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Economy-wide impact of climate smart agriculture in India: a SAM framework

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Abstract

In the context of climate change, the Indian agricultural sector treads in a certain duality between promoting food security in response to the increasing population, but at the same time in ensuring environmental sustainability, and sustained economic growth, especially in developing countries like India. The concept of Climate Smart Agriculture (CSA) emerged from the recognition of this duality. Using the Indian Social Accounting Matrix (SAM) 2017–18, the economy-wide effects arising out of agricultural interventions were estimated, keeping accord with the impacts on sectoral outputs and household incomes from the adoption of varying CSA interventions such as Conservation Agriculture, System of Rice and Wheat Intensification (SRI-SWI) and Natural Farming, fitting the three-pillared criterion of CSA—(1) Productivity (2) Adaptation and (3) Mitigation. Additionally, a shift in cropping patterns from Paddy and Wheat to less emission-intensive crops was also studied. Results show that SRI-SWI provides the highest economy-wide impacts while accounting for lower GHG and water footprint. Alternative crops such as Maize, Sorghum, and Millet have minimal increase in income and output effects while having lower water and carbon intensity compared to rice and wheat. The current study would sensitize policymakers to prioritize suitable policy and institutional measures for upscaling climate smart interventions in India.

Keywords: Climate change, Conservation agriculture, Social accounting matrix, Organic farming, Zero budget natural farming

JEL Classification: Q16, Q18

1 Introduction

Agricultural sector plays a pivotal role in promoting food security in response to the increasing population. In 2020, it was estimated that nearly 690 million people, or 8.9% of the global population live in hunger (FAO 2020a, b). This situation is expected to aggravate the need of producing 70% more food by 2050 to feed an estimated 9 billion people. Developing countries with close agrarian economic linkages are particularly more vulnerable to the effects of climate change and are headed towards severe livelihood challenges due to declining agricultural productivity and increasing food demand, culminating in income and food insecurity (Mendelsohn 2008; Fischer et al. 2005; Wheeler and Von Braun 2013). Calzadilla et al. (2013) predict by 2050, there will be an overall minimum loss in global welfare and GDP of about USD 268 billion and USD 265 billion respectively,

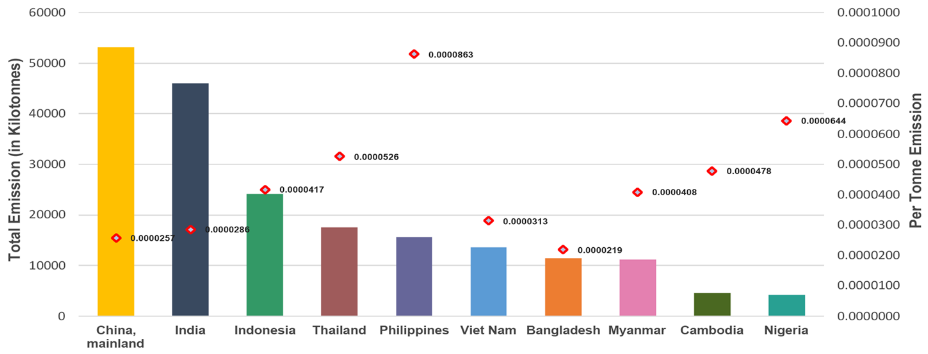

Fig. 1 Top 10 GHG Emitting Countries from Paddy Cultivation (2010–19)

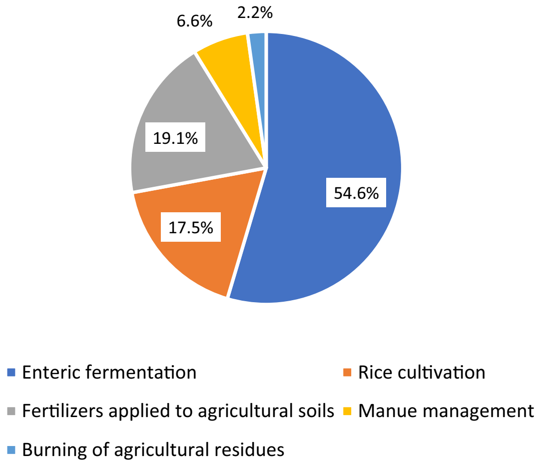

Fig. 2 Category-wise CO_2eq. Agricultural emissions in India 2016 (in percentage)

due to a fall in agricultural production from the impacts of climate change. In a country like India, 54.6% of the total workforce is employed in the agriculture sector, contributing 17.8% to the country's Gross Value Added (GVA) (FAO 2020a, b),

The emissions from the agriculture sector are generated from production and post-farm processes, accounting for 18.4% of the total global greenhouse emissions in 2016 (Ritchie & Roser 2020). The GHGs N_2O and CH_4 constitute a higher share of agricultural emissions with Global Warming Potential (GWP) of 34 and 298 times (IPCC 2013). Of the countries among the top ten GHG emissions from paddy cultivation, nine countries are located in Asia of which, India ranks second (Fig. 1).

In the case of India, 14% of the cumulative CO_2eq. Emissions were attributed to the agriculture sector (UNFCCC 2021). The category-wise agricultural emissions in India are presented in Fig. 2.

The agricultural GHG emission is primarily attributed to enteric emissions of livestock and cultivation of emission-intensive foodgrain crops such as rice and wheat, contributing 41% of the anthropogenic methane and 74% of nitrous oxide emissions (FAO 2020a, b; Pathak Bhatia and Jain 2014; Kashyap and Agarwal 2020) (see Appendix 1). The CH_4 emissions constitute the highest share (54.6%) and N_2O emissions are through the application of fertilizers to agricultural soils (19.1%). Rice cultivation also leads to CH_4 and N_2O emissions, with a GWP of 467, which is 169% higher compared to wheat and maize (Linquist et al. 2012). In 2021, rice cultivation encompassed an area of 43 million hectares which was 34% of total foodgrain area coverage in the country (GOI 2022a, b, c) and is the second highest rice producer in the world (Shahbandeh 2022). Along with the agriculture sector contributing significantly towards non-CO_2 emissions, it is also input-intensive, especially in energy, water, fertilizers, and pesticides. Indian agriculture accounts for 80% of the total freshwater consumption in the country (Dhawan 2017; Sen 2018). The agricultural water consumption is largely unregulated and inefficient (Dhawan 2017). This leads to the over-extraction of groundwater resources, thus making India the largest consumer of groundwater in the world, more than the USA and China combined (Jovial 2022). Globally, around 40% of irrigation is sourced from groundwater whereas in India it is well over 50%. The electricity consumption by the agriculture sector accounts for 17.35% share (CEA 2023), however, the agricultural power load is becoming an increasing challenge (PIB 2015). Between 2010 and 2021, agricultural power consumption increased by 80% (CEIC 2021) in the country.

At the policy and institutional levels, the Government of India has taken several steps that attempt to create sustainability in agricultural production systems. Initiatives such as the Paramparagat Krishi Vikas Yojana (organic farming) are aimed at reducing chemical fertilizer usage which is 209 kg/ha in India, compared to the world average of 146 kg/ha (World Bank 2022). The government has set a target of achieving 10% of the cultivated area into organic farmlands by 2025 (GOI 2016). Additional programs in tackling unsustainable agricultural practices have been initiated such as Pradhan Mantri Krishi Sinchayee Yojana (efficient irrigation), Neeranchal (watershed development), National Initiative on Climate Resilient Agriculture (NICRA), reduction in fossil fuel subsidies, and National Adaptation Fund (Praveen and Ramachandran 2020).

