Carbon Footprint of Major Crops in Indian Agriculture: Trends and Regional Disparities

Pooja Mehra [1], Sunayana Mittal [1], Gurinderjit Kaurr [2] and Gurbax Singh [3]

[1] Amity University, Uttar Pradesh, India
[2] S.G.A.D. Govt. College Tarn Taran, Punjab, India
[3] Khalsa College Charitable Society, Amritsar, Punjab, India

pmehra@amity.edu

Abstract. Agriculture plays a critical role in India's economy and food security, but its increasing reliance on high-carbon inputs has raised concerns about sustainability. This study evaluates the carbon output from major crops across different Indian states, identifying regional variations in carbon sequestration potential and assessing long-term trends in carbon efficiency. By analyzing data on crop productivity, soil carbon storage, and emission factors, the study aims to provide insights into state-wise contributions to total agricultural carbon output. The findings highlight significant regional differences in carbon sequestration potential, influenced by cropping patterns, land-use practices, and agro-climatic conditions. Additionally, long-term trends indicate that while agricultural productivity has increased, carbon-use efficiency has declined due to excessive input reliance. The study underscores the need for region-specific sustainable practices, such as precision farming, conservation agriculture, and climate-resilient cropping systems, to enhance carbon efficiency and environmental sustainability. These insights can aid policymakers in designing low-carbon agricultural strategies that balance productivity with ecological sustainability.

Keywords: Agro climatic zones, Carbon output, Crops, Indian States, Sustainable Agriculture

1 Introduction

Agriculture is often seen as one of the most sensitive sectors to climate change. Agriculture now accounts for more than 40% of the world's land, indicating a fundamental shift in land use for human survival. Agriculture is vital to India's economy since it produces rural jobs, guarantees food security, and supports economic progress. Rainfed agriculture accounts for 56% of all arable land in India [1] and 75% of cropped area in dry and semiarid regions [2], [3]. Agriculture is the principal source of income for around 58% of rural households, with 157.35 million hectares under cultivation. India is predominantly an agrarian country, and agriculture is critical to the economy [4]. In 2017, 17.32% of the country's GDP came from agriculture and other industries. However, it also has a big impact on environmental problems, particularly greenhouse gas emissions, which are a major cause of climate change. Due to shifting dietary habits and economic expectations, competition for food will increase as the world's population is expected to exceed two billion people over the next fifty years. This will put a burden on the soils, water, and other resources that support agriculture. Climate change-related events happen swiftly. According to this approach, climate change poses a major threat to the agriculture sector. The crop-growing season has a variable precipitation pattern, with severe, short-lived downpours alternating with dry intervals [5]. Decision-makers and stakeholders must support policies that ensure food production and encourage sustainable management to lessen human impacts on the environment in light of those global issues [6]. The study finds that greenhouse gas emissions from farming in India have increased by 161% over India's agriculture sector has grown its greenhouse gas emissions by 161% over the past 50 years, according to the research, from 14.81 tgCE (carbon equivalent) per year in 1960 to 38.71 tgCE per year in 2010. The use of synthetic nitrogen fertilizer and a shift away from conventional

R. Nagariya et al. (eds.), *Proceedings of the International Conference on Sustainable Business Practices and Innovative Models (ICSBPIM-2025)*, Advances in Economics, Business and Management Research 349,
https://doi.org/10.2991/978-94-6463-872-1_68

energy sources and toward carbon-intensive technology are the causes of this growth. Additionally, rice production has climbed by 22% despite a 16% fall in less carbon-intensive coarse cereals [7].

