Review Article

Carbon Farming: Best Management Practices and Factors affecting farmers' Acceptance

ABSTRACT

Carbon farming is a critical intersection of agriculture and climate change mitigation, aiming to reduce greenhouse gas emissions while sequestering carbon in agricultural landscapes. This practice entails using sustainable farming methods to increase soil carbon storage, such as cover cropping, reduced tillage, agroforestry, and improved grazing management. Farmers who integrate these techniques can not only improve soil health and agricultural productivity, but also make a significant contribution to global efforts to combat climate change. India, with its vast agricultural landscape, can benefit from carbon farming by improving soil health, increasing crop yields, and ensuring food security for its growing population. Economic incentives, such as carbon credits and markets that reward sustainable practices, provide additional motivation to Indian farmers. This review paper explores the principles and practices of carbon farming, as well as the policy frameworks that encourage its adoption. It highlights the institutional support available, such as government programs, research initiatives, and extension services aimed at promoting sustainable agriculture. However, Indian farmers face unique challenges and barriers when implementing these practices, including small landholdings, a lack of awareness, and financial constraints. Institutions play an important role in overcoming these barriers by providing technical assistance, financial support, and education. Strong research, education, and policy support are required to realise carbon farming's full potential in creating a sustainable and resilient agricultural sector in India.

Keywords: Agricultural productivity, carbon farming, greenhouse gases,resilient, sustainable agriculture,

UNDER PEER REVIEW

INTRODUCTION

Agriculture faces numerous challenges today, including significant contributions to climate change through greenhouse gas emissions and the depletion of soil health.The conventional farming erodes the soil structure, decreases organic cover, and reduces water-holding capacity thereby lowering crop yields and making the farming area more susceptible to drought (Arriaga *et al.,* 2017). They also negatively impact biophysical diversity, and the services offered by ecosystems besides affecting biological control of pests. From the economic aspect, the use of chemicals puts the cost of farming on the farmers and at the same time reduce the future profitability of farming. This means that sustainable practices are not well implemented, which hinders the ability of agriculture to cope with climate change, thus deriving food security and sustainability of land resources in the future. Thus, new strategies of cropping systems and soil management practices to deal with the increased level of CO_2 in the environment, efficient use of water and soil health are being developed (Sharma *et al*., 2021). The soil quality studies focus on the ways of handling soil to harness the properties of the soil, with special emphasis on the aspect of organic matter (Bolan *et al.,* 2011). Agricultural operations that contribute organic residues are needed to prevent the increase of consequent environmental CO_2(Hartmann *et al.*, 2013). Different farming systems have impact on the amount of carbon which is built up by the rate of residues returned to the soil, the rate at which plant residues and other organic matter decompose (Campbell *et al.*, 2000). The major constraint for the Indian agriculture in the forthcoming period will be to feed and cloth the world and at the same time preserve and even enhance the soil capital (Gopalasundaram*et al.*, 2012).

The pressure to reduce greenhouse gas emissions has therefore arisen for various ways that include incorporating carbon farming practices in soils (Avasiloaie*et al.*, 2023). Through the process of sequestering carbon, carbon farming whereby one practices regenerative agriculture, is vital in the reduction of the emission of greenhouse gases. It is beneficial in enhancing the health status of the soil, increasing the water-holding capacity of the soil and increasing the yield of crops through an improvement in the organic content of the soil. It helps expand the usage of crop rotation and has benefits within the area of low-input technique, which is environmentally friendly, cost-efficient, and ensures the setting up of steps for receiving money from carbon credits. Second, carbon farming enhances food security, resilience to such fluctuations for future generations as well as sustainability of the land. One discovers that it is approximately natural emissions from agriculture, forestry, and land-use activities (Sharma *et al.*, 2021). Carbon Farming practices like the application of agroforestry systems and cover crops, increase the ability of the soil to store carbon making the soil healthy and fertile (Spotorno *et al.*, 2024; Sharma *et al.*, 2021). Moreover, carbon farming also has implications for enhancing biomass, soil, and crops' resistance, as well as mitigating nitrous oxide relative emission and nitrate leaching impacting nitrogen cycling and climate change (Almaraz *et al.*, 2021). Through increasing organic carbon content in the soil, more efficiently using resources and, thus, practicing carbon farming helps achieve environmental sustainability and fight climate change.

CARBON FARMING

A method of managing agriculture called "carbon farming" helps the land store more carbon and emit less greenhouse gases into the environment (Jansson*et al.*,2021). Indian farmers, for instance, may manage their grazing areas to preserve and replenish the flora, including the tree cover that borders streams. In a similar vein, farmers may lower the quantity of greenhouse gases attached to vegetation by using fertiliser reduction techniques like using compost or biochar. Agriculture that is carbon neutral is quickly becoming essential for maintaining environmental balance, enhancing public health, and ensuring the safety of future generations' food(Chen *et al.*, 2022).By enabling farmers who use these measures to sell their carbon credits, carbon farming initiatives give farmers financial incentives. The initiatives started in the US and Europe and are currently expanding even in India.It is possible to attain carbon economy in Indian agriculture by implementing the necessary interventions to increase the efficiency factors in the use of water, nutrients, and energy. A soil that has a higher carbon storage capacity uses less energy during tillage operations and is more efficient in using water and nutrients (Mehra *et al.*, 2018). By lowering the demand for mineral fertilisers, increased nutrient usage efficiency can improve the C and energy economy indirectly by reducing the need for greater fertiliser application rates. Similar to this, modifying the microclimate with simple actions like mulching can aid

UNDER PEER REVIEW

in enhancing water efficiency and C economy. While the United States, Australia, China, and Vietnam have established systems for obtaining carbon credits from agricultural firms, India does not have such a system. The net decrease in CO_2equivalent emissions (after discounting the sink) needs to be appropriately priced and monitored in order to increase C economy (NAAS, 2014). The monitoring and verification of carbon credits that may be obtained from crops and crop-based activities, such as soil carbon sequestration, are currently not standardised. It is necessary to identify a few benchmark sites or systems in each agro-ecological zone in order to quantify changes in soil C stock over time and repeat the measurements. With the competing need for crop leftovers, such as feed, in mind, the amount of crop residues that can be retained and incorporated into the soil should be maximised. It is necessary to evaluate whether crop residues should be retained or incorporated into various soil types and to quantify the influence on soil C improvement. Adopting Best Management Practices (BMPs) can assist Indian agriculture attain carbon economy by optimising energy, water, and nutrient utilisation and promoting the build-up of carbon in the soil (Das *et al*., 2023). Farmers do not adopt BMPs on their own in the real world, despite the fact that doing so can increase the C economy. It might not be feasible to punish farmers in India for using their land improperly. It will be simpler if farmers that implement BMPs are offered incentives, which can be tracked using the right approach. Furthermore, soil C credits fetch substantially lower unit prices due to the extreme volatility of the agricultural C market. The problem of the C offset technique is not a compelling one because of these two facts. Rather, a steady stream of incentives for farmers who use climate-smart and best agricultural practices can assist spread the use of BMPs and tackle the problems associated with global warming. NGOs and small farmer groups can assist in keeping an eye on the farmers and providing incentives to them. It is necessary to create a system to give farmers incentives for the C advantages they have accumulated by using BMPs. This technique will raise crop productivity while maintaining improved soil health and C economy.