The government of India is also promoting millets as an alternative to other foodgrains such as wheat and rice. India is responsible for 20% of global millet production (GOI 2022a, b, c). To this end, at the request of the government, the United Nations declared 2023 as the International Year of Millets. Davis et al. (2019) show that the substitution of rice in each district with alternative cereals leads to a significant decrease in blue water footprint while ensuring the availability of higher nutrient content such as protein (+ 1%), iron (+ 27%), and zinc (+ 13%). Furthermore, these alternative cereals have a significantly lesser GHG footprint as, unlike rice, they do not require continuous flooding conditions. While there aren't any methane emissions compared to wheat, they require the same or lesser fertilizer inputs, thus curbing down the nitrogen emissions (Sah and Devakumar 2018). Simultaneously, ensuring judicious resource utilization and sustained economic growth is essential for a country's long-term sustenance. The concept of Climate Smart Agriculture (CSA) emerged from the recognition of this duality of environmental sustainability and economic stability; proposed by FAO (2009) to address the impact of both the 2008 food price crisis and global warming on the agricultural sector. Even though FAO has set it to be context specific in accordance with local needs, the operationalization of CSA has so far also drawn heavily on conventional, top–down, technical solutions to achieve impact at scale.

The three objectives of CSA of productivity, adaptation, and mitigation can be pursued with a viable spectrum of varied options, ranging from agroforestry with strict adherence to organic practices to technologically intensive practices advocating for a higher level of mechanization and biotechnology. Lipper and Zilberman (2018) consider CSA to be a relatively new concept which attempts to integrate responses to climate change into sustainable agricultural development, hence it should be considered more of a guiding objective rather than a fixed prescriptive solution. The agenda of CSA is outcome oriented compared to agroecological approaches which are more method driven, while the latter is consistent with the former but not vice-versa. A better pathway to the CSA's Sustainable Agricultural Intensification (SAI) has been raised to be Agroecological Intensification (AI), which is pro-organic and adverse to any form of mechanization or biotechnological push towards agriculture.

Mockshell and Kamanda (2018) identify both Conservation Agriculture (CA) and the System of Rice Intensification (SRI) under the purview of a blended view of sustainability, recognizing the synergies and tradeoffs between the two approaches to determine the best practices through an integrated approach. The overlap between CSA and Agroecology (AE) is at landscape and farm levels where, CSA is more about the policy, finance, and institutional aspects; being more influential at a national and global scale aimed at large transformational changes. Meanwhile, AE is more involved at the farm level in accordance with the specific agronomic behaviour of the biotope (Saj et al. 2017). The present study has considered four scenarios of varying practices under the ambit of CSA in consonance of AE along with considerations for promoting sustainable cropping patterns by assessing the emission impacts of the dominant foodgrain cropping systems in India.

1.1 Relevance of CSA in Indian rice–wheat-cropping system (RWCS)

The Indian agricultural sector has been considered vital towards country's economy and food sovereignty and was also found to be the only sector that was resilient in the period of economic downturn, during the COVID-19 pandemic, with a positive growth rate of 3.4% in GVA (Kapil 2021). Although, among the myriad of problems in the agriculture sector; there have been persisting concerns over low productivity in Indian agricultural yield, which has been further exacerbated by the projections of uncertain adversities that may arise due to climate change. Simulating the relation between the effects of climate change on agriculture is often complex along with uncertain projections. This is due to wide variability in agro-climatic conditions, farming practices, and technologies among agronomically diverse regions of India. Yet most studies do predict the varying level of crop losses due to climate change impacts (Mall et al. 2006). A majority of studies that are concerned with simulating climate change impact delve primarily into cereals, pulses, and oilseeds, as they are regarded as the main sources of human and livestock calories globally for instilled food security.

The focus on rice and wheat cropping systems is of particular significance in the Indian context, as they constitute the staple of the Indian diet and household consumption basket. India is also the second largest producer of rice and wheat; accounting for 76% of the total foodgrain output and 59% of the area under foodgrains (GOI 2020). Birthal et al. (2014) predict that in the medium term (2035) there will be a decline in the yield, from 2.5 to 7.1% in rice and a decline of 0.5–8.3% in wheat, while in the long term (by 2100) a decline in yield of 5.9–15.4% in rice and 8.2–22% in wheat is to be expected.

Thus, the triple objective framework set by the CSA approach holds great relevance in instilling resilience. Therefore, practices such as CA have been identified to be particularly relevant in relation to smallholder farmers' interests (Mizik 2021) which inherently adhere to the principles of AE, while also vying for the objectives set forth under CSA. One of the most promising CSA practices of SRI which initially faced apprehensions due to being perceived as unviable, particularly in developing countries due to labour scarcity and yield loss has seen a resurgence in adoption (Thakur and Uphoff 2017). This renewed emphasis on SRI practices is driven by its potential conservation of water and farmer experiences which is being reworked to be context-specific from an AE perspective. Similarly. in this study we have taken into account Zero Budget Natural Farming (ZBNF), a practice specific to India which adheres with the objectives set by CSA and also originates from smallholder community movement (Ghosh 2019).

1.2 Conservation agriculture

Conservation Agriculture (CA), is a holistic approach, characterized by numerous interactions among households, crops, and livestock, to create a sustainable farming system (Hobbs et al. 2008). The CA approach involves a wide range of practices that are part of its three main principles: (i) the minimization of soil disturbance from mechanical tillage, (ii) the maintenance of a permanent organic soil cover, and (iii) the diversification of crop species through crop rotation (Jat et al. 2020). The study by Aune (2012) shows CA achieves similar levels of yield as the conventional practices while having reduced emissions. Thus, our study has ascertained the economy-wide benefits of adopting CA beyond the farm household, while also qualifying the three-pillar criteria set by the CSA framework; through quantified water and GHG footprint reduction.

The practice of CA came of particular relevance in the context of the Rice–Wheat Cropping Systems (RWCS) of Indo-Gangetic Plains (IGP). The Indian IGP is spread over the states of Punjab, Haryana, Delhi, Uttar Pradesh, Bihar, and West Bengal, where RWCS is dominant, covering about 10 million Ha (Timsina and Connor 2001). Prior to the Indian green revolution, rice cultivation was quite limited to pockets of high quality but low productivity Basmati rice (Prasad and Nagarajan 2004). This invited opportunity for the cultivation of the high-yielding variety rice cultivars such as IR-8 in the non-traditional areas of the IGP.[1] This pattern of RWCS soon took over in large areas, particularly in the upper IGP due to it having lesser associated risk and high market value, replacing other foodgrains, oilseeds, and pulses, although, this pattern of cropping has created several issues pertaining to water scarcity, associated Global Warming Potential (GWP) and loss in diversity and resilience in crop varieties.

The introduction of CA in the IGP emerged towards addressing the delayed Rice–Wheat cropping cycle, which arises from drained soil fertility post-water intensive Rice cropping period resulting in planting delays for Wheat. Initially, the idea of CA was instilled in form of Zero-Tillage Wheat through the use of mechanized inputs such as

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[1] This move was also in response to the introduction of improved variety of dwarf wheat cultivars of *Sonara 64* and *Lerma Rojo* which led to a late sowing period for wheat.

seed drillers with efficient fertilizer delivery mechanism. These initial adoption of Zero-Tillage Wheat practices, paved the way for technological developments among the Indian manufacturers through innovations such as fixed openers, happy seeder technology and other mechanisations that allow for Zero Tillage cropping for other crops such as maize, legumes, mustard and sunflower. The recent progress to further enhance the CA approach has resulted in the substitution from traditional puddled transplanted rice to Zero-Tillage Direct-Seeded Rice (DSR-ZT). This form of farmer-participatory research led to the wider spread and rapid adoption of ZT wheat (Hobbs et al. 2019). Currently, about 1.5 million Ha is under partial conservation agriculture (Jat et al. 2014). The practice of CA has been widely recognized under CSA due to it providing yield enhancements, resource efficiencies, emission savings, and resilience in case of uncertain rainfall conditions (Kassam et al. 2015; Michler et al. 2019; Bhattacharyya et al. 2015).

