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Challenges and opportunities in soil carbon trading promoted to reduced greenhouse gas emissions and climate change mitigation: A perspective

S.S. GREWAL*

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ABSTRACT

The United Nations Intergovernmental Panel on Climate Change (UNIPCC 2007) held that it is important for agriculture sector to adapt to such climate changes particularly for food and water security. Paris Agreement was adopted by India in 2015 which aimed to strengthen international cooperation in climate action and provided for creation of global carbon market to mitigate climate change impacts. The Ministry of Forest, Environment and Climate Change Government of India framed programs, policies and regulations to address the climate change threats and mitigation strategies. The Government of India and FAO took an initiative on transforming Rice-Wheat system with regenerative practices. The Ministry of Agriculture and Farmer Welfare (2023) prepared draft green credit program implementation rules under which the National Mission for Sustainable Agriculture (NMSA) was included as one of the nine missions outlined under National Action Plan on Climate Change. The soil carbon trading is now carried out under NMSA. Punjab and Haryana are central to India's rice-wheat production system, vital for national food security and agricultural exports. However, this intensive system faces increasing stress due to groundwater depletion, stubble burning, soil degradation, and climate vulnerability. Agriculture practices account for about 20% India's total emission and majority of which comes from crop residue burning or agriculture biomass burning. Soil carbon credit and trading for climate change gradually emerged as a prominent tool to reduce green house emissions. This attracted the attention of several companies dealing with soil carbon trading based on elimination of residue burning but incorporation in soil to increase tradable soil carbon. The paper highlights the experience of monitoring and evaluation of a soil carbon credit project based on direct sown rice in Punjab and Haryana by a US based team and encapsulate salient results of a comprehensive review of literature on challenges and opportunities in soil carbon trading.

Key words: Green house gas emission, Climate change, Adaptation, Agriculture residue burning, Soil carbon trading, Direct sown rice

INTRODUCTION

The greenhouse gas (GHG) emission and consequent climate change debate became intense after United Nations Intergovernmental Panel on Climate Change (UNIPCC, 2007) report indicating that the global climate change not only cause rise in sea level, average temperature and precipitation but also cause increase in frequency of floods, droughts, forest fires, heat waves, cyclones, typhoons and hurricanes, melting of glaciers, change in animal habitats, and diminished biodiversity. It is important for agriculture sector to adapt to such climate changes particularly for food and water security.

At the same time, the United Nations Framework Convention on Climate Change (UNFCCC, 2007) predicted that billions of people particularly in developing countries shall face shortage of water, food and greater risk of health and life as a result of climate change and unfortunately they have fewer resources to adapt socially, technologically and financially. The Intergovernmental Panel on Climate Change (IPCC, 2013) projected the increase in number of hot-days, more frequent and intense heavy rains and change in rainfall pattern in Asia and specifically India. The IPCC 2022 further postulated that any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and be rapidly closing window of opportunities to secure a livable and secure future for all. The IPCC (2023) held that 3.3 to 3.6 billion people live in the highly vulnerable ecosystems with considerable development constraints to fight climate change and between 2010 and 2020; human mortality from floods, droughts and storms was 15 times more in such ecosystems as compared to regions with low