DIRECT SEEDED RICE

According to a 2022 Government of India report (GOI), during the Kharif season in India, about 55 percent of the country's total cultivated acreage (39.54 million hectares) is used for paddy cultivation. Additionally, as per the GOI in 2020 (GOI, 2022) paddy cultivation employs 57.5 percent of the nation's farming workforce directly and makes a substantial contribution to the agricultural gross domestic product. The paddy agriculture has lost land globally as a result of urbanisation, industrialization, and crop diversification. In order to maintain food security, an extra 114 million tonnes of milled rice would be needed by 2035; however, there is not enough land or water available to grow paddy agriculture (Singh *et al.*, 2015). Numerous issues, including salinity of the soil, irrigation, high agricultural wages, water shortages, and fertiliser expenses, constantly put rural India's livelihoods under stress. Managing resources effectively is crucial to addressing these problems (Dey *et al.*, 2023; Kuttippurath*et al.*, 2012). Moreover, agriculture in Southeast Asia, including India, is growing more expensive due to saturation of yield and skyrocketing input prices (Ray *et al.*, 2012; Nguyen *et al.*, 2006). Instead of using traditional methods that hurt the environment, farmers can use climate-smart agriculture techniques that preserve resources and boost efficiency (Dey *et al.*, 2023). A promising water-saving technique for paddy production is direct-seeded rice (DSR), which requires less time for field preparation,

UNDER PEER REVIEW

includes direct planting, and uses less irrigation water and greenhouse gas emissions from the soil (Tabbal *et al.*, 2002).From puddled transplanted rice (PTR), many farmers have made the switchto DSR. Farmers with little resources who deal with extreme weather conditions such as low water tables, sporadic rainfall, and protracted dry spells that hinder the use of rice-intensification systems are the main users of the DSR approach (Kumar *et al.*, 2011; Singh *et al.*, 2017). But other paddy farmers in India and other poor countries are also attempting to replace the more expensive PTR approach with the less expensive DSR technique (Johnkutty*et al.*, 2002).Pathak (2013) carried out a two-year field experiment in the Punjab area of Jalandhar, India, to measure the potential of DSR with TPR for labour-saving, water-saving, and greenhouse gas mitigation. He discovered that the average global warming potential (GWP) of CO_2, CH_4, and N_2O was 1.94 t/ha in DSR and 2.91 t/ha in TPR. Additionally, it was determined that GWP would decrease by 33 percent if the whole state under TPR were to switch to DSR. In addition, three to four irrigations were preserved under DSR without sacrificing production. When comparing DSR to TPR, the utilisation of tractors dropped to 58percentand the use of human labour to 45percent. This demonstrates that DSR can be a workable substitute for PTR in terms of mitigating and adapting to climate change and raising farmers' income by lowering GHG emissions, water use, and labour (both human and machine) without lowering yield (Pathak *et al.*, 2013). In Central Java, Indonesia, at the Indonesian Agricultural Environment Research Institute (IAERI), comparable research was carried out. According to Susilawati (2019), DSR has 47percent fewer CH4 emissions than PTR. Under DSR, GWP decreased by 46.4percentwithout a discernible yield loss.

Previous studies have demonstrated that yield loss in DSR is higher than in transplanted rice in the absence of effective weed management alternatives (Baltazar, 1992; Rao *et al.*, 2007). Effective weed management in DSR is extremely difficult since mismanaged weeds result in very little or no yield (Moody *et al.*, 1982; Singh *et al.*, 2008). Uncontrolled weeds lowered yields by 96percent in dry-DSR, 61percentin wet-DSR, and 40percent in the crop that was machine-transplanted (Kim *et al.*, 1998; Maity *et al.*, 2008). Weed infestation may be decreased with proper tillage and soil preparation. Accurate field levelling promotes greater pesticide efficiency and accurate water management, which both aid in better crop establishment (Jat *et al.*, 2009, Chauhan, 2012). According to Singh *et al.*(2009), the DSR stale seedbed approach reduced weed density by 53 percent compared to control. Additionally, Singh *et al.*,(2007) discovered that a 4 t/ha mulch made of wheat residue decreased the development of broadleaf weeds by 56–72percent and grass weeds by 44–47percent in dry drill-seeded rice.A partial budget study revealed that, under most circumstances, rice farmers will earn more money net by switching to DSR. Direct seeded rice (DSR) was found to increase farmers' revenue by 66percent in China when compared to puddled transplanted rice (Sha *et al.* 2019). Both Younas *et al.* (2015) and Sarangi *et al.* (2020) projected greater benefit-cost ratios and net economic advantages per hectare in DSR in Eastern India and Pakistan. The DSR (treatment) yield is consistently lower than the TPR (control) yield, which is consistent with certain research (Bhullar *et al.* 2018; Xu *et al.* 2019). This difference appears to be statistically significant. Joshi *et al.'s* (2013) study, which covered the Philippines, India, Cambodia, Thailand, and Nepal, demonstrated that, with appropriate management, DSR output might equal that of puddled transplanted rice and that it could be a workable solution for regions experiencing labour and water constraints.

UNDER PEER REVIEW

According to Alam *et al.* (2018), DSR can outperform Puddled Transplanted Rice in yields if management techniques are optimised. Training on effective weed control methods, such as correct land preparation and water management as preventative measures, is therefore essential to reduce the yield difference between DSR and Puddled Transplanted Rice, which is farmers' main concern.

According to a research study by Bautista *et al.* (2023), area, labour usage, tenurial status, irrigation, and electricity cost appear to have a major impact on farmers' adoption of DSR in both the WS and DS models. Greater acreage may persuade farmers to employ DSR rather than TPR in order to save costs and time. An increased likelihood of a farmer adopting DSR may also be associated with increased seed and pesticide use. Farmers will only use DSR when their usage of pesticides and seeds reaches a particular level. Beyond this, the farmer's probability of continuing or deciding to implement DSR is reduced. Conversely, reduced labour utilisation indicates a higher chance of DSR adoption among farmers. Additionally, it seems that farmers in irrigated areas are less likely to use DSR since irrigation makes transplanting possible, which most of them prefer due to the increased yield. Similarly, reduced electricity expenses indicate a farmer's propensity to employ DSR. Landowner farmers are also empowered to make decisions about their farms. In this instance, they seem more likely to use DSRpossibly in an effort to save labour expenses. The adoption of DSR technology is positively impacted by a number of parameters, including farmers' education, institutional financing, off-farm income, and smartphone ownership, according to research by Dey *et al.*, (2024). But implementation of DSR is limited by the age of farmers and the availability of irrigation. Compared to Transplanted Rice adopters, DSR adopters spend less on irrigation, pest control, fertiliser application, and land preparation.