1.3 System of crop intensification

The system of crop intensification emerged as derivations of SRI principles to other crops such as wheat, finger millet, maize, and sugarcane, also varied types of oilseeds, legumes, and even vegetables primarily in African and Asian countries (Abraham et al. 2014; Thakur and Uphoff 2017). The four principles by which SRI has been classified consistently are: (1) Early, quick, and healthy plant establishment; (2) reduced plant density; (3) improved soil conditions; and (4) controlled water application. While these set of practices are constant, the means of implementing them may vary suiting the farmer's socioeconomic needs and agroecological context. The practices associated with the system of crop intensification often are found to be labour saving upon mechanization of certain processes involved in SRI-SWI such as land-leveling, weeding, and transplanting. (Rana et al. 2017; Saxena et al. 2019).

The basic premise of SRI lies in a management-oriented innovation that is aligned towards increasing productivity through optimal management of plants, soil, water, and nutrients.[2] The initial adaptation constraints to SRI were over concerns of labour scarcity along with risks of yield loss which were witnessed during the on-farm experimentations in Madagascar (Barrett et al. 2004). The labour intensive nature of SRI is context specific depending upon the process of farmer adaptation towards implementation of the core tenets of SRI.[3]

In India, SRI initially got promoted primarily in the southern states.[4] Although, at present there aren't any specific government data on area coverage under SRI but Gupta

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[2] Developed in 1980s by French Agronomist and Jesuit Father Henri de Laulanié, with his core motivation being towards instilling a sense of self-reliance by addressing the varied resource constraints of the peasant farmers of Madagascar (Prasad C. S., 2006; de Laulanié, 1993).

[3] Since it is primarily a management-oriented innovation, the fluctuations in yields and resources are reliant on knowledge adapatation in practice during the transition phase. Therefore, even though there might be immediate increases in per kg labour requirements in the short term, the new methods and practices is witnessed to be labour saving (Thakur & Uphoff 2017).

[4] It started under the extension projects in 2002–03, by the state agricultural universities of the two states of Tamil Nadu and Andhra Pradesh. Tamil Nadu Agricultural University initiated experiments with a modified SRI practice, that used three of the SRI principles of single seeding, wider spacing and use of weeder. It was found, that even though there wasn't initially any differences in yield but significant savings in water usage was witnessed (Thiyagarajan 2002).

et al. (2021) report about 3–4 million hectares under SRI, adopted primarily by the small and marginal farmers.

Similar to SRI, the main practices for SWI are management-oriented which are interventions for root development and of intensive care. The primary motivations behind these adoptions of SRI principles for other crops have been driven by the success stories of farmers facing resource constraints but witnessing higher yields from adopting SRI principles in other crops. SWI was first tested in 2006, by farmers associated with the People's Science Institute (PSI). The pilot project on SWI started with 40 farmers from 25 villages in the states of Himachal Pradesh and Uttarakhand, which found positive yield growth. In the successive three years, the practice got spread to other states of Madhya Pradesh, Bihar, Punjab, Odisha, Uttar Pradesh, and Chhattisgarh (PRADAN 2008; Biswas and Das 2021).

1.4 Zero budget natural farming

ZBNF aims at the complete elimination of chemically induced fertilizers and pesticides leading to a significant reduction in input costs, leading up to zero external financing while aiming at increased crop yield (Biswas 2020). The four pillars of ZBNF are given to be: (1) Natural, chemical-free seed treatment to retain micro-organisms in the soil, preferably under a poly-cropping system. (2) Natural, organic tonic preparation for retaining nutrients in the soil on the root level, with complete elimination of fertilizers. (3) Circulation of air and conservation of water and moisture within the soil and reduce the need for soil tillage, and soil aeration. (4) Integration of livestock with crops for biological and economic synergies is recommended (Korav, Dhaka, Chaudhury, and Mamatha 2020).

Though, differences have been cited between Natural farming and Organic farming mainly in the usage of vermicomposting, manure or the total expenditure where organic farming was found to be costlier, both promote chemical-free agricultural techniques. Overall, there is an increased labor requirement due to elaborate set of timely interventions, yet there's also higher environmental benefits and cost savings. The ZBNF movement extends beyond CA by opposing use of any external inputs and synthetic fertilizers (Palekar 2006). Currently, as per varying estimates, ZBNF practices in the southern states of Karnataka and Andhra Pradesh are approximately 700,000 ha. while pilot initiatives have been undertaken in the states of Himachal Pradesh, Maharashtra, Odisha, and Chattishgarh.

The practice is primarily oriented and has been receptive to groups of small, marginal, and tribal farmers (Khadse et al. 2018). The attempt here has been towards transformation rather than adjustments in existing practices, hence its knowledge-intensive nature being a potential barrier towards wider adoption. The success of the ZBNF movement has been through the persevering social capital focused on relations of trust; reciprocity and exchange; common rules; norms and sanctions and connectedness (Bharucha et al. 2020).

Given this backdrop, the objective of our study is to estimate economy-wide effects arising out of agricultural interventions that fit with the three-pillared criterion of CSA—(1) Productivity, (2) Adaptation, and (3) Mitigation, while being considerate of the local niches, finding their origin either in community driven movements or on-farm experiments. The purpose of studying the economy-wide effect of Climate Smart Agriculture

(CSA) is to ascertain the impact on the economy upon scaling particular agricultural intervention. Also, it portrays the impact of additional yield gain on the household incomes and the associated sectors, which in turn help in priority setting and country-wide policy investment planning. This is in cognizance of the first criterion of CSA productivity. Further, in lieu of the second and third criterion pertaining to adaptation and mitigation, our study has also taken into account the water savings (for assessing the second criterion; adaptation) and reductions in GWP (for assessing the third criterion; mitigation) of CSA practices. To calculate direct and indirect water usage, based on per tonne production, water coefficients were estimated based on the water footprints calculated by Mekonnen and Hoekstra (2011). Similarly, the respective CO2¬eq. coefficients were collected from multiple studies. The direct and indirect intensities have been further calculated based on methodology set by Perman et al. (2011). Apart from changes in practice and technological interventions, we have also considered changes in cropping patterns primarily viable substitutions in the dominant RWCS of India, with other foodgrain crops that aren't emission intensive.

The subsequent Sect. 2 provides detailed information on the Methodology and Scenario development adopted for this study to evaluate Climate Smart Agriculture approaches. Section 3 provides the results from the scenarios followed by Discussion in Sect. 4 and Conclusion and Policy recommendation in Sect. 5.

2 Materials and methods

2.1 Social accounting matrix for macroeconomic policy

Social Accounting Matrix (SAM) is an accounting framework in form of a square matrix that portrays the flow of funds in an economy through cells that represent transactions from column accounts to row accounts. The structure of SAM is generally composed of seven types of accounts; activities, commodities, factors of production, households, government, savings and investment (S-I), and the rest of the world (Breisinger, Thomas, and Thurlow 2009).

Several SAM-based studies have been undertaken in the past towards capturing the role of agriculture as a driver of growth in the overall economy. Further, the agricultural sector is of particular significance in many developing nations as it accounts for a substantial part of the economy and its role in improving household incomes (Havinga et al. 1987; Townsend and McDonald 1998; Pyatt and Round 1977). The focus of these studies has been at analyzing the interdepencies between the agricultural sector and the rest of the economy or towards estimating the impacts and distributive effects of policies. While being one of the first papers to take into account the aspects of technical changes in agricultural sectors and in consequence, their macroeconomic effects have been studied by Khan and Thorbecke (1989). Their study over the SAM multipliers analyses the policy outcomes of technology choices between "traditional" and "modern" techniques by disaggregating the types of commodity in relation to the differing production techniques, in the context of the economy of Indonesia.

