

Reducing carbon emissions from agriculture for environmental security

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Climate change, caused by enhanced greenhouse gases (GHGs) emission arisen as the most prominent environmental issue globally. Agriculture contributed 11.9, 10.0 and 14% of total GHG emission of world, G20 countries and India, respectively. During 2016, GHG emissions from Indian agriculture was 407.8 Mt CO₂ eq. Enteric fermentation contributed highest (54.6%), followed by agricultural soil (19.1%), rice cultivation (17.5%), crop residues burning (6.7%) and manure management (2.2%). During 1970–2016, GHG emission from Indian agriculture increased by 75%, however, relative contribution decreased from 33 to 14% during same period. Despite carbon emission, agriculture offers several options for GHG mitigation through enhancing nitrogen-use efficiency (NUE) by judicious use of nitrogenous fertilizers, reducing CH₄ emissions from paddy fields and enhancing carbon sequestration in agricultural soils. India has taken several initiatives to reduce carbon emission from agriculture and recently committed to reduce the GHG emission intensity by 45% by 2023 to achieve the net zero emission by 2070. A win-win solution would be to develop such mitigation strategies that help in sustainable agricultural development.

Keywords: Agricultural sustainability, Carbon neutrality, Climate change, Environmental security, Greenhouse gases

AGRICULTURE is a key sector, contributing to the United Nation's 2030 agenda for the Sustainable Development Goals (SDGs). Globally, agricultural lands occupy about 36% (4.74 billion ha) of the earth's land surface of which 29.2% are arable lands, mainly devoted to annual crops (FAOSTAT 2023). In India, arable agricultural land occupies about 43% (140 Mha) of total geographical area and plays a pivotal role in ensuring food and livelihood securities of country. Agriculture sector provides employment to about 2/3rd of the work-force and contributes 17% of the country's gross domestic product (GDP). During COVID-19 lockdown period, when all the sector of the economy was locked down, agriculture was the only sector that contributed significantly to the GDP and ensured the livelihood security.

Climate change caused by enhanced atmospheric concentrations of greenhouse gases (GHGs), has arisen as the most important environmental issue globally. Three greenhouse gases (GHGs), viz. carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) trap the outgoing infrared radiations from the earth's surface and thus raise the atmospheric temperature. The 6th Assessment Report of Inter-Governmental Panel on

Climate Change observed that the climate change impacts are widespread, rapid and intensifying. Carbon dioxide concentration has crossed the mark of 415 parts per million (ppm) and global mean temperature has already increased by 1.1 in last century (IPCC 2021). The seasons are shifting and extreme weather events such as cyclones, heat wave, heavy rain and flood becoming more frequent globally and particular in India. Climate change associated risk of the extreme events has intensified and threatening the agricultural production and food security.

Globally, agriculture is the major source of the food production, however it is also a source of GHG emission. In India, agriculture is second largest emitter of GHG with 14% contribution to total GHG emissions (MoEFCC 2021). Various agricultural activities such as land clearing, crop cultivation, irrigation, animal husbandry, fisheries and aquaculture have a significant impact on the GHG emissions. Enhancing food security and climate resilience of agriculture while reducing carbon emission or achieving carbon neutrality is therefore crucial for the SDGs, particularly No poverty (Goal 1), Zero hunger (Goal 2) and Climate action (Goal 3), is a big challenge for the agriculture sector. Therefore, this

article assesses the carbon emission from agriculture, explore the various options and technologies for the reducing the carbon emission from the agriculture for the environmental security.

Greenhouse gases emission from agriculture

The agriculture sector is a main source of CH_4 and N_2O emission. Methane emission occur from livestock and submerged paddy fields. In paddy fields, CH_4 is produced by microbial decomposition of soil organic carbon in anaerobic condition. Higher soil organic carbon and use of crop residues/organic manure in puddled transplanted paddy field can boost CH_4 emission in submerged condition. Nitrous oxide emitted from soil through nitrification (microbial conversion of ammonium to nitrate under aerobic condition) and denitrification (reduction of nitrate to nitrogen gas under anaerobic condition) processes. Application of organic manures and chemical fertilizers can enhance the N_2O emission from soils. About 70% of N_2O emission from agriculture is because of the use of nitrogenous fertilizers in agricultural soils. Carbon dioxide emitted from soils as result of tillage, which triggers CO_2 emission through biological decomposition of soil organic matter. Tillage breaks soil aggregates, enhances oxygen supply, and exposes soil organic matters, promoting its decomposition. Use of fossil fuels for various farm operations and on-farm burning of crop residues are other sources of CO_2 emission.