UNDER PEER REVIEW

CONSERVATION TILLAGE PRACTICES

The equilibrium of the carbon cycle between agricultural soils and the environment is seriously upset by frequent and extensive soil tillage, which raises greenhouse gas emissions and depletes soil organic carbon stores (Lal 2007, 2008; Yang *et al.* 2019). Quite the reverse; according to Liu *et al.* (2022), conservation tillage may significantly alter the size and distribution of soil aggregates, which in turn influences the buildup of organic carbon (Six and Paustian 2014). According to Uri *et al.* (1998) and Bayer *et al.* (2006), conservation tillage lowers soil carbon emission rates while simultaneously increasing soils' ability to absorb organic carbon. But it also affects agricultural growth, which raises atmospheric CO_2 fixation (Li 2002). Conservation tillage has been listed by the Intergovernmental Panel on Climate Change (IPCC) as one of the key agricultural measures to mitigate climate change (Shukla *et al.* 2019).

The estimated area under CA-based systems is around two million hectares. This may be divided by the average landholding size in the regions where CA is most often used, namely Punjab (3.62 hectares) and Haryana (2.20 hectares) (DAC & FW, 2019). This will yield an approximation of the total number of farmers practicing CA in the nation. By dividing the total area by the average landholding size of these two states, it may be estimated that around 700,000 farmers throughout the nation practise CA. Since only rice, wheat, sugarcane, and maize-based cropping systems in India are encouraged to employ CA, the research focuses on crop yields for these crops, particularly in the IGP. Zero-tillage is said to have produced 10-17percent greater yields of wheat and rice in the IGP than traditional tillage. (Pradhan *et al.,* 2018; Joshi, 2011). Specialists in the domain primarily focus on the idea that reduced costs stem from optimised input costs. For example, labour, energy, and water reductions are expected to reduce the cost of production by around 15-16 percent, increasing farmers' revenue(Bhadu and others, 2018). According to systematic research conducted in the IGP, the average cost savings are estimated to be INR 5,760 per hectare (USD 78), or around 5 to 10 percent; the range of cost reductions varies depending on the soil and ecoregion and range from INR 3,055 to INR 8,500 per hectare (USD 40-115/ha).

CA techniques, like as zero or low till, save nutrients in the soil and release them gradually to plants. Nonetheless, nitrogen levels may be lowered by nitrogen immobilisation during the first few years following conversion to CA (Bhadu*et al.,* 2018). Using crop leftovers to maintain a permanent layer of soil enhances the physical, chemical, and biological qualities of the soil, lowers evaporative water loss, and boosts the soil's capacity to retain water. In the end, the crop waste is utilised as mulch to suppress weed growth, regulate soil temperature, and lessen evaporation once it breaks down (Bhan *et al.,* 2014). Crop diversification recovers nitrates that have leached into the soil profile and improves the efficiency of nitrogen usage.A meta-analysis of CA practices in the IGP revealed that the SOC stock increased annually by 0.16 to 0.49 mg C ha-^{1} yr-^{1}. Zero tillage and partial residue retention increased the advantages of SOC, according to a study by Powell and associates (2016) that monitored the concentrations of SOC in rice-wheat rotations in the eastern IGP for almost seven years (Sapkota *et al.,* 2017). According to a review research, no-tillage methods sequester between 367 and 3,667 kgs CO_2/hectare annually(Biswas *et al.,* 2016).According to tests, traditional till farms in the IGP released 0.6 mg of CO_2 equivalent per hectare. At the same time, zero-till systems sequestered 0.84 Mg of CO_2 equivalent per hectare, though no difference was observed between the two systems in terms of nitrous oxide emissions. Besides, on average, zero-till is known to save about 60 litres of fuel per hectare, reducing CO_2 emissions by 156 kg per hectare per year (Pratibha *et al.,* 2017).

Research has indicated that adoption of no-till California is more probable among farmers with greater levels of education since these farmers are more likely to comprehend new ideas and technology more readily (Knowler *et al.,* 2007; Nyambose*et al.,* 2013). The differences in land, income, group participation, financing availability, and CA training were substantial. Compared to adopters, farmers who did not embrace no-till CA farmed larger mean land areas. Income disparities between adopters who wait till California and those who don't. Adoption rates are positively correlated with income levels. The mean income of adopters of no till farming practices was Rs 1746, whereas that of non-adopters was Rs 1271. (Sheikh *et al.,* 2003; Kahimba*et al.,* 2014). A farmer with a higher income may purchase farming supplies and, as a result, practise conservation agriculture. Even Nevertheless, low-income families did not readily embrace CA, despite the fact that the majority of CA technologies are less expensive (low external input). This is likely due to the fact that these households were either unaware of the full benefits of CA or thought it would be expensive due to their ignorance. Once again, more conversations with farmers disclosed that small-scale farmers typically do not own infrastructure, such as fence materials, which need to be purchased with some money.

UNDER PEER REVIEW

According to the results of the Ntshangase *et al.* (2018) study, farmers who did not use no-till CA farmed greater land areas, earned less money, and had less access to financing and extension. The three main sources of income for those who adopted the no-till California model were government handouts, piece employment, and farming. Government grants are primarily social support funds that households eligible for Department of Social Development child, disability, and elderly assistance receive. However, a greater percentage of non-adopters of the no-till California system (65%) said that they relied on piece labour as a source of income. Farmers who receive more regular visits from extension agents are more likely to implement new farming techniques or technology that they learn about from these visits.

ORGANIC FARMING

Numerous studies have examined the sets of demographic and other social features of farmers, including professional skills, and have concluded that these qualities have an influence on farmers' decisions about moving forward with the conversion to carbon neutral farming techniques. More precisely, factors such as gender and off-farm activities, household wealth, age and experience (measured in years of farming), and household size (connected to the available workforce) were significant determinants of farmers’ decisions (Darnhofer*et al.*, 2005; Läpple, 2011; Läpple, 2013; Bui, 2020). A higher intention to proceed with organic conversion was linked to young farmers, a higher level of education and/or specialised agricultural training, and the use of ICT (Khaledi *et al.*, 2010; Koesling*et al.*, 2008; Kallas *et al.*, 2010). However, adoption of this strategy is constrained by household labour constraints (Adebiyi *et al.*, 2019). Because information and expertise play a significant role in helping organic farmers replace synthetic agrochemicals, a lack of awareness and understanding of climate smart technologies may prevent their adoption (Serra *et al.*, 2008; Adebiyi *et al.*, 2019). Thus, among the most crucial elements influencing conversion decisions were farmers' expertise, education, and training. Farmers acquire the majority of their knowledge through social learning and experiential learning, in addition to formal schooling and training (Veldstra*et al.*, 2014; Darnhofer*et al.*, 2005). Conversion decisions towards climate wise farming are also influenced by the connections among farmers, as demonstrated by their involvement in community organisations and the advantages that come with membership (Khaledi *et al.*, 2010; Darnhofer*et al.*, 2005). More precisely, views of other farmers' environmental activities and prior personal experiences have an impact on farmers' evolving attitudes towards environmental practices (Sutherland *et al.*, 2012). The adopted decision-making process was simultaneously impacted by a number of other variables, including the usage of the Internet (Khaledi *et al.*, 2010), farmers' livelihood assets, their vulnerability settings, in conjunction with livelihood activities and gender-related aspects (Adebiyi *et al.*, 2019).