In the Indian context, one of the first attempts at building a SAM was by Sarkar and Subbarao (1981), although prior studies pertaining to sectoral linkages had already been undertaken using an Input–Output approach (Hazari 1970; Hashim 1971). While a recent study by Mythili and Harak (2012) emphasizes the importance of agricultural sector in it's income-generating potential, even if the Indian economy has gone through a structural transformation in the post-liberalization era. The service sector transition has become prominient over the years, although the employment growth in service sector has been lagging. The study also further accentuates, the missing link between agriculture and service sector, due to which the spillover effects have been limited from the latter.

There has not been any studies for India that use the SAM framework to assess the direct and indirect, sectoral and household impacts arising out of changes in agricultural practices. To this end, our study has taken into account the economywide impact of agroecological approaches towards agricultural development, while keeping the pillars of CSA intact. In this study, we have considered both the changes in technology and existing practices, along with propositions for shifting into alternative foodgrain cropping patterns, while meeting the three-pillared objectives of CSA. Therefore, the focus here is not only on increasing crop yields but also on its effects on household income patterns along with wider sectoral changes and also the associated resource savings (in terms of Water and GHG footprints). By taking into consideration the climate change ramifications from agricultural practices, our study is also aligned with the Sustainable Development Goals of 'Taking Action against Climate Change (Goal 13). The usage of the SAM framework, hence provides a macro view of considered propositions, in contrast to most studies which are often at the farm level.

2.2 Methodological framework of SAM model

In this study, the 2017/18 Social Accounting Matrix for India published by the International Food Policy Research Institute (henceforth IFPRI-SAM) has been used (Pal et al. 2020). The 2017–18 IFPRI-SAM constitutes 112 sectors composed of 39 sectors belonging to agriculture and allied activities, 18 sectors relating to agriculture-based processing activities, 24 manufacturing sectors, 4 mining sectors, 3 utilities sector, 1 construction sector and 23 service sectors. The factors inputs are classified into labor, capital, and land. The labor has been classified into rural and urban, with a further division based on education level. Capital has been divided into 4 types: crop, live animal, mining, and other financial capital. The household has been divided into rural farm households, rural non-farm households, and urban households with five quintiles of income level (Pal et al. 2020). The IFPRI 2017–18 SAM has 5 endogenous accounts (Activities, Commodities, Factors, Enterprises, and Households) and 4 exogenous accounts (Government, Taxes, Savings-Investments, and Rest of the World) (IFPRI-SAM framework provided in Table 8 in the Appendix 2). Using IFPRI-SAM database as baseline of our study, we have followed the following steps in Table 1 to fulfill our objectives of this study.

Although the above table describes in detail various technical steps involved in this study, the SAM multiplier model needs special attention. Therefore, in the following paragraph we have described the SAM multiplier model and its various components in lieu of our objective of this study.

In this study, we have adopted SAM multiplier model described in the study by Breisinger, Thomas, and Thurlow, (2009). The SAM structure involved in that study is similar

Table 1 Method of extending IFPRI-SAM and multiplier model with CSA practice

Technical steps	Descriptions
Step 1:	Identify CSA practices for paddy and wheat Rice—(1) Direct Seeded Rice, (2) Systems of Rice Intensification, and (3) Natural Farming Wheat—(1) Zero Tillage Wheat, (2) Systems of Wheat Intensification, and (3) Natural Farming
Step 2:	Estimate intermediate and value-added input coefficients for CSA practice. Please see Sect. 2.3 to understand the changes in input–output coefficients due to CSA practice
Step 3:	Develop 2017/18 SAM multiplier model without CSA interventions
Step 4:	Simulate 2017/18 SAM multiplier model by changing input–output coefficients of paddy and wheat activities corresponding to changes in input–output coefficients due to above selected CSA practices
Step 5:	Split paddy and wheat activities between traditional and CSA practices and balance the 2017/18 SAM. In this case we have not split the commodities as the commodity output between traditional and CSA practices are homogenous but the level of output corresponding to CSA activities depends on level of adoption of CSA in the country
Step 6:	Extend the SAM multiplier model with CSA practices and simulate it for different levels of adoption CSAs. Given the existing SAM of 112 sectors, the extended SAM will consist of two additional modified paddy and wheat sectors as discussed in step 1 (114 sectors)
Step 7:	We have assumed 2.5%, 5% and 10% scale of adoption of CSA technologies to simulate the multiplier model. In this case to simulate the model, the changes are made to the production levels, resulting from increase in land area under cultivation based on the aforementioned incremental percentages

to the 2017–18 IFPRI-SAM structure. The SAM multiplier model dervied by Breisinger et al. (2009) is given below.

$$Z = (I - M)^{-1}E$$

where, $Z - NX1$ vector of output endogenously determined using multiplier model. 'N' is number of endogenous accounts. $M - NXN$ coefficient Matrix, $E - NX1$ Vector of Exogenous Variables.

$I = NxN$ identity matrix.

In the above equation $(I - M)^{-1}$ is the multiplier matrix that describes the linkages effect on endogenous variable due to any exogenous shock. Therefore, it is worth noting that the multiplier impact depends on value of the coefficient matrix M. Further the selection of endogenous and exogenous variables largely depends on the research question the study concerns. In this study, we have considered government transactions, gross fixed capital formation, change in stock, direct and indirect taxes, and the rest of the world transactions as exogenous accounts to estimate SAM multiplier model.

The multiplier model derived above does not include climate smart crop cultivation activity account. Again, as the IFPRI-SAM has 112 activity output, 112 commodity output, 1 trade and transport margin, 13 types of value-added income, income of 15 types of households, together of them accounts 253 endogenous variables to be estimated using this SAM multiplier model. Hence, dimensions of Z, and E vectors in the multiplier model have 253 rows and the matrix M is a square matrix of dimension $253x253$. Again, the M matrix contains various components, and this is described in the Table 2.

The M matrix presented in the above table has 8 non-zero components. The blank part of the above table represents zero elements of M matrix which implies no direct relation between the components. However, they have an indirect relationship due to the circular flow of income and inter-industry linkages. The multiplier matrix $(I - M)^{-1}$ captures

Table 2 Endogenous account and components of '*M*' matrix

	ACT	**Endogenous accounts**			
		COM	**TRC**	**FAC**	**HHS**
ACT		(Domestic production)$M_{A,C}$			(Consumption from home produce)$M_{A,HHS}$
COM	(Inter-industry flow) $M_{C,A}$		(Receipts from Trade & transport margin) $M_{C,TRC}$		(Private marketed consumption)$M_{C,HHS}$
TRC		(Trade and transport margin) $M_{TRC,C}$			
FAC	(Payment for factor input)$M_{F,A}$				
HHS				(Factor income of households)$M_{HHS,FAC}$	

both the indirect and direct relationship between the endogenous variables in SAM multiplier model. Thus, each component of multiplier matrix $(I-M)^{-1}$ has its own economic significance. For example, the components $(FACXACT)$ record the impact on activity-wise gross value added due to any exogenous shock into the economy.

However, the above-described multiplier model does not consider environmental impacts. Therefore, we have incorporated impact on water and emission footprint in this multiplier model and the modified equations are as follows.

$$GHG = g(I-M)^{-1}E \ldots \text{(emission footprint)}$$

$$BLUWAT = w(I-M)^{-1}E] \ldots \text{(water footprint)}$$

Where,

GHG= total GHG emissions of the economy,

g = The emission coefficients of respective activities (wherein, g is a column vector with direct emission per unit output of each activity sector, while for the other endogenous accounts is zero)

$BLUWAT$ = total blue water use

w= water use intensity in agriculture sector (wherein, w is a column vector with water use per unit output of each associated agriculture activity sector, while for the other non-agriculture activity sectors and the endogenous accounts the value is zero)

Finally, as discussed in step 7 in the earlier table, we have incorporated different levels of adoption corresponding to different CSA scenarios described above. Results of the SAM multiplier model corresponding to above scenarios are described in the following section.