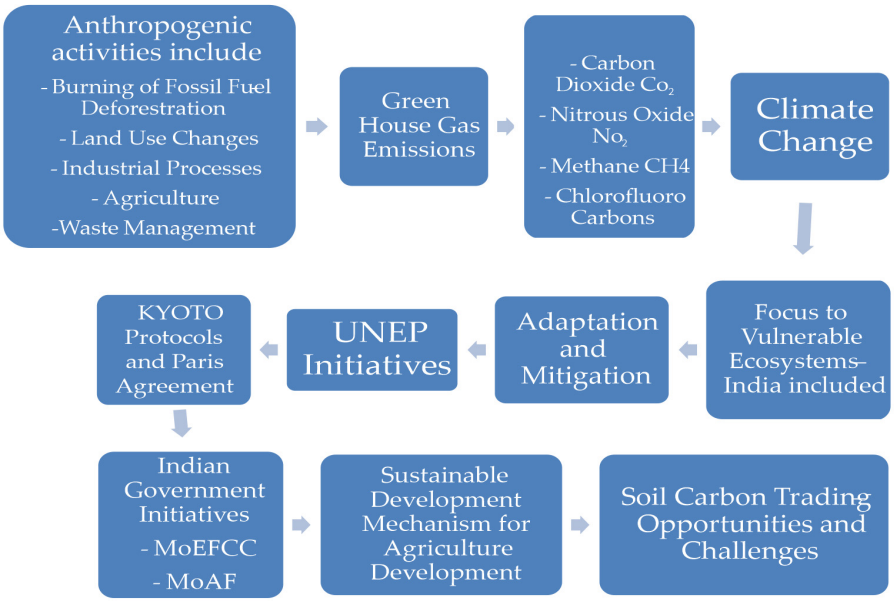
*Former Director, Punjab Agriculture University Regional Research Station Ballowal, Punjab
Email id: drgrewal0114@yahoo.com

vulnerability. The Kyoto Protocol was adopted by India in 1997, ratified in 2002 and followed by Paris Agreement adopted in 2015 which aimed to strengthen international cooperation in climate action. Article 6 of Paris Agreement provide for creation of global carbon market to mitigate climate change impacts. Soil carbon credit and trading for climate change gradually emerged as a prominent tool to reduce greenhouse emissions (Goel, 2025). Under the Kyoto Protocol, carbon trading and clean development mechanism (CDM) are the two robust processes to mitigate the GHG emissions in any country (Gorain *et al*., 2021). The actions under CDM programs like payment to ecosystem services, sustainable farming support, Mission LIFE (Lifestyle for Environment) makes environment protection and conservation a participative process in India (MoEFCC, 2022).

India ratified Kyoto Protocol in 2002 and up to 2010 India had registered 2313 projects under CDM. Most of these projects taken up from 2006 to 2012 were mainly on poultry waste based power generation, methane reduction by municipal solid waste processing, methane recovery by distillery plant, methane avoidance in rice cultivation, methane recovery from manure management at dairy farms, alternate wetting and drying project in rice cultivation (Dumbrell *et al*., 2016). Agriculture practices account for about 20% India's total emission and majority of which comes from crop residue burning or agriculture biomass burning. The major crop residues are produced from rice, wheat, maize, sugarcane, mustard, groundnut and jute. India can earn lot of international exchange through carbon trading if stubble burning can be checked. In residue burning, CO_2 accounts for 149240, NO_2 6.9, SO_2 24627 gigagrams (Gorain *et al*., 2021). Carbon dioxide generation is highest in residue burning. By avoiding crop residue burning, India could have earned 109.97 billion rupees in 2011.

It is important for agriculture, forestry and environment domains to adapt to climate changes particularly for food and water security. An attempt was made by The Ministry of Forest, Environment and Climate Change and Ministry of Agriculture Farmers Welfare of Government of India which mainly deals with climate change to frame programs, policies and regulations to address the climate change threats and mitigation strategies. In the meantime, Government of India and Food and Agriculture Organization also took an initiative on transforming Rice-Wheat system. The Supreme Court of India constituted a high-powered committee to critically look into farmer's crisis and suggest viable solutions to resolve farmers concerns emanating from climate change.

The paper is primarily based on a comprehensive review of literature on the anthropogenic causes of GHG emissions resulting in rise of global temperature causing climate change and its consequence on food and water security and impacts on livelihood of billions of people residing in vulnerable ecosystems. Soil carbon credit and trading for climate change gradually emerged as a prominent tool to reduce green house emissions. The pathway to soil carbon trading is presented in a chart given below.