Farmers were more likely to implement climate smart farming practices if they were more proactive in learning about the financial feasibility of carbon neutral farming and had higher regard for the environment and human health (Koesling*et al.*, 2020; Luh *et al.*, 2020; Adebiyi *et al.*, 2019). Particularly significant are the beliefs of farmers about carbon neutral farming, the financial risks (particularly during the conversion phase), the scepticism of social media, the doubts about the environmental advantages of organic farming, institutional

UNDER PEER REVIEW

factors, and communications from regulatory bodies (Siepmann *et al.,* 2018). Adoption decisions are heavily influenced by the sources of perceived hazards on the farms, which include unpredictable rainfall, a lack of expertise, and the market for organic goods (Nalubwama *et al.,* 2019). It is also necessary to consider the disincentive of anticipating increased expenses (Luh *et al.,* 2020). As technology developers transition into producers, the cost of setting up production facilities frequently results in difficult-to-achieve profits and raises the price of the novel good or service (Cullen *et al.,* 2013; Faber and Hoppe, 2013; Luthra *et al.,* 2014); these are known as "early adopter costs" (del Río Gonzalez, 2005) and affect both producers and consumers of technology. Changes in input prices (Kemp and Volpi, 2008), the existence of perverse subsidies for existing technologies (Weiss and Bonvillian, 2013), or consumer willingness to pay a premium for goods or procedures with less of an environmental impact (Reinstaller, 2008) are pertinent factors that influence the actual and relative costs of innovations.The adoption of innovations and technology in industrialised nations' agricultural contexts has been the subject of very little investigation. These include included Australian wool growers (Sneddon *et al.,* 2011), precision agricultural technology (PATS) (Tey and Brindal, 2012), vineyards in New Zealand (Cullen *et al.,* 2013), and the adoption of organic or genetic engineering approaches within Australian agriculture (Wheeler, 2008). These studies show that, although there are certain context-specific elements, such as industry-specific details or varying national regulatory regimes, there are overall few differences in the adoption of more generic technical innovations. For example, several of these studies draw attention to the effects of technological innovation adoption in these contexts, which appear to be illogical and wasteful. Examples of successful adoptions of innovations and technologies that are rejected by usersreverting to the original practice or technology even in situations where benefits are being realizedare cited in this context (Bewsell and Kaine, 2005; Cullen *et al.,* 2013; Sneddon *et al.,* 2011; Wheeler, 2008). These are explained in terms of the perceived advantages of adoption, as well as the function of social networks and communication channels and the primacy of perception. The relationship between information sources and how they affect perception (including imitation within adopter groups) is considered crucial, as is the part played by strong outside influencers like champions or consultants for new technologies (Sneddon *et al.,* 2011; Wheeler, 2008). It was said that among prospective consumers of CSA technical breakthroughs, the term "CSA" was not well understood. More generally, "jargon" was linked to climate change and sustainability measures (including CSA), making them difficult for non-experts to comprehend and unsettling. The lack of attention to "business impacts," such as how technological changes would affect "efficiency" or if they were "cost effective," was cited by potential users as a reason why it was difficult for them to embrace the necessity of CSA technical innovations.

A policy mix that may consist of rules, guidelines (like eco-brands, like biolabels), direct producer subsidies, input taxes, financing for research, provision of information and training, funding for investments, and sponsorship of communication tools (like consulting and promotional campaigns) (Sutherland, 2010; Dessart *et al.,* 2019; Cranfield *et al.,* 2010). The adoption of climate-smart practices and conversion decisions are strongly encouraged by subsidies, which are effective horizontal tools (Nalubwama *et al.,* 2019; Serra *et al.,* 2008; Läpple, 2010). For instance, it was discovered in a previously published study that adoption on poorer Spanish farms is motivated by an increase in subsidies. Adoption may be

UNDER PEER REVIEW

encouraged on a significant number of farms if the farmers received subsidies at levels comparable to those in the EU. The discovery that affluent farmers are early adopters is intriguing. However, poorer farms also switch to carbon neutral techniques like organic farming when the economic climate becomes more favourable for conversion (Serra *et al.*, 2008). This suggests that it is not anticipated that horizontal subsidies will be adequately effective and efficient if the variability across agricultural enterprises is not taken into account.

UNDER PEER REVIEW

INSTITUTIONAL SUPPORT FOR CARBON FARMING IN INDIA

The Indian government's Ministry of Rural Development and Ministry of Agriculture oversee a number of rural development initiatives, including the National Horticulture Mission (NHM), the Mahatma Gandhi National Rural Employment Guarantee Act (MNREGA) scheme, the Rashtriya Krishi Vikash Yojana (RKVY), the Pradhan Mantri Krishi Sinchayee Yojna (PMSKY), the Paramparagat Krishi Vikas Yojna (PKVY), the Natural Farming Bhartiya Prakratik Krishi Paddhati (NF-BPKP), the National Mission on Sustainable Agriculture (NMSA), and others (Prasad *et al.*, 2011) For example, planting legume fodder crops in bunds and green leaf manuring crops, conserving soil and water, and afforestation on waste areas and common lands can all be included in the national programmes. Agroforestry, micro irrigation, crop diversification, natural/organic farming, soil health management, integrated farming systems, and other initiatives launched by the Indian government are only a few of the programmes designed to entice farmers to participate in the carbon trading in agriculture. (Soni *et al.*, 2022). Carbon emitters can purchase created carbon credits to offset their emissions through voluntary carbon markets.(Kreibich and Hermwille, 2021)To guarantee the integrity and calibre of the initiatives, validation and verification are essential. The Carbon Credit Trading Scheme (CCTS), which allows obliged companies to trade carbon credits with one another, was issued by the Ministry of Power by notice S.O. 2825 (E). The National Action Plan on Climate Change (NAPCC) comprises missions in specific areas of solar energy, energy efficiency, water, sustainable agriculture, Himalayan ecosystem, sustainable habitat, green India, and strategic knowledge for climate change. (Chandel *et al.*, 2016)Thirty-three States /Union Territories (UTs) have prepared their State Action Plan on Climate Change (SAPCC) in line with NAPCC taking into account the State-specific issues relating to climate change.

CHALLENGES IN CARBON NEUTRAL FARMING:

Agro-environmental policies are required by the carbon farming initiatives (CFI) in order to encourage farmers to implement optimum farm management practices. However, the complexity of the scheme's design and implementation, as well as the competing interests of policymakers and farmers, can make it challenging to engage farmers in such programmes.The acceptance and use of novel farm management techniques are also known to be influenced by a number of other variables, such as the landowners' own interests and the characteristics of the farm (Liu *et al.,* 2018; Valdivia *et al.,* 2012). Inadequate management or skill sets and landholder interests also play a part in some of the obstacles faced by carbon farmers. Political unrest has a significant impact on these strategies' adoption and use as well (Conant *et al.,* 2011). Furthermore, a lack of knowledge about such programmes and policies as well as confusion about the effects on the environment might potentially impede their adoption (Funk *et al.,* 2014; Toensmeier, 2016). Most of the time, Indian farmers lack adequate access to knowledge about the many alternatives for carbon farming (Ingram *et al.,* 2016). As a matter of fact, a great deal of farmers are ignorant of the precise definition of carbon farming and are not well-versed in its advantages and disadvantages. High input prices and concerns about the impact of carbon farming on yield and agricultural productivity further exacerbated the problem. The absence of recognised practices and processes, more administrative costs, and the challenge of becoming certified as a competent carbon offset provider are among the other major obstacles facing CFI (Dhanda *et al.,* 2011; Macintosh *et al.,* 2012). Furthermore, it has been determined that the necessary capital expenditure, the incompatibility of carbon farming with current farm management techniques, and the potential effects on farmers' capacity to get bank loans or other funding sources are all important considerations (Evans *et al.,* 2015). Other obstacles that are worth mentioning in this context are the fluctuating prices of carbon, (Narassimhan*et al.,* 2018) the lack of clarity surrounding the advantages of carbon farming, (Alexander *et al.,* 2015) the challenge of tracking the development of these programmes, (Renwick *et al.,* 2013) the unpredictability of carbon market selling practices, (Kragt *et al.,* 2017) and the financial implications of involvement (Lo, 2016). Farmers that engage in agroforestry may be reluctant to adopt carbon farming since they have trouble selling the goods from their tree plantings (Ingram *et al.,* 2016; Macintosh *et al.,* 2012). In addition, the carbon farming policy incentivizes them for their historical mismanagement of the land, which inhibits their participation and raises the possibility that, in addition to the other hurdles already stated, farmer attitudes or interests might be a barrier to CFI participation (Tesfahunegn, 2019; Wang *et al.,* 2014). Under such circumstances, it appears that financial incentives alone won't be enough to address the obstacles that farmers typically encounter when they want to participate more in CFI.

CONCLUSION

Carbon farming encompasses a range of sustainable agricultural practices designed to enhance carbon sequestration and reduce greenhouse gas emissions. Among these practices, direct seeded rice, conservation tillage, and organic farming stand out as effective methods for improving soil health and mitigating climate change. Direct seeded rice reduces water usage and methane emissions compared to traditional puddled transplanting. Conservation tillage practices minimize soil disturbance, preserving soil organic matter and enhancing carbon storage. Organic farming eliminates synthetic inputs, promoting biodiversity and soil fertility, thereby contributing to long-term carbon sequestration.Factors affecting farmers' acceptance of carbon farming practices include economic viability, awareness, and access to technical knowledge. Financial incentives, such as carbon credits and subsidies, play a crucial role in encouraging adoption. Institutional support in India, including government schemes, research initiatives, and extension services, is essential for promoting these sustainable practices. Policies that facilitate access to resources, provide education, and offer financial

UNDER PEER REVIEW

assistance can significantly boost the adoption rates of carbon farming.However, challenges persist in achieving widespread carbon-neutral farming. Small landholdings, financial constraints, and lack of awareness hinder the transition to sustainable practices. Addressing these challenges requires a coordinated effort involving policymakers, research institutions, and the farming community. Enhancing institutional support, providing targeted education and training, and developing market mechanisms for carbon credits are vital steps toward overcoming these barriers. Carbon farming has the potential to transform Indian agriculture, making it more sustainable and resilient to climate change. By adopting best management practices such as direct seeded rice, conservation tillage, and organic farming, and addressing the factors affecting farmers' acceptance, India can lead the way in carbon-neutral farming. Strengthened institutional support and targeted policy interventions are crucial for overcoming challenges and realizing the full potential of carbon farming in India.

UNDER PEER REVIEW

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

REFERENCES:

Adebiyi JA, Olabisi LS, Richardson R, Liverpool-Tasie LSO, Delate K. Drivers and Constraints to the Adoption of Organic Leafy Vegetable Production in Nigeria: A Livelihood Approach. Sustainability. 2019; 12(96).

Alam MJ, Humphreys E, Sarkar MAR, Sudhir-Yadav. Comparison of dry seeded and puddled transplanted rainy season rice on the High Ganges River Floodplain of Bangladesh.. European Journal of Agronomy. 2018; 96: 120–130

Alexander P, Paustian K, Smith P, Moran D. The Economics of Soil C Sequestration and Agricultural Emissions Abatement. Soil. 2015; 1, 331–339.

Almaraz M, Wong MY, Geoghegan EK, Houlton BZ. A review of carbon farming impacts on nitrogen cycling, retention, and loss. Annals of the New York Academy of Sciences. 2021; 1505(1), 102–117. https://doi.org/10.1111/nyas.14690

Arriaga FJ, Guzman J, Lowery B. Conventional agricultural production systems and soil functions. Soil health and intensification of agro-ecosytems. Academic Press. 2017; 109-125

Avasiloaiei DI, Calara M, Brezeanu PM, Gruda NS, Brezeanu C. The evaluation of carbon farming strategies in organic vegetable cultivation. Agronomy. 2023; 13(9), 2406. https://doi.org/10.3390/agronomy13092406

Baltazar AM, De Datta SK. Weed management in rice. Weed Abstr. 1992; 41:495–508

Bautista APG, Mataia AB, Austria CP, Tiongco M.M, Laborte AG. Adoption and Performance of Direct-seeded Rice (DSR) Technology in the Philippines. Philippine Journal of Science. 2023; 152 (1): 459-484

Bayer C, Martin-Neto L, Mielniczuk J. Carbon sequestration in two Brazilian Cerrado soils under no-till. Soil Tillage Res. 2006; 86(2):237–245.

Bewsell D, Kaine G. Adoption of environmental best practice amongst dairy farmers. In: 11th Annual Conference of the New Zealand Agricultural and Resource Economics Society Inc. Nelson. 2005.

Bhadu K, Choudhary R, Poonia T, Patidar P, Choudhary KM, Kakraliya SK. A Review Paper on Concept, Benefits and Constraints of Conservation Agriculture in India. International Journal of Chemical Studies. 2018; 6(4): 36-40.

Bhan S, Behera UK. Conservation Agriculture in India - Problems, Prospects and Policy Issues. International Soil and Water Conservation Research. 2014; 2(4): 1-12. doi:10.1016/S2095-6339(15)30053-8.

Bhullar MS, Singh S, Kumar S, Gill G. Agronomic and economic impacts of direct seeded rice in Punjab. Agricultural Research Journal. 2018; 55(2): 236–242.

Biswas AK, Chaudhary RS. Consortia Research Platform on Conservation Agriculture. Bhopal; 2016. Available at: http://www.jiss.nic.in/CRP on Conservation Agriculture.pdf.

Bolan NS, Adriano DC, Kunhikrishnan A, James T, McDowell R, Senesi N. Dissolved Organic Matter: Biogeochemistry, Dynamics, and Environmental Significance in Soils. Advances in Agronomy. 2011; 110: 1-75.

Campbell CA, Zentner RP, Selles F, Biederbeck VO, McConkey BG, Blomert B, Jefferson PG. Quantifying short-term effects of crop rotations on soil organic carbon in southwestern Saskatchewan. Canadian Journal of Soil Science. 2000; 80: 193-202.

Chandel SS, Shrivastva R, Sharma V, Ramasamy P. Overview of the initiatives in renewable energy sector under the national action plan on climate change in India. Renewable and Sustainable Energy Reviews. 2016; 54: 866-873.

Chauhan BS. Weed ecology and weed management strategies for dry-seeded rice in Asia. Weed Technology. 2012; 26: 1-13.