Table 3 Scenario description

Scenarios	Descriptions
Baseline scenario	Estimate the multiplier value using IFPRI-SAM multiplier model without CSA interventions. Since our focus is on Paddy and Wheat, we are assuming puddled transplanted paddy and direct seeded wheat are the baseline technology as most of the Indian farmers follow these methods of cultivation across states
Scenario 1: Direct Seeded Rice and Zero tillage wheat	Economy-wide impact of different CSA practices. Here we have changed the input–output coefficient of 'M' matrix corresponding to paddy and wheat activity
Scenario 2: Systems of Rice Intensifications and Systems of Wheat Intensification	
Scenario 3: Zero Budget Natural Farming (ZBNF) of Paddy and Wheat	
Scenario 4: Change in cropping pattern	Here an overall shift in final demand from Rice and Wheat to alternative foodgrains such as Maize, Sorghum, and Millet has been considered. A modest 10% rice and wheat cultivation area is substituted with maize, sorghum, and millet sectors, which comparatively require the same or lesser input requirements in terms of fertilizer, labor, and water requirements. Additionally, in this scenario a comparison has been made of the multiplier effects and outcomes of the alternative foodgrains in relation to the traditional Rice and Wheat sectors. There are no changes in technological coefficients in this scenario but rather a comparison of the multiplier effects of the varying sectors

2.3 Intervention scenarios

The original Rice and Wheat sectors have been split to add two additional modified Rice and Wheat sectors where the technological interventions have been carried out and compared with their generic counterparts. The modified Rice and Wheat sectors, initially have the same input and value-added coefficients as the aggregated sectors. But towards simulating the effects of various intervention scenarios the input and value-added coefficients have been modified accordingly. Finally, to satisfy the Hawkins–Simon condition (implying that the column sum of coefficient matrix for activity column-commodity row being equal to 1), the changes in the intermediate inputs and value-added labour have been adjusted accordingly with the value-added capital. The cost of adoption of newer technology necessary to justify the intervention scenarios is considered to be the additional capital in all three scenarios.

The economy-wide effects of the intervention scenarios have been analyzed for land shift under the new intervention crop sector at 2.5, 5, and 10% of the total land coverage of the respective crops.

The SAM multiplier model thus developed has been applied to simulate under three distinct scenarios and the detail about them is given in Table 3.

However, prior to solving the SAM multiplier model corresponding to various climate-smart agriculture scenarios, we solved that model without such interventions and considered it as a baseline scenario. Therefore, under the baseline scenario, farmers are following the traditional method of crop cultivation that includes puddled transplanated paddy and direct-seeded wheat cultivation.

On the other hand, in scenario 1; the practice of Conservation Agriculture (CA) has been applied to both Rice and Wheat sectors, under the practice of Direct Seeded Rice (DSR) and Zero Tillage (ZT) Wheat.

Table 4 Input-wise changes and yield increase in scenarios compared to traditional farming practices (in percentage)

Input changes	Scenario 1 (DSR-ZT)		Scenario 2 (SRI-SWI)		Scenario 3 (ZBNF)	
	Rice	Wheat	Rice	Wheat	Rice	Wheat
Fertilizer usage	− 20	− 0	− 21	0	− 90	− 90
Labour usage	− 44	− 30	− 17	− 17	+ 9.5	+ 9.5
Fuel usage	− 40	− 70	− 37	0	− 70	− 70
Chemical	− 30	− 30	+ 20	+ 20	− 100	− 100
Water usage	− 20	− 30	− 20	− 20	− 60	− 60
Emission reduction	− 33	− 21	− 36	0	− 89	− 89
Yield increase	**+ 5**	**+ 12**	**+ 22**	**+ 30**	**+ 16**	**+ 16**

Source: (Jackson 2009; Laxmi, Erenstein, & Gupta 2007; Abrol, Gupta, & Malik 2005; Pathak & Aggarwal 2012; Dhar et al. 2016; Nirmala et al. 2021; Nayar et al. 2020; Jain et al. 2014; Biswas 2020; Suresh et al. 2020)

Yield increase highlighted in bold indicates the productivity of the respective crop cultivation in the respective scenarios

In scenario 2, the extensively studied practice of SRI, along with nascent emerging SWI has been undertaken.

In scenario 3, the recent drive towards Zero Budget Natural Farming (ZBNF) has been taken into consideration. India has set a target of achieving 10% of the cultivated area to be organic in nature by 2025 (GOI 2021a, b). ZBNF technology, even after its differences with organic farming promotes chemical-free technologies as established above. In this scenario, 10% of the total rice and wheat cultivated area is assumed to be achieved through ZBNF. The input structure changes in each of the aforementioned scenarios are presented in Table 4.

Further, scenario 4 has been considered where an overall shift in final demand from Rice and Wheat to alternative foodgrains such as Maize, Sorghum, and Millet has been considered. A modest 10% rice and wheat cultivation area is substituted with maize, sorghum, and millet sectors, which comparatively require the same or lesser input requirements in terms of fertilizer, labour, and water requirements. Additionally, in scenario 4 a comparison has been made of the multiplier effects and outcomes of the alternative foodgrains in relation to the traditional Rice and Wheat sectors. There are no changes in technological coefficients in this scenario but rather a comparison of the multiplier effects of the varying sectors.

3 Results

In this section, the results from the intervention scenarios are discussed, where, the impact of technology-related scenarios is presented first, followed by the results from the alternative substitution scenario.

3.1 Economy-wide effects

3.1.1 Technological intervention scenarios

The aggregate effects, due to an increase in exogenous final demand for Rice and Wheat have been given in Table 5. The multiplier effect or the economy-wide impact using the SAM model does not take into consideration the cost of adoption of these technologies in agricultural practices, but only the resulting effects in macroeconomic outcomes due to changes in key inputs into the sectors.

Table 5 Scenario-wise aggregate multiplier effects

Aggregate effects	**Rice**				**Wheat**			
	Baseline	**DSR-ZT**	**SRI-SWI**	**ZBNF**	**Baseline**	**DSR-ZT**	**SRI-SWI**	**ZBNF**
Aggregate multiplier effects								
Output	3.78	3.99	4.58	4.39	3.49	3.92	4.49	4.07
GDP	2.24	2.40	2.77	2.75	2.13	2.42	2.75	2.58
Income	1.95	2.09	2.42	2.42	1.87	2.12	2.42	2.28
Changes in household income by groups								
Rural farm	1.00	1.12	1.29	1.30	0.98	1.18	1.29	1.29
Rural non-farm	0.39	0.39	0.47	0.48	0.37	0.38	0.48	0.40
Urban	0.55	0.58	0.66	0.64	0.51	0.57	0.65	0.59

Source: Authors' calculations

The results indicate the highest output, GDP, and income changes in the case of SRI-SWI. The associated higher yields are a major driver in case of SRI-SWI practice compared to the DSR-ZT and ZBNF scenarios (Table 5).