Analyzing the carbon generation of significant crops is critical for long-term agricultural development as India faces increasing pressure to meet rising food demand while lowering environmental implications. The three primary pillars of the Indian agricultural system—grains, pulses, and oilseeds—are the main focus of the studies, which examine the environmental effects of agriculture. Since a significant amount of India's greenhouse gas emissions come from the country's agricultural sector, it is critical to comprehend the factors affecting these emissions and create sustainable crop production methods. Even though the majority of greenhouse gas emissions come from agriculture alone, scientific evaluations of carbon footprints are still being conducted, mostly for consumer goods and industrial processes; agricultural systems are not well-suited for these analyses [8]. As previously stated, updating the current estimates of the emissions and sink capacity of the agriculture sector requires a comprehensive monitoring network that considers a range of geographic locations, environmental circumstances, and management practices [9]. In addition to soilborne GHGs and carbon sequestration, agriculture's perspective must be broadened to encompas all relevant GHG emissions and removal, given the increasing energy and chemical inputs utilized in farming. [8]. Despite being an emission source, there are opportunities to lower emissions and even use cultivated soil as a GHG offsetting method if improved management practices are found and put into place [10]. Soils are the greatest terrestrial carbon store because they contain both organic and inorganic carbon molecules. Because of oxidation and erosion, the amount of organic carbon in the soil has drastically decreased. Scientific studies show that with proper management, 50–66% of the soil's prior carbon loss can be restored [11]. Carbon sequestration is the process of increasing the quantity of organic carbon in soil so that it won't reach the atmosphere for centuries. The two primary strategies for enhancing soil carbon sequestration are lowering soil disturbance and raising organic matter inputs. Thus, some of the suggested management techniques are mulching, cover crops, no-tillage, organic manure, and shortening the fallow time [12]. Intercropping with legumes and specific combinations of crop rotations are proven to be highly beneficial because improvements in nutritional status, especially in nitrogen and phosphorus, also boost carbon. [13]. According to suggested management, soils in the UK and the EU can offset 0.010 and 0.09 Pg C per year, respectively [14], at the global level, soils offers the annual sequestration potential of 0.6–2.0 Pg C [15]. According to long-term studies, adding organic manure improves the soil's ability to sequester carbon by 70–551 kg C year when compared to mineral fertilizer [16]. The amount of agricultural land per person in India has been steadily declining, while technical developments have allowed agricultural production to rise sharply, increasing the amount of food available per person. As the population grows, the number of farms per person and the amount of arable land decrease. Since there is little to no chance of bringing more land under cultivation, India's growing food production must come from increased production per unit area from its current land [17]. The world's temperature has increased by 0.6 ± 0.2◦C during the past century as a result of agricultural practices and the use of fossil fuels, with an average increase of 0.17◦C every decade since 1950 [11]. By storing carbon in soils and biota and lowering net greenhouse gas emissions from the industrial and agricultural sectors, agriculture can help mitigate global warming even though it is one of the primary contributors. [12].

As concerns about global warming have grown, the term and concept of "carbon footprint" have gained popularity. A measure of agriculture's carbon footprint is the quantity of greenhouse gases (GHGs) generated by agricultural operations, measured in CO2 equivalents (CO2e) [17]. Agriculture may be able to play a major role in mitigating climate change by reducing net greenhouse gas emissions from the industrial and agricultural sectors and storing carbon in soils and biota [11]Despite growing concerns about the carbon footprint of India's agricultural industry, there is currently little to no research on the differences in carbon emissions and sequestration potential among different agro-climatic zones within a state. In favor of a national or crop-specific assessment, most primary research overlooks the sub-national components of carbon cycling. Additionally, even though some studies have noted the increase in emissions from agriculture, very few have comprehensively explored the long-term trends in carbon-use efficiency and the contribution of different states towards total carbon emissions. Moreover, there is a gap in the literature that incorporates the potential of soil carbon sequestration with crop yields, thereby hindering an understanding of the impacts of agricultural practices across timeframes. The impact of climate-resilient and precision farming methods on the improvement of carbon efficiency is still lacking at the sub-national scale. Addressing these issues is necessary for formulating region-specific approaches aimed at emission reductions and fostering sustained agricultural growth in India. The paper examines the spatial heterogeneity of carbon sequestration potential and analyze the dynamics of carbon emissions from principal crops over time.

2. Material and Methods

The study utilizes secondary data on crop production and harvested area of major crops such as Rice, Wheat, Coarse cereals, Pulses, Oilseeds, Sugarcane, Cotton and tobacco. from various issues of Agriculture Statistics at Galane (2006-2007 to 2022-2023) published Directorate of Economics and Statistics. This study estimates the carbon output (C output) from various crops cultivated across different agro climatic zones in India. The states are divided into six agro-climatic zones namely southern semi-arid region, north eastern hill region, eastern region, western dry region, northern plain region, central region.