Pathway to soil carbon trading

The author was involved in the monitoring and evaluation of a soil carbon trading project promoted by a company on direct sown rice in some districts of Punjab and Haryana. The valuable information collected from the evaluation of this field study and lessons learnt for the benefit of policy planners and implementing agencies are encapsulated. In addition to the initiatives by different organization, the salient results of a comprehensive review of literature on challenges and opportunities in soil carbon trading are presented in the paper.

RESULTS AND DISCUSSION

Major Government of India climate change mitigation initiatives

The Ministry of Forest, Environment and Climate Change and Ministry of Agriculture and Farmers Welfare mainly deals with climate change mitigation initiatives.

A. Ministry of Environment, Forest and Climate Change (MoEFCC)

India's long term low carbon strategies was prepared by the Ministry of Forest Environment and Climate Change; Govt. of India (MoEFCC, 2022) for submission to the United Nations Framework Convention on Climate Change under article 4 para 19 of the Paris Agreement. The strategies of low gas emission included, low carbon electricity systems, low carbon transport system, adaptation in urban-design, energy and material efficiency in sustainable urbanization, innovative low-emission industrial system, CO_2 removal and related engineering solutions, enhanced forest and vegetation cover consisted with socio-economic and ecological considerations, economic and financial support for low carbon development, focus to research and innovation, adaptation and resilience, Mission LIFE – lifestyle for environment and International cooperation. The forest and vegetation cover development programs include National Mission for Green India, India Afforestration Program, Compensatory afforestation fund, Nagar Van Yojna, National Rural Development Mission, Mission for Forest Fires Prevention, AMRIT – Atal Mission for Rejuvenation and Urban Transformation. It also covers restoration, conservation and management of trees outside forest area.

The future risks of climate impacts and vulnerability are outlined as under:

Agriculture: Rain-fed and irrigated rice yields are likely to reduce 2.5 to 7% by 2050. The wheat yield may reduce by 8-25% by 2100, the maize yield may reduce by 18-23% because of increase in soil erosion, crop water requirement and land degradation

Water: Substantially altered flow in Himalayan Rivers, increase in the annual and summer monsoon rainfall, increase in frequency of heavy rainfall events, rise in surface temperature over Hindu-Kush Himalayas by 2.2 to 3.4°C by the end of century, significant decline in snowfall and glacial retreat by 18 to 25 m/year would increase vulnerability in water sector. Increase in severity of floods and droughts, increase in frequency of extreme precipitation, increase in landslides and cloud bursts would increase the siltation of reservoirs and water bodies and would so impact the livelihood of people who depend on such water resources.

Forest: Due to rising temperature and decreased availability of moisture on forest landscape, the incidence of forest fires would increase. As the suitable moisture regime for woody perennials would reduce, the hardy invasive shrubs with low economic value would proliferate. The degradation in grassland would be impacting wildlife of the area. The combined impact of ecological degradation in forest ecosystem would result in loss of habitat for large number of animal species and gradual extinction.

Weather: The rise in sea level, increasing frequency of typhoons and high rise tides impacting fish production are commonly reported. The unprecedented temperature of 51°C in June of 2023 in the Jaisalmer area of Rajasthan caused large scale mortality of fauna and flora. The apple crop in Himalayas requires 18 days of snow for optimum flowering and fruiting. The snow fall depth and days have reduced impacting apple productivity. As a result apple is now shifting from lower to higher elevation ecosystems in Indian mountains. The rise in March temperature impacts wheat yield in Punjab as high temperature result in shriveled grains. The wind storms in March result in premature fruit fall in case of mango and lichhi. Some climate change impacts are summarized below:

- The level of sea has increased by 59cm in the last 100 years.
- The global temperature has risen by 0.74°C in last 100 years.
- The carbon dioxide level has increased from 280 to 329ppm in last century.

