019, the total forest and tree cover of the country is estimated to be 24.56 per cent (807276 sq km). It has been estimated that the total carbon stock in the forest is 7,124.6 million tonnes, with an increase of 42.6 million tonnes compared to the 2017 assessment. The annual increase is estimated to be 21.3 million tonnes, which is 78.1 million tonnes CO2 eq. Soil Organic Content (SOC) represents the largest pool of carbon stock in forests with 4004 million tonnes (56%) of the total forest carbon stock of the country (GoI, 2019). Forestry has been recognized as a means to reduce CO2 emissions as well as enhance carbon sinks. The total carbon sequestration potential of global croplands is about 0.75-1.0 Pg/yr or about 50 per cent of the 1.6-1.8 Pg/yr lost due to deforestation and other agricultural activities (GOI, 2019).

Practices that reclaim the productivity of degraded lands such as plantations with multipurpose tree species and bioenergy crops can enhance soil carbon sequestration and substitute fossil fuels to some extent. The technical mitigation potential of restoring degraded land in India would be ca. 7 MtCO2e per year. (Sapkota et al,2019). However, it needs additional costs and incentives for the farmers to adopt tree-based agriculture. In India, the carbon sequestration potential of the agroforestry system is estimated between 0.25 - 19.14 and 0.01 to 0.60 Mg C/ha/yr for tree and crop components, respectively. The contribution of agroforestry in soil carbon sequestration varied between 0.003 to 3.98 Mg C/ha/yr. (Dhyani and Handa 2013, Dhyani et al, 2016).

Agroforestry provides a unique opportunity to combine the twin objectives of climate change adaptation and mitigation. India has several agroforestry systems, which differ from region to region. Agroforestry systems and alternative land-use systems for India had estimated a sequestration potential of 68-228 MgC/ha. However, the magnitude of carbon sequestration from forestry activities would depend on the scale of operation and the final use of wood. Maikhuri et al. 2000 estimated species wise annual carbon sequestration potential of planted tree species on abandoned agricultural land (3.9 t/ha/yr) and degraded forest land (1.79 t/ha/yr).

- The highest carbon sequestration was found for Alnus nepaliensis 0.256 tC/ha/yr and Dalbergia sissoo 0.141 tC/ha/ yr intercropped with wheat and paddy.

- In an agri-silvicultural system, Dalbergia sissoo at age 11 years was able to accumulate 48-52 t/ha of biomass.

- In a Poplar based agroforestry system, trees could sequester higher soil organic carbon up to 30 cm depth during the first year of plantation (6.07 t/ha/yr) than in subsequent years (1.95-2.63 t/ha/yr) with greater soil carbon storage in sandy clays than loamy sand. Poplar (Populus deltoides) is a fast-growing industrial softwood (plywood/plyboard, paper and pulp, match stick, etc.) recommended for growing in association with field crops in the Indo-Gangetic plains in India (Sharma et al, 2016).

Farm forestry or agroforestry systems have the potential to sequester carbon in a short period. Leucaena and eucalyptus-based plantation systems with closer spacing are found in several districts of Andhra Pradesh. It was found that farm forestry system with Leucaena and eucalyptus has the potential to sequester about 62 Mg/ha when planted at 1 × 1 m and 3 × 2 m. Also, the carbon sequestration potential of farm forestry system with eucalyptus was found was 34 Mg/ha for a rotation of 4 years when planted at 3 × 0.75 m and 7 × 1.5 m (Prasad et al, 2012).

12. Livestock sector

Green fodder supplements and increased concentration in the rations of ruminants would have the potential to mitigate ca. 3.4 MtCO2e per year, although adoption of these measures would incur an additional cost. These options, particularly green fodder supplements, appeared to be highly cost-effective if additional yield benefits were taken into account (Sapkota et al, 2019).

13. Solar pumps

India has an estimated 15 million electric tube wells and requires 1,68,611 million units of electricity worth Rs.1,19,294 crore (2014-15). Hence, solarizing all these electric tube wells with solar pumps will reduce the GHG emissions.

Conclusion

Evidence indicates that several technologies and practices are available to sequester carbon and mitigate GHG emissions in the Indian context. However, these technologies are crop and location specific. Further, these are not implemented at scale due to lack of funding. Hence, there is a need for adequate funding support to scale up these technologies/ practices. Further, facilitating policy is essential to harness investment in the agricultural sector through carbon financing.

Recommendations

1. There is a scope for documentation of the potential CSA technologies and practices and storing them in a common domain for the use of various stakeholders. National institutes like the Indian Council of Agricultural Research (ICAR) may act as a knowledge domain for potential CSA technologies and practices.

2. Policymakers may provide substantial funds to public and private extension systems to identify potential technologies, prioritise and promote them at the field level.

3. Extension advisory service providers may promote the identified potential CSA technologies and practices in their project areas and sites. This will help farmers to adopt sustainable technologies, reduce the risks of climate change and minimise the emission of GHGs into the atmosphere.

4. The Government may organise regular stakeholders meetings with international carbon financing agencies to route carbon finance for upscaling potential technologies and practices.

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