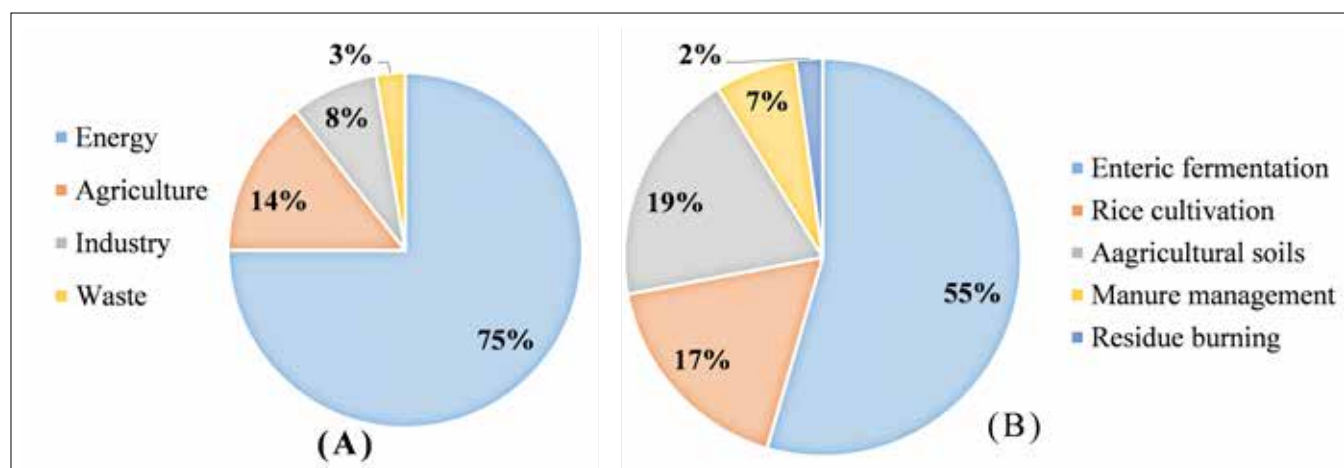
Agriculture contributes 10–12% of global GHG emissions. In India, the total GHGs emissions from all sector of Indian economy during 2016 was 2,822 Mt CO_2 eq. which is about 6% of global GHG emission (MoEFCC 2021). Energy sector contributes the highest (75%) followed by agriculture (14%), industry (8%) and waste (3%) to total GHG emission of India. Indian agriculture contributes 7.6% of global agricultural emissions, and 0.8% of total global GHG emissions. First time a decrease of 2.25% during 2016 from Indian agriculture was registered between two consecutive years. In 2016, enteric fermentation (emission from livestock) contributes highest (54.6%) to India total GHG emission from agriculture, followed by fertilizers

applied to agricultural soils (19.1%), rice cultivation (17.5%), manure management (6.7%) and on-farm burning of agricultural residues (2.2%). GHGs emission from Indian agriculture has doubled from 1970 to 2016, however, its relative contribution to total GHG of country has decreased from 33% in 1970 to 14% in 2016. It was because of higher increase in the GHG emissions from other sectors.

Reducing greenhouse gases emission from agriculture

Agriculture offers several opportunities for GHG mitigation such as enhancing nitrogen-use efficiency (NUE) through judicious use of nitrogenous fertilizers, reducing CH_4 emission from enteric fermentation, reducing CH_4 emission from paddy fields, and enhancing carbon sequestration. The IPCC has recognized following mitigation options in agriculture: (1) Fertilizer's type and use of nitrification/urease inhibitor, (2) Use of high-yielding variety and crop rotation, (3) Conservational tillage and crop-residue retention, (4) Irrigation management through drip and sprinkler irrigation, (5) Land use change such as agro-forestry and plantations crops, and (6) Biochar application. Some of the mitigation option relevant to Indian agriculture are discussed below.