- 2013 experienced unprecedented rainfall in Kedarnath.
- In 2015 Chennai broke 100 years rainfall record.
- Year 2016 was the driest year of the century.
- In 2023, rainfall and cloudburst in Himachal Pradesh broke all records.
- Frequency of cloudburst has increased 20 times in the last 20 years.
- In 2024, temperature of 51°C was recorded in Rajasthan breaking records

B. Ministry of Agriculture and Farmers Welfare Government of India

The MoAFW 2023 prepared draft green credit programme implementation rules. As per this draft, the National Mission for Sustainable Agriculture (NMSA) is one of the nine missions outlined under National Action Plan on Climate Change. The topics to be covered under NMSA includes, (i) Climate ready crops and variety and resilience to climate change; (ii) livestock and fish culture; (iii) water use efficiency; (iv) pest surveillance and forewarning; (v) agriculture waste management; (vi) insurance and risk management; (vii) Integrated Farming System, Agro-forestry, Bamboo; (viii) strengthening value chain; (ix) energy management and farm mechanization; (x) organic farming; (xi) soil health and nutrient management

The NMSA covers Voluntary Carbon Mechanism. In the green credit programme implementation rules, a frame work for voluntary carbon marketing has been proposed.

C. MoAFW, 2024: Framework for voluntary carbon market in agriculture sector

India seeks to reduce emission intensity and achieve net zero by 2071 as per a report submitted to UNFCCC. Agriculture provides livelihood to a significant portion of population and also provide food security but there are environmental challenges associated with this sector like degradation of agricultural lands, loss of productivity and greenhouse gas emission. This challenge is converted to opportunity through Voluntary Carbon Mechanism (VCM) which is a key initiative that provide platform to farming community to adopt sustainable agriculture but earn revenue by selling carbon credits to those companies seeking to offset their carbon emission. The priority to climate action in agriculture sector is manifested in National Mission on Sustainable Agriculture (NMSA).

Accordingly, NMSA Strategy (2018-2030) as formulated in 2018 encourages all programs of the Ministry to adopt above 11 measures. The vision of NMSA is:

- Bring resilience in agriculture production against climate variability and change.
- Conserve natural resources like soil, water, pollinators, and biodiversity to achieve sustainable crop and livestock production.
- Increase green cover and carbon stocks.
- Ensure food security and economic stability.

The focus of NMSA is on (i) Regenerative agriculture, (ii) Organic farming, (iii) NVCM National Voluntary Carbon Mechanism, (iv) VCM in agriculture to be promoted through SAU, KVK / ICAR, (v) Prime Minister Krishi Vikas Yojna. In India, 20, 34 and 52% farmers are large, marginal and small. The strategies should focus to small farmers.

1. Government of India and FAO initiative on transforming Rice-Wheat system

Punjab and Haryana are central to India's rice-wheat production system; however, this intensive system faces increasing stress due to groundwater depletion, stubble burning, soil degradation, and climate vulnerability. To address these challenges, the Food and Agriculture Organization (FAO) of the United Nations in collaboration with the Ministry of Agriculture and Farmers Welfare Government India is implementing the Global Environment Facility (GEF) Project titled "Promotion of Sustainable Food System in India through transforming Rice-Wheat System in Punjab, Haryana, Odisha and Chhatisgarh."

To support and promote climate resilient and resource efficient residue management, a Workshop on Mainstreaming Sustainable Rice Production; Insights and Innovations from the field was organized on July 17 2025 at Chandigarh. As part of the project, Kheti Virasat Mission an NGO of repute was involved to promote conservative tillage in wheat cultivation across Sangrur and Patiala districts of Punjab and Karnal and Kaithal districts of Haryana. The initiative aimed to reduce stubble burning by in-situ management of paddy residue with a focus on improving soil organic carbon, improving soil physical properties, reducing irrigation water use, enhancing wheat yield and comparing economics of conventional and improved technique.