Table 1: Agro Climatic Regions in India

Region	States
Southern Semi-Arid Region	Andhra Pradesh, Kerala, Tamil Nadu, Telangana
Northern Eastern Hill region	Assam, Himachal Pradesh, Jammu and Kashmir, Uttrakhad, Manipur, Meghalaya, Mizoram, Nagaland, Tripura, Sikkim
Eastern Region	Bihar, Jharkhand, Odisha, West Bengal
Western Dry Region	Gujrat, Karnataka, Maharashtra, Rajasthan
Northern Plain Region	Haryana, Punjab, Uttar Pradesh
Central Region	Madhya Pradesh, Chhattisgarh

Source: Naik, Jatav&Awais,2023

The study calculates the total biomass produced for each crop using agricultural production and Harvest Index values from published literature. Specific Values of harvest index were used for all crops.

Table 2: Harvest Index of Major Crops

Crop	Harvest Index
Rice	0.5
Wheat	0.4
Coarse Cereal	0.4
Pulses	0.3
Cotton	0.3
Sugarcane	0.27
Oilseed	0.3
Tobacco	0.27

Source: Maheswarappa, Srinivasan &Lal,2011

To compute the total biomass of production or yield of each crop was divided by harvest index

$$BioMass = \frac{Production}{Harvest\ Index}$$

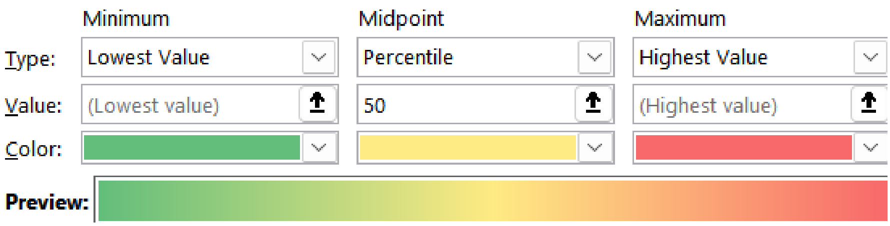
.

It estimates the carbon output (C_O) from crop biomass, assuming 40% of total biomass is carbon from major crops across different agro climatic zones [17]. This helps evaluate regional differences in carbon output from agricultural activities.

$$C_O = \sum 0.4\, BioMass$$

1 Teragram(tg)= 1 Million tons

Table 3: Scale for Heat Map



3. Results and Discussion

Examination of the crop yield data from the year 2006-07 to 2021-22 across India's agro-climatic regions reveals striking discrepancies between regions, trends over time, and the changing dynamics of agriculture. This study encompasses all important crops: rice, wheat, coarse cereals, pulses, oilseeds, sugarcane, cotton, and even tobacco. Each crop is characterized by distinctive growth patterns based on climate, resource access, technology investment, policy backing, and infrastructure. It is apparent both from the observation that regions undergo systematic and unsystematic changes over time that Indian agriculture is indeed progressive.

Table 4: Regional Distribution of Carbon Output (2006-2022) Rice (tg)

Year / Region	**2006-2007**	**2009-2010**	**2012-2013**	**2015-2016**	**2018-2019**	**2021-2022**
Central Region	3.53	4.01	3.75	3.86	4.41	5.13
Eastern Region	10.62	11.32	11.97	11.24	11.76	13.49
Northern Plain Region	9.85	10.27	11.9	10.98	13.15	11.26
Southern Semi-Arid Region	12.39	6.7	6.33	7.47	8.56	11.23

Western Dry region	1.38	1.47	1.35	1.08	0	0

Source: Author's Calculation

The evaluation of agricultural output data from the years 2006-2007 through 2021-2022 outlines trends, expansion, reduction, and volatility in crop output over several regions. Additionally, rice is a staple crop that has been on the rise in most regions, save for the western dry region which stopped all production after the year 2015-2016. There has been a steady rise in rice cultivation in the Central Region due to better irrigation, hybrid seeds, and modern farming practices. However, the production in the eastern region seems to have experienced some fluctuations which could have been the result of climatic changes or even population changes.