Chen L, Msigwa G, Yang M, Osman AI, Fawzy S, Rooney DW, Yap PS. Strategies to achieve a carbon neutral society: A review. Environmental Chemistry Letters. 2022; 20(4): 2277-2310.

Conant RT, Ogle SM, Paul EA, Paustian K. Measuring and Monitoring Soil Organic Carbon Stocks in Agricultural Lands for Climate Mitigation. Frontiers in Ecology and the Environment. 2011; 9: 169-173.

Cranfield J, Henson S, Holliday J. The motives, benefits, and problems of conversion to organic production. Agriculture and Human Values. 2010; 27: 291-306.

Cullen R, Forbes SL, Grout R. Non-adoption of environmental innovations in wine growing. New Zealand Journal of Crop and Horticultural Science. 2013; 41: 41-48.

DAC&FW. Agriculture Census 2015-16. New Delhi; 2019. Available at: http://agcensus.nic.in/document/agcen1516/T1_ac_2015_16.pdf.

UNDER PEER REVIEW

Darnhofer I, Schneeberger W, Freyer B. Converting or Not Converting to Organic Farming in Austria: Farmer Types and Their Rationale. Agriculture and Human Values. 2005; 22: 39-52.

Das TK, Kumar S, Das A, Ansari MA, Raj R, Ghosh S. Sustainable production systems. In: Trajectory of 75 years of Indian agriculture after Independence. Singapore: Springer Nature Singapore; 2023. p. 541-575.

del Río Gonzalez P. Analysing the factors influencing clean technology adoption: a study of the Spanish pulp and paper industry. Business Strategy and the Environment. 2005; 14: 20-37.

Dessart FJ, Barreiro-Hurlé J, van Bavel R. Behavioural factors affecting the adoption of sustainable farming practices: A policy-oriented review. European Review of Agricultural Economics. 2019; 46: 417-471.

Dey A, Singh R, Sharma P, Patel S. Empirical evidence for economic viability of direct seeded rice in peninsular India: An action-based research. Heliyon. 2024; 10: e26754.

Dey S, Abbhishek K, Swain DK. Resource use efficiency estimation and technology verification trial for sustainable improvement in paddy production: An action-based research. International Journal of Plant Production. 2023; 17: 337–352. https://doi.org/10.1007/s42106-023-00243-6.

Dey S, Singh PK, Abbhishek K, Singh A, Chander G. Climate-resilient agricultural ploys can improve livelihood and food security in Eastern India. Environment, Development and Sustainability. 2023. https://doi.org/10.1007/s10668-023-03176-2.

Dhanda KK, Hartman LP. The Ethics of Carbon Neutrality: A Critical Examination of Voluntary Carbon Offset Providers. Journal of Business Ethics. 2011; 100: 119-149.

Evans MC, Carwardine J, Fensham RJ, Butler DW, Wilson KA, Possingham HP, Martin TG. Carbon Farming via Assisted Natural Regeneration as a Cost-Effective Mechanism for Restoring Biodiversity in Agricultural Landscapes. Environmental Science and Policy. 2015; 50: 114-129.

Faber A, Hoppe T. Co-constructing a sustainable built environment in the Netherlands: Dynamics and opportunities in an environmental sectoral innovation system. Energy Policy. 2013; 52: 628-638.

Funk JM, Field CB, Kerr S, Daigneault A. Modeling the Impact of Carbon Farming on Land Use in a New Zealand Landscape. Environmental Science and Policy. 2014; 37: 1-10.

Gopalasundaram P, Bhaskaran A, Rakkiyappan P. Integrated nutrient management in sugarcane. Sugar Tech. 2012; 14: 3-20.

Government of India (GOI). Economic Survey 2020-21. Ministry of Finance, Department of Economic Affairs, Economic Division; 2022.

Hartmann J, West AJ, Renforth P, Köhler P, De La Rocha CL, Wolf-Gladrow DA, Dürr HH, Scheffran J. Enhanced Chemical Weathering as a Geoengineering Strategy to Reduce Atmospheric Carbon Dioxide, Supply Nutrients, and Mitigate Ocean Acidification. Reviews of Geophysics. 2013; 51: 113-149.

Ingram J, Mills J, Dibari C, Ferrise R, Ghaley BB, Hansen JG, Iglesias A, Karaczun Z, McVittie A, Merante P. Communicating Soil Carbon Science to Farmers: Incorporating Credibility, Salience and Legitimacy. Journal of Rural Studies. 2016; 48: 115–128.

Jansson C, Faiola C, Wingler A, Zhu XG, Kravchenko A, De Graaff MA, Beckles DM. Crops for carbon farming. Frontiers in Plant Science. 2021; 12: 636709.

Jat ML, Gathala MK, Ladha JK, Saharawat YS, Jat AS, Kumar V, Sharma SK, Kumar V, Gupta RK. Evaluation of precision land levelling and double zero-till systems in the rice-wheat rotation: Water use, productivity, profitability and soil physical properties. Soil and Tillage Research. 2009; 105: 112–121.

Johnkutty I, Mathew G, Mathew J. Comparison between transplanting and direct-seeding methods for crop establishment in rice. Journal of Tropical Agriculture. 2002; 40: 65-66.

Joshi E, Kumar D, Lal B, Nepalia V, Gautam P, Vyas AK. Management of direct seeded rice for enhanced resource-use efficiency. Plant Knowledge Journal. 2013; 2(3): 119–134.

Joshi PK. Conservation Agriculture: An Overview. Indian Journal of Agricultural Economics. 2011; 66(1): 53-63.

Kahimba FC, Mutabazi KD, Tumbo SD, Masuki KF, Mbungu WB. Adoption and Scaling-Up of Conservation Agriculture in Tanzania: Case of Arusha and Dodoma Regions. Natural Resources. 2014; 5: 161–176.

Kallas Z, Serra T, Gil JM. Farmers' objectives as determinants of organic farming adoption: The case of Catalonian vineyard production. Agricultural Economics. 2010; 41: 409–423.

Kemp R, Volpi M. The diffusion of clean technologies: A review with suggestions for future diffusion analysis. Journal of Cleaner Production. 2008; 16: S14-S21.

Khaledi M, Weseen S, Sawyer E, Ferguson S, Gray R. Factors Influencing Partial and Complete Adoption of Organic Farming Practices in Saskatchewan, Canada. Canadian Journal of Agricultural Economics. 2010; 58: 37-56.

Kim HH, Pyon JY. Weed occurrence and yield loss due to weeds in different direct seeded rice paddy fields. Korean Journal of Weed Science. 1998; 18(1): 12–19.

Knowler D, Bradshaw B. Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy. 2007; 32: 25–48.

Koesling M, Flaten O, Lien G. Factors influencing the conversion to organic farming in Norway. International Journal of Agricultural Resources, Governance and Ecology. 2008; 7: 78.

Kragt ME, Dumbrell NP, Blackmore L. Motivations and Barriers for Western Australian Broad-Acre Farmers to Adopt Carbon Farming. Environmental Science and Policy. 2017; 73: 115–123.

Kreibich N, Hermwille L. Caught in between: Credibility and feasibility of the voluntary carbon market post-2020. Climate Policy. 2021; 21(7): 939-957.