Reduction of methane emission from paddy fields: Several researchers suggested that direct seeded rice (DSR), alternate wetting and drying (AWD), intermittent drying, and system of rice intensification (SRI) could be potential options for the CH_4 mitigation from the paddy fields (Table 1). DSR could be a potential option for CH_4 mitigation from paddy fields as they does not require continuous soil submergence, and therefore, may totally eliminate CH_4 emission when rice is grown as an aerobic crop. DSR reduces GHG emission by 30–50 as compared to the conventional puddled transplanted rice. Overall, up to 50% of GHG mitigation from paddy fields can be achieved with package of practice which included use of shorter duration varieties with application of neem coated urea in alternate wetting and drying condition. Rice residue management through on farm retention, biochar preparation, and composting are the options for GHG mitigation from rice residue burning.



Relative contribution of various sectors of (a) Indian economy, and (b) sub-sector of agriculture to greenhouse gas emission

Source: MoEFCC 2021

Reduction of nitrous oxide emission from agricultural soils: Options to mitigate N_2O emission from soils include enhancing NUE and reducing losses of applied fertilizers by enhancing nitrogen uptake, integrated use of fertilizer and manure to reduce dependence on chemical fertilizer, soil-test basis N application, use of advanced slow-release fertilizers. Increasing NUE with the application of right type and amount of fertilizer material with at rate at the right time in the right place through right method of application are the keys to reduce N_2O emission. Various Resource Conservation Technologies (RCTs) with N_2O mitigation potential and relative yield compared to conventional practices are mentioned in Table 1. Demand-driven N use with help of leaf colour chart or green seeker reduces N_2O emission by 10–15%. Currently, all the urea fertilizer used in the country is neem-coated leading to substantial reduction in N_2O emission. Several researchers reported the potential of crop residue-based biochar application for N_2O mitigation ranged 40–50%. RCTs are the most cost-effective strategy to mitigate GHGs emission, whereas, integrated N management cost higher. Most of the RCTs except no tillage, mid-season drying and alternate flooding reduced the net income of the farmers.

Enhancing carbon sequestration in agriculture: The CO_2 mitigation from agriculture can be achieved by increasing carbon sequestration. Carbon sequestration is the long-term (30 years or more) capture and storage of carbon in the soils and perennial plants that would otherwise be emitted to the atmosphere. For assessing carbon sequestration in agricultural soil, all the three GHGs, both organic and inorganic carbon, whole soil profile rather than surface soil needs to be considered for assessing C stock, and all components of agro-ecosystems and their life cycle should be assessed. For management of soil for carbon sequestration, firstly, the amount of carbon needs to be increased in soil system by crop residue retention, growing perennial crops/trees, and by addition of slow degradable C sources such as biochar. Secondly, added soil organic carbon needs to be protected by reducing decomposition rate with zero tillage/reduce tillage and cover crops.

The carbon sequestration potential of agricultural soils in India is assessed to be 300 to 620 Mt. Relative change in the soil carbon stock, and soil organic carbon (%) due to various sustainable RCTs are mentioned in Table 2. The recommended doses of N, P and K sequestered 0.16 Mg C/ha/yr compared to no fertilizer addition. Compared to conventional agricultural practices, carbon sequestration potential of various RCTs ranged between 0.16 Mg C/ha/yr in zero/no tillage to 3.22 Mg C/ha/yr in biochar. Biochar, organic manure, and compost application enhances SOC pools, and under their long-term application the effects may persist for a century. However, soil carbon sequestration is a big challenge in tropical and subtropical climate where the rate of carbon mineralization is very high. Agro-forestry and plantation of perennial crops or trees make carbon sequestration more sustainable rather than soil.