Table 5: Regional Distribution of Carbon Output (2006-2022): Pulses(tg)

Year/ Region	**2006-2007**	**2009-2010**	**2012-2013**	**2015-2016**	**2018-2019**	**2021-2022**
Central Region	5.49	6.38	0.65	6.82	10.41	7.58
Eastern Region	4.65	1.02	0	1.74	2.2	1.2
Northern Plain Region	2.82	2.66	0.37	1.69	3.2	3.49
Southern Semi-Arid Region	2.18	2.17	0.81	2.4	2.08	2.84
Western Dry Region	7.01	6.29	2.61	5.18	10.26	18.32

Source: Author's Calculation

Pulses represent an important source of protein and offer useful dietary components making it necessary to examine their production trends which vary greatly between different regions. They form a major portion of diet in the western dry region which is the main pulses producer surrounded by central and northern regions which are key contributors to the category while eastern region showcases inconsistent production due to season variability

Table 6: Regional Distribution of Carbon Output (2006-2022): Coarse Cereals (tg)

Year Region	**2006-2007**	**2009-2010**	**2012-2013**	**2015-2016**	**2018-2019**	**2021-2022**
Central Region	2.03	3.02	2.77	3.83	5.02	8.68
Eastern Region	2.53	2.36	3	3.33	4.45	5.22
North Eastern Hill Region	1.58	1.37	1.55	1.49	0	0

Northern Plain Region	4.83	4.63	5.22	4.71	4.92	4.35
Southern Semi-Arid Region	4.36	4.96	7.09	7.06	7.47	8.82
Western Dry Region	18.22	17.7	19.49	14.88	13.6	20.29

Source: Author's Calculation

Coarse grains, including millets and sorghum, play a vital role in both food security and climate change adaptation. On the other hand, North Eastern Hill Region did not advance because of a shift to other cash crops or climate constraints. The trends in pulses production depict marked increase in production, attaining a peak of 18.32 in 2021-22 which is indicative of significant investments coupled with favourable climatic conditions. Semi-arid and dry regions support the growth of coarse cereals, which include millets, sorghum and maize.

Table 7: Regional Distribution of Carbon Output (2006-2022): Wheat (tg)

Year/Region	**2006-2007**	**2009-2010**	**2012-2013**	**2015-2016**	**2018-2019**	**2021-2022**
Central Region	7.33	8.41	13.13	17.69	15.47	22.98
Eastern Region	5	5.59	6.56	5.71	6.15	10.1
North Eastern Hill Region	1.79	2.38	1.8	1.94	1.51	1.41
Northern Plain Region	49.69	53.19	57.53	54.79	63.56	55.97
Western Dry Region	11.9	12.5	13.15	13.28	13.79	13.94

Source: Author's Calculation

There has been an increase in wheat production across most regions, particularly in the central and northern plains which have seen a huge increase. Moving on, wheat is another crop that has seen a continuous rise in production from 7.33 in the year 2006-07 to 22.98 in the year 2021-22. In the Northern

Plain region, it increased in general till 2018-19, after which it started declining because of the overuse of groundwater and soil fertility problems. Output in the Western Dry Region on the other hand kept increasing, having adapted to drought resisting wheat varieties, reaching 13.94in 2021-22.

Table 8: Regional Distribution of Carbon Output (2006-2022): Oilseeds (tg)

Year / Region	**2006-2007**	**2009-2010**	**2012-2013**	**2015-2016**	**2018-2019**	**2021-2022**
Central Region	7.74	10.18	12.37	8.32	11.98	10.56
Eastern Region	1.29	1.41	0.22	1.57	1.54	1.58
Northern Plain Region	2.58	2.37	7.24	3.84	5.04	3.52
Southern Semi-Arid Region	3.25	3.25	3.38	2.38	1.92	2.1
Western Dry Region	9.89	25.32	19.38	17.41	20.37	30.2

Source: Author's Calculation

Oilseeds are vital for edible oil production, and their output varies across regions. For regions that grow oilseeds, each area has its own unique competition. Harvesting oilseeds takes place in the Western Dry Region, in the Central and Semi-Arid regions. This area's population grows slowly so it relies on climate policies. Observing a growth of 9.89 in the year 2006-07 to 30.02 in the year 2021-22 suggests strong support from the government. There is limited cultivation in oilseed zones which means cultivation is restricted geographically.