Kumar V, Ladha JK. Direct seeding of rice. In: Advances in Agronomy. Academic Press; 2011. p. 297–413. https://doi.org/10.1016/B978-0-12-387689-8.00001-1.

Kuttippurath J, Abbhishek K, Chander G, Dixit S, Singh A, Das D, Dey S. Biochar-based nutrient management as a futuristic scalable strategy for C-sequestration in semiarid tropics. Journal of Agronomy. 2023; 115(5): 2311–2324. doi:10.1002/agj2.21424.

Lal R. Constraints to adopting no-tillage farming in developing countries. Soil and Tillage Research. 2007; 96(1): 1–5. doi:10.1016/j.still.2007.06.001.

UNDER PEER REVIEW

Lal R. Promise and limitations of soils to minimize climate change. Journal of Soil and Water Conservation. 2008; 63(4): 113A-118A. doi:10.2489/63.4.113A.Läpple, D. 2010 Adoption and Abandonment of Organic Farming: An Empirical Investigation of the Irish Drystock Sector: Adoption and Abandonment of Organic Farming. J. Agric, Econ., 61, 697–714.

Läpple D, Rensburg TV. Adoption of organic farming: Are there differences between early and late adoption? Ecological Economics. 2011; 70: 1406–1414.

Läpple D. Comparing attitudes and characteristics of organic, former organic and conventional farmers: Evidence from Ireland. Renewable Agriculture and Food Systems. 2013; 28: 329–337.

Li K-R. Land use change, net greenhouse gas emissions and terrestrial ecosystem carbon cycle. Beijing, China; 2002. pp. 260-261.

Liu T, Bruins RJ, Heberling MT. Factors Influencing Farmers' Adoption of Best Management Practices: A Review and Synthesis. Sustainability. 2018; 10: 432.

Liu X, Li Q, Tan S, et al. Evaluation of carbon mineralization and its temperature sensitivity in different soil aggregates and moisture regimes: a 21-year tillage experiment. Science of the Total Environment. 2022; 837: 155566. https://doi.org/10.1016/j.scitotenv.2022.155566.

Lo AY. Challenges to the Development of Carbon Markets in China. Climate Policy. 2016; 16: 109–124.

Luh Y-H, Tsai M-H, Fang C-L. Do first-movers in the organic market stand to gain? Implications for promoting cleaner production alternatives. Journal of Cleaner Production. 2020; 262: 121156.

Luthra S, Kumar S, Kharb R, Ansari MF, Shimmi SL. Adoption of smart grid technologies: an analysis of interactions among barriers. Renewable and Sustainable Energy Reviews. 2014; 33: 554–565.

Macintosh A, Waugh L. An Introduction to the Carbon Farming Initiative: Key Principles and Concepts. Environmental Planning Law Journal. 2012; 2: 439–461.

Maity SK, Mukherjee PK. Integrated weed management in dry direct-seeded rice (Oryza sativa L.). Indian Journal of Agronomy. 2008; 53(2): 116–120.

Mehra P, Baker J, Sojka RE, Bolan N, Desbiolles J, Kirkham MB, Ross C, Gupta R. A review of tillage practices and their potential to impact the soil carbon dynamics. Advances in Agronomy. 2018; 150: 185-230.

Moody K, Mukhopadhyay K. Weed control in dry seeded rice—problems, present status, and research direction. In: Rice Research Strategies for the Future. International Rice Research Institute, Manila, Philippines; 1982. pp. 147–158.

Nalubwama S, Kabi F, Vaarst M, Kiggundu M, Smolders G. Opportunities and challenges for integrating dairy cattle into farms with certified organic pineapple production as perceived by smallholder farmers in Central Uganda. Organic Agriculture. 2019; 9: 29–39.

Narassimhan E, Gallagher KS, Koester S, Alejo JR. Carbon Pricing in Practice: A Review of Existing Emissions Trading Systems. Climate Policy. 2018; 18: 967–991.

National Academy Of Agricultural Sciences (NAAS). Carbon Economy in Indian Agriculture. Policy Paper 69. New Delhi; 2014.

UNDER PEER REVIEW

Ntshangase NL, Muroyiwa B, Sibanda M. Farmers' Perceptions and Factors Influencing the Adoption of No-Till Conservation Agriculture by Small-Scale Farmers in Zashuke, KwaZulu-Natal Province. Sustainability. 2018; 10: 555.

Nyambose W, Jumbe C. Does Conservation Agriculture Enhance Household Food Security? Evidence from Smallholder Farmers in Nkhotakota in Malawi. Sustainable Agriculture Research. 2013; 5: 118–128.

Pathak H, Sankhyan S, Dubey DS, Bhatia A, Jain N. Dry direct-seeding of rice for mitigating greenhouse gas emission: Field experimentation and simulation. Paddy and Water Environment. 2013; 11: 593–601.

Powlson DS, Stirling CM, Thierfelder C, White RP, Jat ML. Does Conservation Agriculture Deliver Climate Change Mitigation through Soil Carbon Sequestration in Tropical Agro-Ecosystems? Agriculture, Ecosystems and Environment. 2016; 220: 164-174. https://doi.org/10.1016/j.agee.2016.01.005.

Pradhan P, Verma A, Kumar M. Need of Conservation Agriculture in India: Sustainability. International Journal of Current Microbiology and Applied Sciences. 2018; 7(1): 308-314.

Prasad N, Kumar K, Chandra J, Naik R. Ministry of Rural Development. 2011.

Pratibha G, Biswas PP, Chaudhari SK. Best Practices of Conservation Agriculture in India. In: Pandey PR, Gurung TR, editors. SAARC Agriculture Centre. Dhaka: SAARC Agriculture Centre; 2017. p. 190.

Rao AN, Johnson DE, Sivaprasad B, Ladha JK, Mortimer AM. Weed management in direct seeded rice. Advances in Agronomy. 2007; 93: 153–255.

Rao AN, Nagamani A. Available technologies and future research challenges for managing weeds in dry-seeded rice in India. In: Proceedings of the 21st Asian Pacific Weed Science Society Conference; 2–6 October 2007; Colombo, Sri Lanka. 2007. pp. 391–491.

Reinstaller A. The technological transition to chlorine-free pulp bleaching technologies: Lessons for transition policies. Journal of Cleaner Production. 2008; 16: S133–S147.

Renwick A, Ball AS, Pretty JN. Economic, biological, and policy constraints on the adoption of carbon farming in temperate regions. In: Capturing Carbon and Conserving Biodiversity. Routledge, Oxfordshire, UK; 2013. pp. 197–218.

Sapkota TB, Jat RK, Singh RG, Jat ML, Stirling CM, Jat MK, Bijarniya D, et al. Soil Organic Carbon Changes after Seven Years of Conservation Agriculture in a Rice-Wheat System of the Eastern Indo-Gangetic Plains. Soil Use and Management. 2017; 33(1): 81-89. https://doi.org/10.1111/sum.12331.

Sarangi SK, Singh S, Kumar V, Srivastava AK, Sharma PC, Johnson DE. Tillage and crop establishment options for enhancing the productivity, profitability, and resource use efficiency of rice-rabi systems of the salt-affected coastal lowlands of eastern India. Field Crops Research. 2020; 247: 107494.