Kheti Virasat Mission conducted 192 farmer field demonstrations and trained 1800 farmers across four districts. The technology promoted includes use of zero-till machine for wheat sowing, mulch rice straw on the soil surface after wheat sowing. Alternatively, incorporate rice straw with the help of decomposer and machines. The preliminary results indicated increase in soil organic carbon, decreased soil pH, reduced irrigation requirement, lowered input costs and increased crop yield. The paddy straw breaks down to enrich the soil, reduce weed growth, and buffer against drought and heat stress.

2. Supreme Court of India appointed high powered committee recommendation on Carbon Credit trading in agriculture

Recently, the Supreme Court constituted a high powered committee headed by a High Court Judge to critically look into farmer's crisis and suggest viable solutions to resolve grievances of the farmers. The committee made number of suggestions and also recommended that one of the viable options is that farmers can monetize carbon credit which can be earned by adopting agriculture practices like agro-forestry and zero till farming. The National Bank of Agriculture and Rural Development (NABARD) has collaborated with the Ministry of Agriculture and Farmers Welfare Govt. of India for implementation of a Voluntary Carbon Market (VCM) scheme for agriculture in India. The credit earned would be traded in VCM generating income for the farmer. 25% would be charged as monitoring and evaluation fee and remaining 75% would go to the farmers. One of the team member suggested that pilot projects should be started for carbon credit trading in Kandi area of Punjab and Yamuna Nagar area of Haryana where agro-forestry is very common (The Tribune dated Aug 11, 2025).

3. Evaluation of a Direct Sown Rice Project promoted for soil carbon credit in Punjab and Haryana by Carbon Direct USA

Carbon Direct, a California based US Company provide technical support to prospective soil carbon credit buyers in evaluating the mechanism of measurement, monitoring, reporting and verification (MMRV). The team of experts from Carbon Direct visit the project sites, interact with farmers, interview the promoter companies and evaluate their approaches including soil sampling and analysis methodology adopted, data generation and processing. CARBON DIRECT recently evaluated a project promoted by a Gurugram based company named VARAHA on direct sown rice (DSR) by registering more than 600farmers each in Punjab and Haryana. The team visited India from in July 2025 for evaluation of this project. Incidentally, the author was included by the CARBON DIRECT as one of the evaluating team. The salient details of this interesting project and lesson learnt are presented.

VEERA and some other international companies are engaged in carbon trading since almost two decades and mostly facilitated trade in industrial sector where some companies reduced their emission foot-prints by revising their technologies and traded with companies whose emission foot prints were above permissible level and had to buy carbon credit from such companies. VEERA also promoted carbon trading projects in Brazil, Kenya and India. VARAHA is a similar group promoted by a group of industrial houses and located in Gurgaon. It started its activities by hiring the services of a well-educated young energetic group of professionals and started carbon trading work in 2022. It first started carbon trading in Biochar made from waste of saw mills and wood chips in Madhya Pradesh and gradually added DSR based Carbon Trading since 2023. VARAHA has entered into a carbon trading contract with a US based company who is interested to buy carbon credits from the farmers adopting DSR through the services of VARAHA. In case of DSR, VARAHA have registered 600 farmers in Mansa area of Punjab and 650 farmers in Karnal District of Haryana.

The contractual details

As per terms of agreement with the US Company, two quality concerns were cited by buyer before making decision about carbon purchase:

- Rigorous measurement of carbon enrichment, monitoring, verification on the ground and reporting.
- Long term durability of carbon stored in the soil.

In the context of verification on the ground, the detailed technology adopted by VARAHA, complete details of farmers, characteristics of fields selected, activities carried out from sowing till harvest needs to be recorded and put on a portal, all data computerized for third party monitoring and verification. The farmers are registered for a period of 20 years and long term durability of carbon stored in the soil would remain a concern

and need experimental support for modeling. The incremental increase in the soil carbon of the selected fields is determined by regular soil samplings and cores are drawn to find out bulk density of soil. VARAHA has entered in contract with Central Soil Salinity Research Institute (CSSRI) Karnal where all soil samples are sent, processed and analyzed for carbon content. VARAHA has improvised special seed drills (Happy Seeder) for sowing of rice and wheat where seed and fertilizer is added at pre-decided spacing and depth and maximum germination is ensured. It has procured more than 200 such modern drills each costing Rs.2.5 Lakh which is given free to the registered farmers for sowing of wheat and rice.