Table 9: Regional Distribution of Carbon Output (2006-2022): Sugarcane (tg)

Year / Region	**2006-2007**	**2009-2010**	**2012-2013**	**2015-2016**	**2018-2019**	**2021-2022**
Central Region	4.16	3.76	3.73	7.45	10.31	7.97
Eastern Region	12.59	9.65	25.74	25.68	17.27	6.04
North Eastern Hill Region	9.03	8.65	9.95	8.85	9.37	5.22
Northern Plain Region	221.55	113.39	218.04	234.78	277.74	289.06
Southern Semi-Arid Region	93.05	61.42	75.36	56.78	41.348	23.95

Western Dry Region	182.02	158.51	164.81	183.25	84.13	288.42

Source: Author's Calculation

Relying excessively on water restricts where sugarcane can be grown. The Northern Plain is the largest producer, reaching 289.06 (2021-22). The primary reason why production is so high in the Northern region is for these climatic conditions. The rest of the country is still struggling to meet baseline requirements. This strongly indicates the impact of water supply, global prices, and domestic competition. Improved irrigation is essential for the area. Focus started in 2021-2022 indicates a shift towards water reserving. In a nutshell, it suggests severe over-dependence on the local climate.

Table 10: Regional Distribution of Carbon Output (2006-2022): Cotton (tg)

Year / Region	**2006-2007**	**2009-2010**	**2012-2013**	**2015-2016**	**2018-2019**	**2021-2022**
Central Region	0.97	8.04	2.93	2.8	3.1	1.89
Eastern Region	0	0	0	0	0	0.84
Northern Plain Region	5.85	3.92	6	0.6	1.62	0.86
Southern Semi-Arid Region	3.26	4.61	10.46	8.84	7.45	10.54
Western Dry Region	23.8	20.82	25.17	16.82	22.24	26.92

Source: Author's Calculation

For the optimization of cotton production to occur, regions exhibiting moderately hot climate, like the Western Dry and Southern Semi-Arid, have the most stable productivity. The highest cotton production is recorded at 26.92 (2021-2022) in the Western Dry region and is observed at a slow but steady overall growth of 10.54 (2021-2022) in the Southern Semi-Arid region. The Central and Northern Plains regions seem to have stagnated or declining productivity. Cotton production trends indicate the lack of a uniform cyclic pattern across regions however, the Western Dry Region adopts an unvarying rhythm towards being the highest runner in production, reinforcing cultivation of cotton in these areas, which increases demand. The Northern plain was growing steadily until 2018-19, after which there was a decrease because of the government policies and changing agricultural focus.

Table 11: Regional Distribution of Carbon Output (2006-2022): Tobacco (tg)

Year / Region	**2006-2007**	**2009-2010**	**2012-2013**	**2015-2016**	**2018-2019**	**2021-2022**

Eastern Region	0	25.56	27.76	3.45	54.51	52.66
Northern Eastern Hill Region	0	0	0	0	0	1.2
Northern Plain Region	0	118.45	184.74	195.55	303.7	182.26
Southern Semi-Arid Region	0	549.24	390.19	57.61	285.92	209.33
Western Dry Region	0	294.81	570.37	102.22	900.74	763.94

Source: Author's Calculation

Tobacco is produced in the Western Dry region and the Southern Semiarid area and has the highest output levels with their value ranging from 763.94 (2021-22). The production soars down than increases and fluctuates in the Southern Semi-Arid & Northern Plains regions. The Eastern Region suggests policy influences or changes in market demands as its output increases from zero to 52.66 (2021-22).