Serra T, Zilberman D, Gil JM. Differential uncertainties and risk attitudes between conventional and organic producers: The case of Spanish arable crop farmers. Agricultural Economics. 2008; 39: 219–229.

UNDER PEER REVIEW

Sha W, Chen F, Mishra AK. Adoption of direct seeded rice, land use, and enterprise income: Evidence from Chinese rice producers. Land Use Policy. 2019; 83: 564–570. https://doi.org/10.1016/j.landusepol.2019.01.039.

Sharma M, Kaushal R, Kaushik P, Ramakrishna S. Carbon farming: Prospects and challenges. Sustainability. 2021; 13(19): 11122. https://doi.org/10.3390/su131911122.

Sheikh AD, Rehman T, Yates CM. Logit models for identifying the factors that influence the uptake of new "no-tillage" technologies by farmers in the rice-wheat and the cotton-wheat farming systems of Pakistan's Punjab. Agricultural Systems. 2003; 75: 79–95.

Shukla J, Skea E, Calvo BV, et al. Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. IPCC Special Report. 2019.

Siepmann L, Nicholas K. German Winegrowers' Motives and Barriers to Convert to Organic Farming. Sustainability. 2018; 10: 4215.

Singh H, Buttar GS, Brar AS, Deol JS. Crop establishment method and irrigation schedule effect on water productivity, quality, economics and energetics of aerobic direct-seeded rice (Oryza sativa L.). Paddy and Water Environment. 2017; 15: 101-109. doi:10.1007/S10333-016-0532-4.

Singh M, Bhullar MS, Chauhan BS. Influence of tillage, cover cropping, and herbicides on weeds and productivity of dry direct-seeded rice. Soil and Tillage Research. 2015; 147: 39–49. https://doi.org/10.1016/j.still.2014.11.007.

Singh S, Bhushan L, Ladha JK, Gupta RK, Rao AN, Shivprasad B. Weed management in aerobic rice systems under varying establishment methods. Crop Protection. 2008; 27(3-5): 660–671.

Singh S, Chhokar RS, Gopal R, Ladha JK, Gupta RK, Kumar V, Singh M. Integrated weed management: A key to success for direct-seeded rice in the Indo-Gangetic Plains. In: Ladha JK, Singh Y, Erenstein O, Hardy B, editors. Integrated Crop and Resource Management in the Rice-Wheat System of South Asia. Los Baños, Philippines: International Rice Research Institute; 2009; 261–278.

Singh S, Ladha JK, Gupta RK, Bhushan L, Rao AN, Sivaprasad B, Singh PP. Evaluation of mulching, intercropping with Sesbania and herbicide use for weed management in dry-seeded rice (Oryza sativa L.). Crop Protection. 2007; 26: 518–524

Six J, Paustian K. Aggregate-associated soil organic matter as an ecosystem property and a measurement tool. Soil Biology and Biochemistry. 2014; 68(1): A4–A9.

Sneddon J, Soutar G, Mazzarol T. Modelling the faddish, fashionable and efficient diffusion of agricultural technologies: A case study of the diffusion of wool testing technology in Australia. Technological Forecasting and Social Change. 2011; 78: 468–480.

Soni R, Gupta R, Agarwal P, Mishra R. Organic farming: A sustainable agricultural practice. Vantage: Journal of Thematic Analysis. 2022; 3(1): 21-44.

Spotorno S, Gobin A, Vanongeval F, Del Borghi A, Gallo M. Carbon farming practices assessment: Modelling spatial changes of soil organic carbon in Flanders, Belgium. Science of The Total Environment. 2024; 922: 171267. https://doi.org/10.1016/j.scitotenv.2024.171267.

UNDER PEER REVIEW

Susilawati HL, Setyanto P, Kartikawati R, Sutriadi MT. The opportunity of direct seeding to mitigate greenhouse gas emission from paddy rice field. In: IOP Conference Series: Earth and Environmental Science 2019; 393(1): 01204.

Sutherland LA, Darnhofer I. Of organic farmers and ‘good farmers’: Changing habitus in rural England. Journal of Rural Studies. 2012; 28: 232–240.

Tabbal DF, Bouman BAM, Bhuiyan SI, Sibayan EB, Sattar MA. On-farm strategies for reducing water input in irrigated rice: case studies in the Philippines. Agricultural Water Management. 2002; 56: 93-112. doi:10.1016/S0378-3774(02)00007-0.D.K. Ray, N. Ramankutty, N.D. Mueller, P.C. West, J.A. Foley (2012). Recent patterns of crop yield growth and stagnation, Nat. Commun. 3:1293, https://doi. org/10.1038/ncomms2296.

Tesfahunegn GB. Farmers’ Perception on Land Degradation in Northern Ethiopia: Implication for Developing Sustainable Land Management. Social Science Journal. 2019; 56: 268–287.

Tey Y, Brindal M. Factors influencing the adoption of precision agricultural technologies: A review for policy implications. Precision Agriculture. 2012; 13: 713–730.

Toensmeier E. The Carbon Farming Solution: A Global Toolkit of Perennial Crops and Regenerative Agriculture Practices for Climate Change Mitigation and Food Security. London, UK: Chelsea Green Publishing; 2016.

Uri N, Atwood J, Sanabria J. An evaluation of the environmental costs and benefits of conservation tillage. Environmental Impact Assessment Review. 1998; 18(6): 521–550.

Valdivia C, Barbieri C, Gold MA. Between Forestry and Farming: Policy and Environmental Implications of the Barriers to Agroforestry Adoption. Canadian Journal of Agricultural Economics. 2012; 60: 155–175.

Van Nguyen N, Ferrero A. Meeting the challenges of global rice production. Paddy and Water Environment. 2006; 4: 1–9. https://doi.org/10.1007/S10333-005-0031-5.

Veldstra MD, Alexander CE, Marshall MI. To certify or not to certify? Separating the organic production and certification decisions. Food Policy. 2014; 49: 429–436.

Wang X, VandenBygaart AJ, McConkey BC. Land Management History of Canadian Grasslands and the Impact on Soil Carbon Storage. Rangeland Ecology & Management. 2014; 67: 333–343.

Weiss C, Bonvillian WB. Legacy sectors: Barriers to global innovation in agriculture and energy. Technology Analysis & Strategic Management. 2013; 25: 1189–1208.

Wheeler SA. The barriers to further adoption of organic farming and genetic engineering in Australia: Views of agricultural professionals and their information sources. Renewable Agriculture and Food Systems. 2008; 23: 161–170.

Xu L, Li X, Wang X, Xiong D, Wang F. Comparing the grain yields of direct-seeded and transplanted rice: A meta-analysis. Agronomy. 2019; 9(11).

Yang Y, Tilman D, Furey G, et al. Soil carbon sequestration accelerated by restoration of grassland biodiversity. Nature Communications. 2019; 10: 718. https://doi.org/10.1038/s41467-019-08636-w.

UNDER PEER REVIEW

Younas M, Rehman M, Hussain A, Ali L, Waqar M. Economic comparison of direct seeded and transplanted rice: Evidence from adaptive research area of Punjab Pakistan. Asian Journal of Agriculture and Biology. 2015; 4(1): 1–7.

UNDER PEER REVIEW