Furthermore, it is observed that the highest income is generated among the rural farming households and also the highest quintile among the urban households (Table 6). The additional GDP increase in scenario 1; DSR-ZT, is 2.40 billion due to Rice and 2.42 billion due to Wheat. Similarly in scenario 2; SRI-SWI, the GDP multiplier is 2.77 billion due to Rice and 2.75 due to Wheat. Lastly, we see for scenario 3; ZBNF, there is GDP multipliers are 2.75 billion for Rice and 2.58 for Wheat. Hence, ZBNF gives the second highest collective GDP increase along with the highest income and output multipliers among the three scenarios. These effects are directly associated with yield enhancement and labour changes in the three scenarios. Furthermore, the pertinent reason behind high output associated with SRI-SWI, could be also from increased requirements from machinery sector which further has several backward linkages in manufacturing sectors.

The simulated effects of the same final demand deliveries but the introduction of varying interventions in Rice and Wheat sector into the SAM were estimated, with a shift in the area for 2.5, 5, and 10, for three of the scenarios. The top five output changes occurred among the sectors represented in Table 6. Sectoral output increase is transmitted primarily into sectors such as Raw Milk, Wholesale & Retail Trade, and Land Transport in all three scenarios. Sectors such as Raw Milk and Other Vegetables are closely linked to all crop sectors since most of the farming households also grow subsistence vegetable crops and possess cattle and livestock both for consumption and commercial purposes. Raw Milk is among the top sectors due to the presence of cattle among the RWCS farmers. Furthermore, wheat particularly is accounting for among the top backward linkages into the output of the Cattle and Raw Milk sector. The Wholesale & Retail Trade and Land Transport sectors are among the top sectors due to their strong backward linkages in both Rice and Wheat sectors as facilitators of the supply chain. Furthermore, in the case of both SRI-SWI and DSR-ZT, other manufacturing sectors and other business services are also among the top five sectors, which could be due to associated higher machinery requirements or higher cohesion with certain agro-processing and services sectors with an increase in agricultural output. Moreover, the presence of Cotton Yarn, among the top five sectors, in the case of SRI-SWI and ZBNF is primarily

Table 6 Net change from shift in cultivation area for Top 5 Sectors (in Rs. billion)

Scenario-1 (DSR-ZT)				**Scenario-2 (SRI-SWI)**				**Scenario-3 (ZBNF)**			
Sectors	**Output changes**			**Sectors**	**Output changes**			**Sectors**	**Output changes**		
Area shift	**2.5%**	**5%**	**10%**	**Area shift**	**2.5%**	**5%**	**10%**	**Area shift**	**2.5%**	**5%**	**10%**
Raw milk	1.17	2.27	4.48	Raw milk	0.75	1.43	2.82	Raw milk	3.09	6.12	12.18
Wholesale and retail trade	0.60	1.08	2.08	Wholesale and retail trade	0.49	0.86	1.61	Wholesale and retail trade	1.53	2.93	5.75
Land transport	0.35	0.66	1.29	Land transport	0.29	0.54	1.05	Land transport	1.12	2.21	4.40
Other business services	0.32	0.53	0.97	Other manufacturing	0.19	0.29	0.54	Other vegetables	0.62	1.23	2.46
Other manufacturing	0.27	0.38	0.61	Cotton yarn	0.13	0.23	0.51	Cotton yarn	0.61	1.22	2.44

Source: Authors' calculations

Table 7 Factor input requirements and aggregate multiplier effects from shift towards alternative crops

	Maize	**Sorghum & Millets**	**Rice**	**Wheat**
Factor input requirements				
Labour	0.11	0.15	0.16	0.16
Land	0.27	0.36	0.33	0.36
Capital	0.20	0.27	0.26	0.28
Aggregate multiplier effects				
Output	3.81	3.64	3.78	3.49
GDP	2.10	2.19	2.24	2.13
Income	1.80	1.90	1.95	1.87

Source: Authors' calculations

driven by the Wheat sector's backward and forward linkages with the Other Small Ruminants and Other Livestock, which in turn have strong forward linkages with Raw Cotton sector and then that, in turn, being major input into Cotton Yarn (Table 9 in Appendix 3). Sectors such as land transport, wholesale and retail trade have close linkages with the Rice and Wheat cropping systems, during the post-harvest activities.

The fall in labour requirements that has been induced in the case of SRI-SWI should be accounted for with an eventual shift of labour to other sectors. Hence, enhancing the productivity of existing labour can be explored rather than considering additional labour requirements. Therefore, practices of DSR-ZT, even though are of modest enhancements yet are more aligned with the patterns of a shift in the economy. Since they require lesser labour input with a shift into the usage of additional tools and machinery, which might be possible if subsidies are introduced for farm machinery with effective adoption incentives for the farmers, especially those belonging to the small and marginal landholding groups. Also, it is observed that even though the yield increase is the highest in case of SRI-SWI, the economy-wide effects of it is weaker due to the lowering of labour requirements which could have been considered rather as a shift into any of the other sectors to provide the eventual transition paths for the economy.

3.1.2 Shift towards alternative crops

In the case of Scenario 4, where a shift in alternative cereals has been considered, the effects of additional unit final demand on the factor input requirements (Labour, Land, Capital) and the consequent aggregate multiplier effects (Output, GDP, Income) are presented in Table 7. The associated output increase in the case of Maize is the highest followed by Rice, Sorghum & Millets, and Wheat. The income and GDP increase is highest for Rice followed by Sorghum & Millets, Wheat, and lastly, Maize.

Maize, apart from having the highest increase in output has also comparatively lower labour and capital requirements than the other foodgrains, wherein Wheat has the maximum factor input requirements. About 90% of the total labour requirements are being fulfilled by the rural labour group, across the varied foodgrain crops. Hence, in consequence, the household factor incomes are accounted for majorly by the rural farming households constituting half of the factor incomes generated. Furthermore, given that

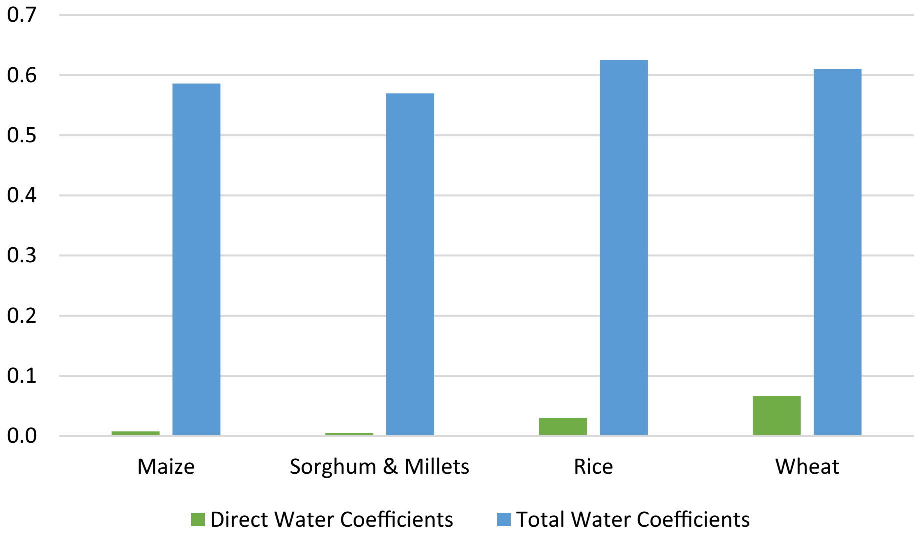

Fig. 3 Direct and Total Blue Water Footprint for Cereals Sector (in BCM/Rs)

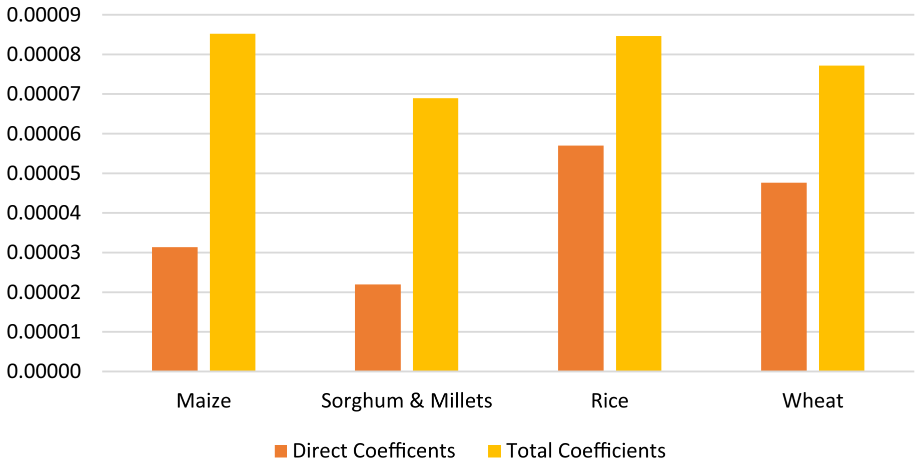

Fig. 4 Direct and Total GHG Footprint of (CO2eq/Rs)

Rice and Wheat have higher area allocation and production, it is not surprising that associated income and GDP generation are also highest among those sectors.