This research identifies different places undergoing a transformation of agronomy, where less resource-consuming and climate-smart crops are being generated. The Western Dry and the Southern Semi-Arid are the two regions that are cotton, maize and tobacco-oriented respectively, which are area-based crops that are mainly drought-resistant and grown using only the rainwater from the field. The Northern Plains are the major wheat and sugarcane producers due to the existence of fertile alluvial soils, constructed infrastructures for irrigation and also great use of inputs. Moreover, the Central Region is the leading place where the growth rate is distributed evenly over rice, coarse cereals, pulses, and oilseeds, which means such crops have adopted the hybridization of varieties and agricultural practices which are effective. Although their performance is not stable, the Eastern Region progress in crops namely rice, sugarcane, and tobacco which is more political and cultural than economical. The report also emphasizes the importance of climate and technological suitability in crop production, whereby drought-resistant crops such as millets and cotton are taking the lead in the infertile and dry parts of the country. There was a tremendous increase in the use of the tobacco and oilseed production probably results from governmental support programs and market demand driven largely by enticing price incentives. Fluctuations abound in Eastern and Northeastern Hill Regions indicating vulnerability quite starkly under climatic variability and scant irrigation infrastructure pressures mounting rapidly. Policy and market influences play a role in crop output with dramatic rise in tobacco production in previously non-producing regions reflecting market-driven expansion. Pulses and oilseeds are thriving remarkably in semi-arid zones indicating a fairly positive shift towards protein-rich foods and soil health awareness nationwide.

The National Food Security Mission – Pulses and Wheat (NFSM) has been effective in MP, while the Rashtriya Krishi Vikas Yojana has facilitated regional agricultural planning. The National Mission on Oilseeds and oil palm has improved soybean productivity, stabilizing farmer incomes in central region. The Green Revolution policies (1960s-) provided heavy input support for agriculture, including seeds, fertilizer, and irrigation. The MSP Procurement System encouraged rice-wheat monoculture. Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) expanded irrigation but worsened groundwater depletion. Sub-Mission on Agriculture Mechanization supported laser land levelling and zero tillage. Regional challenges include ecological stress and ecological stress in northern region. The policy influences include Bring Green Revolution to Eastern India (BGREI), NFSM, Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahabhiyan Yojana (PM-KUSUM), and PMKSY, with BGREI improving rice productivity but unevenly impacting regions. Regional challenges include underutilized potential, floodprone plains, and poor irrigation in eastern region. The Bt Cotton adoption since 2002 has led to significant growth, particularly in Karnataka and Rajasthan. The Millie Missions and Watershed Development Programs have also contributed to the growth of oilseed production in Rajasthan and Gujarat. The Bt Cotton adoption since 2002 has led to significant growth, particularly in Karnataka and Rajasthan. The Millet Missions and Watershed Development Programs have also contributed to the growth of oilseed production in Rajasthan and Gujarat. The policy influences include Mission Organic Value Chain Development for North Est Region (MOVCDNER), NEC agriculture support, Soil Health Card Scheme, but implementation challenges persist due to regional constraints like small farms and poor road access.

4. Conclusion

The research delves into the relationship between agriculture and climate change, as well as the sustainable solutions that have been proposed. The conventional approach to farming which includes over application of fertilizer, emissions from livestock, deforestation, and reckless water usage are some of the primary factors behind the surge of greenhouse gas (GHG) emission. It is essential to rethink traditional agricultural practices and adopt climate friendly farming ways that cut emissions without hindering productivity and as food demand and population grows worldwide. The results underscore the pressing need for adopting sustainable agricultural practices which can be accomplished through a harmonious blend of technological development, policy change, and stakeholder activity. The most effective methods for reducing emissions in agriculture practice include precision agriculture, conservation tillage, organic farming, agroforestry, and better livestock management. Such practices do not only curb the carbon emission but also improve soil quality, increase biodiversity, and sustained agricultural productivity in the long run. Improving soil health is crucial in fighting climate change as well as achieving food security. Building soil organic matter through cover cropping, crop rotation, minimal tillage, and applying organic materials can lessen the need for synthetic fertilizers. Cattle, often known as ruminants, are a major source of methane emissions from enteric fermentation. Changes in nutrition and increased grazing. Circular economy techniques that combine crop and livestock production can increase resource efficiency while decreasing waste. Changes in land-use and deforestation contributes greatly to carbon emission. Adopting agroforestry and restoring land through sustainable policies can address the negative impacts of agriculture on the environment. Policymakers should balance deforestation policies while providing support for farmers adopting sustainable land-use frameworks. Alternative farming methods, precision agriculture, and bioengineering are modern technologies that can also mitigate the carbon cost of agriculture. These policy measures are important in making agriculture more environmentally sustainable. Adoption of these practices ought to be assisted by tax cuts, subsidies, grants and other government aids. Lower emission targets could also be met by encouraging emissions-less practices within agriculture using carbon credits. Farmers being actively supported with better research and extension services would help them implement more sustainable techniques. Sustainable agriculture depends greatly on climate change resilience. Climate Smart Agriculture integrating both mitigation and adaption strategies is fundamental for long term sustainability. In summary, reducing carbon agriculture emissions is a nontrivial task and needs farmers, policymakers and researchers to work together.