Table 2. Effect of various agricultural practices on relative change in carbon stock and soil organic carbon content

Sustainable agricultural practices	Change in soil carbon stock* (Mg/ha/year)	Change in soil organic carbon* (%)	Remarks
Recommended doses of N, P and K	0.16		
Integrated nutrient management	0.71	15.5	Manure availability and additional cost
Organic amendments	0.94		Organic amendments availability and cost feasibility
Zero tillage	0.16	5.3	Zero-till machinery for sowing
Crop rotation	0.30	16.03	
Residue retention	0.32	24.33	Availability of machinery for sowing with residue
Intercropping	0.58		
Biochar	3.22	24.7	

*Compared to convention practices. Source: Kiran Kumara et al. (2023)

Table 1. Impact of various technologies on GHG mitigation and crop yield

Technology	Relative yield potential*	Relative mitigation potential*	Challenges
<i>Methane mitigation from paddy field</i>			
Direct seeding rice	85–100	30–50	DSR crop establishment and weed management
Alternate wetting and drying	90–100	25–30	Require assured irrigation
Intermittent drying	90–100	25–30	Assured irrigation required
Short duration varieties	95–115	15–20	-
<i>Nitrous oxide emission from agricultural soils</i>			
Nitrification inhibitors	105–110	10–15	May add additional cost
Demand-driven N use	105–110	10–15	Require knowledge intensive tools
Conservation agriculture	95–110	5–10	Knowledge intensive and machinery required
Integrated nutrient management	95–110	5–10	Manure availability and additional cost
Biochar	95–105	40–50	-

*Compared to conventional practices. Source: Pathak et al. (2023)

India initiatives for carbon emission mitigation from agriculture

Despite having no binding mitigation obligation under UNFCCC in the pre-2020 period, India has achieved 21% reduction in emission intensity of GDP by 2014 with the voluntary declaration. Government of India has initiated several actions for carbon mitigation from agriculture. Ministry of Agriculture and Farmers' Welfare, launched the National Mission for Sustainable Agriculture (NMSA) in 2010 to address the issues of agricultural sustainability and develop appropriate strategies for food and livelihood security and economic stability. National Initiative on Climate Resilient Agriculture (NICRA), launched by Indian Council of Agricultural Research (ICAR) in 2011 to enhance the resilience of Indian agriculture to climate change. Several major programmes of Government of India such as National Food Security Mission (NFSM), Mission for Integrated Development of Horticulture (MIDH), Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Rashtriya Krishi Vikas Yojana (RKVY) emphasize on implementation of climate-smart technologies at farmer fields. Soil Health Card Scheme, Agriculture Infrastructure Fund (AIF), Rainfed Area Development and Climate Change, National Project on Agro-Forestry, National Mission on Horticulture, National Project on Organic Farming, Micro Irrigation Fund scheme, and National Action Plan on Climate Change (NAPCC) schemes of Government of India have got considerable significance to carbon mitigation from agriculture. As a

result of these actions, for the first time GHG emission from Indian agriculture reduced by 2.25% during 2016 compared to 2014 level. Carbon emission mitigation and carbon sequestration due to various actions taken in agriculture during the 2017–18 and 2018–19 is given in the Table 3.

Table 3. Carbon emission reduction and sequestration (Mt CO₂ eq.) due to various mitigation actions taken by agriculture sector of India

Mitigation intervention taken	2017–18	2018–19	Total
SRI cultivation as alternative to puddled transplanted rice	0.015	0.009	0.024
Direct-seeded rice cultivation	0.058	0.041	0.099
Crop diversification from paddy to other crops	0.026	0.012	0.038
Micro-irrigation systems (sprinkler and drip)	5.554	6.428	11.979
Avoidance of crop residue burning	0.062	0.263	0.325
Neem-coated urea	3.764	3.766	7.530
Distribution of solar pumps under National Solar mission	0.644	0.891	1.538
National Sub-mission on Agro-forestry	0.043	0.088	0.131

Achieving net zero emission in Indian agriculture

Indian agriculture has potential to attain net zero emission or carbon neutrality, at least in the crop sector.