The most important conditions of the contract include that no crop shall be burnt, all residues shall be incorporated after shredding and mixed in the soil by power tillers. Each farmer shall be paid Rs.2500/acre for an increase of one ton of carbon and this increase may vary from 1 to 2 tonnes/acre. VARAHA shall charge more from the company and about 60% shall be paid to the farmers. It is important to note that all what farmer does, how data are collected, how it is entered in portal, procedure followed for soil testing, perceptions of the farmers, role of partners like Indian Agriculture Research Institute (IARI), New Delhi and CSSRI, Karnal all are to be vigorously verified on the ground by an independent monitoring and evaluation team hired by the US based carbon credit buyer.

In this context, a three member American team CARBON DIRECT USA was finalized for monitoring and evaluation of VARAHA work. Since they needed an Indian Scientist preferably a soil scientist and familiar with DSR technology followed in Punjab and Haryana, the author was included as fourth member of the team. The US team evaluated the project for five days including field visits in July, 2025.

Highlights of the monitoring and evaluation project

Some of the research workers interested in carbon trading enterprise suggested that a modeling approach can be tried to find out soil carbon accumulation over a long period of time, say 20 years in this case. The time and labour involved in data collection and analysis on organic carbon can be supplemented if some validated models are worked out. VARAHA has entered into a contract with the Department of Environment Sciences of IARI for developing such workable models based on experimentation. The department has laid out experiments at the IARI farm to work on modeling approach. In addition to the visit to IARI, the team had detailed discussion with VARAHA team in their Gurgaon office on Biochar and DSR. This was followed by the team interaction with three farmers registered by VARAHA for carbon credit program in three Mansa district villages in Punjab. Similarly in addition to the visit to CSSRI, team interacted with three farmers and a facilitating group based in Karnal. What emerged from the interaction with the registered farmers and other stakeholders is presented in this article.

Outcomes from the deliberations with the registered farmers

- The registration and basic data collection started in 2023. First crop rotation with prescribed methodology was taken from Paddy – Wheat rotation. The Paddy was sown from May 20-25, 2023 and harvested in second week of October. The Wheat was sown in the first week of November and harvested in mid of April 2024. In second rotation, paddy was sown in end May and visit was on July 25, 2025 when crop was almost 2 month old. At the time of visit, crop looked lush green with no signs of nutritional deficiency in any of the six plots inspected.
- Mostly 2 to 3 acres of land was taken during first rotation but area increased to around 5 acres in the second rotation. Almost all farmers were so convinced with this technology that they wanted to increase the area but sufficient numbers of special seeder drills were not available.
- Basically, there were several reasons in favour of this DSR technology:
    - The availability of labour from UP and Bihar for puddled paddy transplanting has drastically reduced. Now they are charging about Rs.4000/acre for transplanting. In addition, puddling involves another expenditure of Rs.1000/-.
    - Secondly, the Department of Agriculture provides seed-cum-fertilizer drills, but the seeds are not regularly placed and as a result gaps remain here and there in rows which involve replanting seedlings in these gaps. Moreover, farmers are to pay Rs 1500/ acre as rent.