Disclosure of Interests: The authors have no competing interest to declare that are relevant to content of this article

[18]

[1] A. Suresh, S. S. Raju, S. Chauhan and K. R. Chaudhary, "Rainfed agriculture in India: An analysis of performance and implications," *Indian Journal of Agricultural Sciences.,* vol. 84, no. 11, pp. 1415-1422, 2004.

[2] J. Sehgal and I. Abrol, Soil Degradation in India: Status and Impact, Oxford & IBH Publishing Co. Pvt. Ltd, 1994, pp. 1-80.

[3] V. B and M. Jacintha, "Semi Arid Region," in *Eco-regional Notes on Climate Change and Semi Arid Region*, Centre for Education and Documentation, 2011, pp. 28-35.

[4] "FAO," Food and Agriculture Organisation , 2015.

[5] H. C. J. Godfray, J. R. Beddington, C. Toulmin and S. M. Thomas, "Food Secruity: The challenges of feeding 9 Billion people," *Science,* vol. 327, no. 5798, pp. 812-818, 2010.

[6] P. D' odorico and M. C. Rulli, "The Fourth Revolution," *Commentary,* vol. 6, pp. 417-418, 2013.

[7] D. Sah and A. S. Devakumar, "The carbon footprint of agricultural crop cultivation in India," *Carbon Management,* vol. 9, no. 3, pp. 213-225, 2018.

[8] D. Pandey and M. Agarwal, "Carbon Footprint Estimation in agriculture sector," vol. 1, Singapore, Springer, 2014, pp. 25-47.

[9] H. Seip, "Carbon footprints: Relative Drop for Farming Emissions," *Nature,* p. 321, 2011.

[10] J. G. Hutchinson, C. A. Campbell and R. Desjardins, "Some Perspectives on Carbon Sequestration in Agriculture," *Agricultural and Forest Meterology,* vol. 142, no. 2-4, pp. 288-302, 2007.

[11] R. Lal, "Carbon Emission from Farm Operations.," *Envirnoment International,* vol. 30, pp. 981-990, 2004a.

[12] R. Lal, "Soil carbon sequestration impacts on global climate change and food security," vol. 304, no. 5677, pp. 1623- 27, 2004b.

[13] S. Nishimra, S. Yonemura and T. Swamoto, "effect of land use change from paddy rice cultivation to upland crop cultivation on soil carbon budget of crop land in japan," *Agriculture Eco system and Environment,* pp. 9-20, 2008.

[14] P. Smith and J. Smith, "Carbon Sequestration Potential in European Croplands has been Overestimated.," *Global Change Biology,* vol. 11, no. 12, pp. 2153-2163, 2005.

[15] R. Lal, "World Cropland Soils as a Source or Sink for Atmospheric Carbon," *Advance in Agronomy,* vol. 71, p. 71, 2001.

[16] B. M. T. A. Biswapati Mandal, "potential of double-cropped rice ecology to conserve organic carbon under subtropical climate.," *global climate change,* pp. 2139-2151, 2008.

[17] H. Maheswarappa, V. Srinivasan and R. Lal, "Carbon footprint and Sustainability of Agriculture Production Systems in India," *Journal of Crop Improvement,* vol. 25, no. 4, pp. 303-322, 2011.

[18] D. o. E. a. Statistics, "Agricultural Statistics at a Glance," Government of India, 2008-2023.

[19] S. Sinha, S. Bhargava and A. Goel, "Energy as basis of harvest index," *The Journal of Agricultural Science,* vol. 99, no. 1, pp. 237-238, 1982.

[20] O. Donald and J. Hamblin, "The Biological yield and harvest index of cereals as agronomic and plant breeding criteria," *Advances in Agronomy,* vol. 28, no. 1, pp. 361-405, 1976.

[21] WLE, "Water, land and ecosystem : improves natural resources management for food secruity and livelihoods," *International Water managment institute ,* 2011.