But given the differences are quite marginal, a shift from the Rice–Wheat cropping system can be encouraged, given the associated benefits of labour and emission savings from the other cropping patterns.

3.2 Resource and emission footprints

The water use and emission intensities were calculated on the basis of direct and total GHG and water footprints of the crop sectors along with the primary input sectors such as fertilizer, petroleum, and electricity sector (Mishra et al. 2021). The direct water footprints of the crop sectors were taken as per Mekonnen and Hoekstra (2011) estimates, while the water footprints of primary input sectors were based on

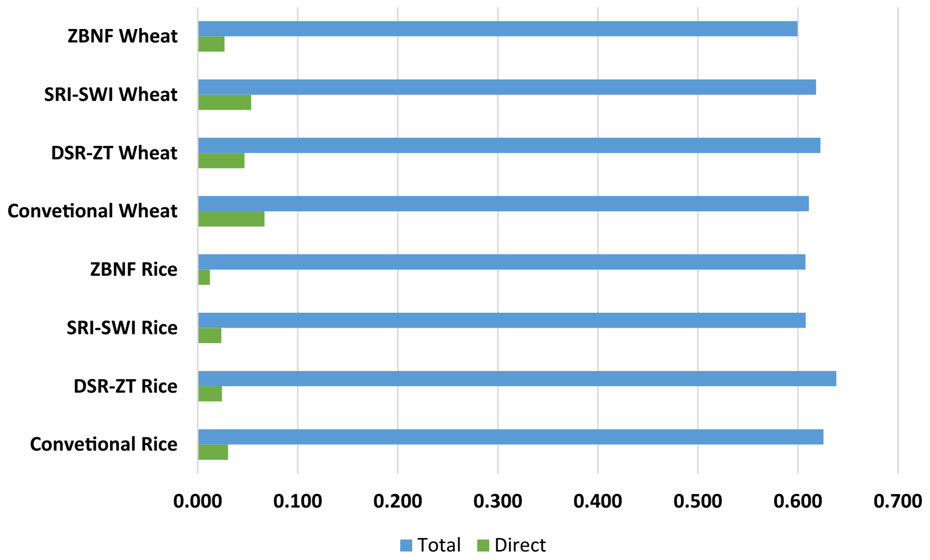

Fig. 5 Blue Water Footprint among the Scenarios (in BCM/Rs)

multiple studies (Vasudha 2022), (Pardikar 2019) (GOI 2022a, b, c) (CSE 2019) (Sun et al. 2018) (GOI 2021a, b). Similarly, the GHG footprints of the crop and the primary inputs were determined in reference to multiple studies (Kashyap and Agarwal 2021; Maheswarappa et al. 2011; Vetter et al. 2017). The respective direct and total footprints of various foodgrains have been presented in Figs. 3 and 4. It is observed that across the sectors, the percentage shares are to a large extent equally distributed among the varied cereal crops. Wheat has the highest share among the direct footprints, this is a primary cause of our consideration of the blue water footprints. Even though as per Mekonnen and Hoekstra (2011), rice would actually be much more water intensive but the primary share of it is accounted from green water, which is reliant on rainfall. Furthermore, the blue water footprints give a better picture of the establishment of irrigation requirements.

The Rice sector has higher water requirements; but since we have considered only the blue water usage, the wheat sector is dominating. Most of the rice fields are rainfed, while wheat is primarily grown on irrigated lands, hence accounting for a majority share. It is evident, that alternative foodgrains such as Maize and Sorghum & Millets, have lower direct water and carbon intensities, compared to Rice and Wheat sectors. Furthermore, Sorghum & Millets particularly have lower total GHG footprints indicating better suitability for substitution of both in terms of environmental sustainability and nutritional security.

The footprint estimation of the CSA practice interventions is presented in Figs. 5 and 6.

The total blue water footprints in the case of ZBNF Rice–Wheat and SRI-SWI Rice were found to be lesser compared to the conventional practice. Whereas, in case of DSR-ZT Rice–Wheat and SRI-SWI Wheat, the total blue water footprints are higher. Although, comprehensive water footprint accounting for each and every sector that has linkages with the RWCS may show significant differences. Yet, the use of an

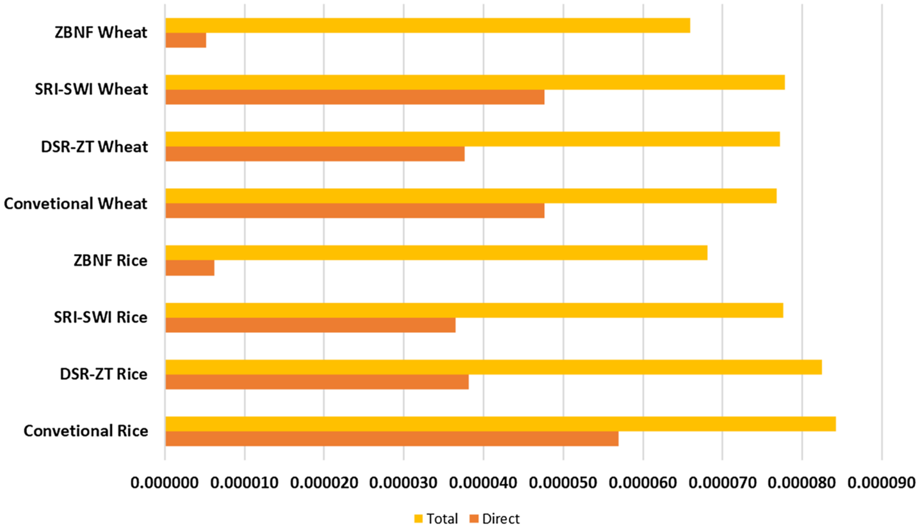

Fig. 6 GHG footprint among the Scenarios (in CO2eq/Rs)

economy-wide framework for envisaging embedded resource footprints and savings is instrumental, even though the direct water requirements among the scenarios are lesser than the conventional practices, but not necessarily when accounted in terms of total water requirements. However, in the case of total carbon footprints, ZBNF Rice–Wheat has the highest reductions in terms of total GHG footprints compared to other scenarios. While, among other scenarios; the reduction in total GHG footprint in case of DSR-ZT Rice is minimal compared to conventional Rice, while being the same as conventional practice, in case of DSR-ZT Wheat. Furthermore, the essence of economy-wide footprints is revealed upon considering the marginal increase that is observed in the total carbon footprint from Wheat under SRI-SWI. Despite there being no consideration for the reduction of direct emissions in this scenario, the overall total footprint is higher than the conventional practices due to higher input demands.