- Thirdly, the VARAHA seed-cum-fertilizer happy seeders provide regular seed placement with no gaps and drills are provided free of cost to the registered farmers.
- Fourthly, the grain of Rs.2500/ton of carbon added/acre and regular advice from the field staff of VARAHA was an additional advantage.
- Lastly, there was no reduction in crop yield and some farmers rather reported 2 to 3 quintals of more yield as compared to the puddle transplanted paddy. It is expected that as organic carbon builds up, the yield differences will further increase.
- Two farmers reported one bag lesser use of urea. The fact remains that as O.C. builds up, leaching losses of applied nitrogen would decrease.
- The issue of weed management was deliberated in all the meetings. Two farmers reported that since they were taking puddled paddy, there was no weed problem as such. One or two need based sprays of organic weedicides can be applied.
- Cultivation of moong crop between wheat harvest and paddy sowing is recommended as this legume shall add nitrogen to the soil. However, high cost of seed, only 3 to 4 quintal yield, marketing problems and problem in residue incorporation all farmers did not favor moong cultivation.

A view of 60 days carbon farming crop at village Jalmana, Asandh (Karnal)

An important lesson emerges from this exercise is that the farmers firmly held that this DSR initiative is a win -win proposition. In case, VARAHA increases the availability of Happy Seeders, large number of farmers would opt for registration. The transparency, commitment and friendly behavior of the VARAHA field staff appears to a have earned the confidence of the farmers. These well meaning farmers were troubled by the shortage of labour, never wanted to leave paddy because of favorable economics and when a visible and viable solution appeared in DSR including several co-benefits, it prompted them to join the band wagon.

4. Studies conducted by group of authors and institutions on Challenges and opportunities in soil carbon credits

A summary of conclusions of 12 studies and reports relevant to soil carbon trading are presented in Table 1.

Total paddy residue in Punjab was 20 million tons during 2020 and burned in the range of 10.0 to 11.5 million tons.

Methane emission from puddle system of rice cultivation

Carbon dioxide emission from residue burning in rice cultivation

Paddy cultivation has double engine impact on green house gas emission

Table 1. Salient results of 12 studies and reports on soil carbon trading and footprints