Conservation agriculture practice: Zero tillage wheat with rice residue retention in (a) sprinkler irrigation, and (b) drip irrigation



Experimental view of zero-tillage wheat with rice residue retention under various irrigation system at ICAR-CSSRI, Karnal, Haryana

The current emission from the crop sector is about 150 Mt CO₂ eq./yr. Our experiences show that alternate wetting and drying in rice with short-duration variety, neem-coated urea with soil health card and leaf colour chart reduces GHG emission from rice by 40-50%. If we go for dry direct-seeded rice (DSR) without continuous submergence, the emission is reduced by about 70%. Crop diversification from rice-wheat to maize-wheat can reduce global warming potential (GWP) by 70-80%. Conservation agriculture including no or minimum tillage, residue retention and direct seeding of rice can reduce GHG emission by 30-40%. If we combine drip or sprinkler irrigation, run with solar or any form of renewable energy the emission is almost zero. Our study showed that with current adoption of conservation agriculture and DSR, mitigation of about 14% of total emission from crop sector has been achieved. A preliminary estimation shows that upscaling of conservation agriculture in 25% of net cultivated area (140 Mha), rehabilitation of 25% of the degraded land (26 Mha), precision agriculture in 30% of the net cultivated area, diversification of rice-wheat system to upland cropping system in 10 Mha, adopting paramparagat Krishi Vikash Yajana (PMVY) and organic farming in 30% of the net cultivated area, and using renewable energy in 50% of the net cultivated area will have net mitigation of about 160 Mt CO₂ eq./yr.

GenNext technologies and macro-scale initiatives

The next generation technologies in micro or field scale and crop-based systems will expedite the goal of achieving the net zero target much earlier than 2070. Implementation of smart TIFER: tillage (Conservation tillage), irrigation (Micro, sensor-based), fertilization (Demand-driven, sensor-based), energy (Solar) and residue management (Recycling and reuse) are the keys for net zero emission. Moreover, there is a need of macro-scale initiatives as given below.

- Agro-ecological planning for agriculture: Growing crops in suitable areas for nature-friendly farming the crop planning is important. Growing rice in upper-Gangetic plain of north-west India emits 3.9 t CO₂ eq./ha, but in the lower IGP the emission is 3.3 t CO₂ eq./ha. Energy consumption in the upper IGP emits 37% of the GWP. This can be substantially reduced to about 20%, i.e. corresponding values for the lower IGP, with crop planning.
- Rehabilitation of degraded lands: Government of India has already a plan for rehabilitating 26 Mha degraded lands with orchards, agro-forestry and so on.
- Use of renewable (solar) energy in agriculture.

Way forward

Besides technologies, however, policy formulation and implementation are bigger challenges. Upscaling of the proven technologies need more emphasis. For example, we are promoting conservation agriculture for last 25 years but the area under this only about 2.5-3.0 Mha. There are a few ground-scale challenges as well. For example, mitigation by a small farm is very small (1.0-1.5 t/ha). Therefore, a large number of farmers need to join together to make a marketable carbon credit. Moreover, agricultural carbon sequestration is long-term phenomenon. Farmers may not continue such practices for such a long time. Wrong or incomplete practices of organic farming and conservation agriculture may increase GHG emission. Adopting natural farming, will reduce emission but may compromise with the food security. Indian crop sector can achieve the target of net zero much earlier than 2070. However, institutions need to be reshaped towards resource conservation and climate-resilience. This requires significant financial and institutional investment in scaling up these technologies including capacity building of farmers, researchers and policy-makers.

SUMMARY

Agriculture provides the options for the carbon reduction through mitigation of CH₄ and N₂O emission and carbon sequestration. Several climate smart agricultural technologies, helpful in mitigation of carbon emission are available, but there is a gap in upscaling and implementation at farmers' field. It is because of availability of suitable machinery, cost effectiveness, yield loss, and lack of farmers' capacity building. The involvement of local farmers, extension agents and research institutions are critical in technology dissemination and adaption at farmers' field. In view of India focus on climate change, with emphasis on achieving net zero emission or carbon neutrality, recently, Government of India has initiated several policies changes and action projects. A single policy change for urea replacement with neem coated reduced carbon emission by 7.53 Mt CO₂ eq. in two years from Indian agriculture. Carbon credit to the farmers from the climate smart technologies is a major concern for technological adoption. A strong inter-institutional, ministerial and social coordination is required for resources, implementation of carbon mitigation technologies, and carbon credit to farmers, to achieve the net zero emission and carbon credit from the agriculture.

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