Sr. No.	Author	Area of study	Main observations
1	Gilbertson and Reyes (2009)	Maharashtra, Gujarat	Wind Power Projects were tarnished by unethical and illegal dealing, corruption and cheating.
2	Madane *et al*. (2023)	Punjab	GHG Emission in Punjab is 71.7% from fertilizer and pesticide use, 16.4% by residue burning and 6.9% from energy. Emission is 13.4, 58.5 & 25.1% in NW, Central and SW Punjab. Paddy residue burnt in Punjab during 2018-2020 was in the range of 10.1 to 11.5 million tons.
3	Gorain *et al*. (2021)	India	India produce 500m.tons of crops residue but 92m.tons are burnt every year. Agriculture practices account for 20% of India's total emission and 66% is emitted by CO2 alone. India can earn in International Exchange of 108.97 billion rupees by carbon trading based on checking stubble burning.
4	Ranguwal *et al*. (2022)	General	Share of emission in residue burning is 59% from paddy. 91% by fertilizer and agro-chemical from wheat, cotton produce least GHG emission.
5	Krishnan and Singal (2023)	General	Agriculture account for 18% of GHG in India. The challenges in implementing carbon farming are lack of assessment, tools and technology, fragment holding, uncertain future of carbon market. The use of digital technology, remote sensing, AI and drones to cut on cost was suggested.
6	Khurana *et al*. (2024)	India	GHG emission can be reduced by zero till, laser leveling, DSR, biochar use, solar energy, efficient irrigation and nutrient management. The pit falls include policy barriers, economic roadblocks, characterization at grass root level and variability in pricing of carbon credit.
7	Cariappa *et al*. (2022)	Punjab, Bihar	Conservation agricultural (CA) practices were promoted for wheat in Punjab and Bihar. Took Patiala and Fatehgarh Sahib for low and Ludhiana and Sangrur for high residue burning. Indicated that CA has the potential to increase farmers income by carbon farming by USD 15/ha in Bihar and 30/ha in Punjab. Through these CA practices, emission can be reduced by 1.23 and 1.97 tones of CO2/ha in Bihar and Punjab respectively.
8	Dupla (2024)	General	In depth analysis of how changing soil organic stocks are calculated is lacking. Protocols relying on regional values and not *in-situ* analysis up with over estimates. In soil sampling, different sampling design, tools, and stock calculations cause problems.
9	Balaji (2024)	India	Voluntary carbon marketing (VCM) has shown success but grapple with quality standards and green working. Gujarat Wind mill projects through generated green energy for grids, but high density of wind mills created problems of noise, oil leak, damage to farmlands and wildlife.
10	Kyker *et al*. (2025)	General	The numbers of projects on soil carbon credit for sale in VCM are very limited due to technical and financial barriers. These are two quality concerns for buyers to take decision.(1) Rigorous measurement monitoring, reporting and verification and (11) Long term durability of carbon stored in soil. Authors addressed these issues and suggested approaches to solve them..
11	Kaur *et al*. (2025)	Punjab	Evaluated the potential of carbon footprints in Paddy-Wheat and Cotton-Wheat rotations taking Mansa and Muktsar Sahib Districts of Punjab. Impact of main resources conservation technologies for wheat and paddy and integrated pest management in cotton were evaluated. Emission from paddy-wheat was 3.5 times higher than wheat-cotton rotation.Adoption of package resulted in 50 to180% reduction in carbon emission. Paddy is the main carbon emitter. The paddy residue burning foot prints were reduced by 95 % after the adoption of resource conservation technologies. Adoption of IPM in cotton reduced emission by 23 % than control.
12	Goel (2025)	General	Reported that 25140 small farmers of UP have earned 202 crores through carbon financing program with vast potential for scale up. Agriculture other than land use, changes and forestry contribute 13.3% to GHG emission. Out of this 13.3 %, share of natural digestion process in animal fermentation is 54.9 %, paddy rice cultivation 17.1%, fertilizer use 19.1%, manure management 6.7% and residue burning 2.2%. DSR can reduce methane emission by 40% as compared to the puddle system in paddy. At present, India has more than 500 carbon offset projects registered at National and domestic level. Money earned from carbon credit can be used for energy efficient appliances at the domestic level refers to as Farm-Food-Fuel. Integrating digital tabs like soil sensors, satellite trackers, artificial intelligence can push carbon trading industry.

CONCLUSIONS AND RECOMMENDATIONS

While climate change is staring at us, Indian policy makers have to ensure food and nutrition security of the most populous country on this planet. This requires agriculture policies to be aligned such that it can give us climate resilience and take us towards low carbon agriculture footprint. The centre and state governments should align existing natural farming, regenerative farming, organic farming, sustainable agriculture, crop diversification, livestock programs to encourage farmers to participate in carbon credit programmes along with the participation of associated organizations. Though rice production is needed but depletion of available resources (water, soil fertility and air quality) have started imposing negative impacts on agricultural production and environment and there is urgent need to take remedial measures to reduce over-exploitation of groundwater, over use of fertilizers and pesticides, burning of paddy residues.

The Voluntary Carbon Mechanism (VCM) has shown success but has its own strength and weaknesses, but grapple with quality standards and green working, need comprehensive environment impact assessment, impacts on livelihoods and social acceptance before the sanction of such soil carbon trading projects particularly wind mill projects in Maharashtra and Gujarat. Meeting today's climate change objectives require a paradigm shift in our approaches. Market based strategies have failed and price incentives will alone fix matters.

While adaptation of Indian agriculture to climate changes is necessary to assure food and water security for safeguarding livelihoods of poor farmers residing in vulnerable ecosystems. The, mitigation of GHG emissions by regenerative agriculture can abate the extent of climate change but the future adaptation needs financial incentives, timely availability of equipment for crop residue management. There are challenges in soil carbon trading but opportunities are also promising which needs to be capitalized for making agriculture a sustainable enterprise.

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