4 Discussion

The results show that a significant difference is observed when it comes to input usage, household incomes, output, and emission intensities when there is the adoption of differing agroecological consonant CSA practices. The changes in income from varied adoption measures are especially relevant for rural farm households. The reductions in water and emissions certainly are of great importance in relevance to the adaptation and mitigation goal from the CSA framework, but reductions or savings in direct footprints need not always translate into similar outcomes upon consideration of total footprints which are primarily associated with sectoral linkages. Furthermore, in our study, all three intervention scenarios can be considered as example cases of blended sustainabilities between SAI and AI.

A balanced approach is required towards the implementation of such CSA interventions for it to be consonant with agroecology, over rigid enforcement of a certain set of guidelines. CA (DSR-ZT) and SRI-SWI in practice are not averse to mechanization or external outputs as long as the core principles of the intervention are understood in the context of their implementation.

ZBNF certainly provides higher environmental benefits when compared to CA (DSR-ZT) and SRI-SWI directly. Yet, the intertemporal limitations of the SAM framework are to be considered in this case, as the transition to a ZBNF scenario is of exigency but not of immediacy since such contrasting changes to the agricultural sector in practice require wider knowledge, dissemination, and adoption support. The negligence of such considerations may lead to a systemic economy-wide crisis. The case of Srilankan agricultural reforms is a prime example of such good-intentioned yet not-so-practical approaches to policy intervention. An abrupt shift to organics resulted in a drop in yields, which caused a surge in food prices that transmitted throughout the system causing marked inflation in the economy (Pandey 2021).

One of the main limitation of the current study has been the calculation of the economic benefits of water and GHG footprint through the existing SAM framework for water resources accounting for the costs associated with irrigation charges. Therefore, economic accounting of resource savings is certainly going to play a major role given the introduced scarcities due to climate change. Similarly, due to the lack of an environmentally-extended SAM accounts, the economic benefits of emissions reduction have not been considered in the present study. Furthermore, the agricultural sector in India is already considered to be stagnant and plagued by low labour productivity.

Hence, the considered ZBNF scenario with an increased labour requirement might not be plausible in terms of increased labour demands. Rather, with constrained labour, an increased productivity scenario has to be considered. The linkages found between the crop and livestock sectors are of importance since they fit the ZBNF criterion—greater livestock integration with farming practices. Meanwhile, CA (DSR-ZT) presents an ideal scenario, fitting the needs of the Indian economy which can be adopted given the suitability of context upon which the resulting labour reductions from the adoption of CA (DSR-ZT), can be absorbed in other productive sectors. Similarly, SRI-SWI also promises greater labour savings, yet as often found in literature, the initial period is certainly labour intensive, as the core essence of SRI-SWI is through effective knowledge transfer in the management of cropping cycles; while the increase in capital requirements can be addressed through appropriate policy measures at the initial stages of transition.

Likewise, scenario 4 which proposes a shift into alternative cereals, is also of greater priority in the Indian context. Apart from the factor requirement efficiencies, additional perspectives of nutrition, climate, and environment also align with the shift to coarse cereals (Davis et al. 2019). The water footprint efficiency presented by the alternative cereals was found to be significant with the given shift from *Kharif* to *Rabi* season for the cereals and is indicative of the shift from monsoon to irrigated farming practices. Hence, the pressure on the surface and groundwater has increased over the years (Kayatz et al. 2019). These developments come from the Green Revolution period in India, which resulted in a transition from coarse cereal production into primarily Rice–Wheat cropping system over large areas of production. These transformations were then considered of priority, towards achieving food security and self-sufficiency.

Achievement of food security has to be paralleled with nutritional security, which India is currently lacking. India is estimated to have 14% of its population undernourished, even though it ranks high among the largest producers of agricultural output. Several studies have been undertaken towards resolving this nutrition crisis. It has been found that even though the calorific value of coarse cereals might be at par or lesser than Rice and Wheat, yet they provide the required nutritional diversity (DeFries et al. 2018; Puranik et al. 2017). Also, the continuance of resource-intensive forms or Rice–Wheat cropping systems for higher yield without undue forbearance has also resulted in unsustainable resource and environmental pressures.

Hence, the current study has attempted towards comprehending the effects of such interventions which can fit the overall three-pillared objectives set under CSA, while originating from on-field experiments.

5 Conclusion and policy recommendations

In this study, we assessed the economy-wide impacts of three different agricultural intervention scenarios. The changes in farmer's practices were considered in the first three scenarios, where the economy-wide effects of the adoption of CA (DSR-ZT), SRI-SWI, and ZBNF were considered. It was seen that while the adoption of the practices prescribed by the SRI-SWI movement provided the highest changes across the economy, ZBNF has the lowest water and GHG footprint compared to conventional practices. Yet, there are associated increased machinery requirements in the case of SRI-SWI and an entirely redesigned cropping pattern and outlook to agricultural practices in the case of ZBNF. In comparison, even though CA (DSR-ZT) has a lesser economic multiplier effect when compared to ZBNF and SRI-SWI, it has lesser labour requirements with additional capital investment requirements towards the funding of mechanized inputs but is relatively easy to adopt as found in literature when compared to SRI-SWI. SRI[5] being a knowledge-intensive innovation, the requirement of skilled manpower has been the major constraint, even after considerable institutional backing and civil society participation. Several state governments have made attempts at encouraging crop intensification on-farm experiments through extension programmes by the state agricultural universities and Krishi Vigyan Kendras (KVKs). Also, central institutions such as the National Bank For Agriculture And Rural Development (NABARD) have been partnering with NGOs towards the spread of SRI practices in states such as Andhra Pradesh, Assam, Bihar, Chhattisgarh, Jharkhand, Maharashtra, and Karnataka. Lastly, while ZBNF provides both economic and environmental benefits, the associated tradeoffs are again with the period of transition from one practice to the other. There are recommendations for a shift into alternative cropping patterns to foodgrains such as Maize, Sorghum, and millet, since economically they are having the same or enhanced income and output effects when compared with Wheat.

Furthermore, the recommendation towards the application of CA beyond the DSR-ZT scenario is certainly of relevance, when it comes to a shift to alternative cereals such

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[5] As Prasad (2006) notes in his book, the evolution of SRI in India can be traced in two parallels; firstly, through developments in on-station experiments of research and extension departments, primarily in the southern states and secondly, in the narrative of SRI as a civil society innovation through activities of civil society organisations and NGOs such as PRADAN (Professional Action Development Action Network) and TATA Trusts.

as Maize, Sorghum, and Millets. A reversion in the trend towards the production of these coarse cereals themselves is not only limited to securing the nutritional security of the population but also has implications for environmental sustainability which can be further enhanced through CA-based cropping systems (Davis et al. 2019). This shall ensure retention of the lost trend to coarse cereal production, in the currently Rice–Wheat dominated cropping patterns of IGP hence, ensuring greater health benefits while addressing the climate change aspect. Furthermore, these cereals are to be brought under the coverage of the Public Distribution System (PDS) akin to those established for Rice and Wheat, to ensure the consumption benefits of these crops are accessible to the poorer sections of the society. Hence, a combined shift into CA-based Rice–Maize cropping pattern is quite plausible. Such a transition aligns with the goals of assuring nutritional security while reducing emission and resource consumption levels. Although, certainly this shift in production has to be accompanied with a shift in dietary preferences and the creation of healthier lifestyle choices.

The choice between CA (DSR-ZT), SRI-SWI, and ZBNF is context-specific depending on varied factors of adoption. Since these practices have certain core guidelines while also being flexible to differing regional factors, effective implementation requires closer region-specific research studies. At the central level, the Ministry of Agriculture and Farmer's Welfare has initiated the promotion of natural farming, under the Bharatiya Prakritik Krishi Paddhati (BPKP). Yet, a well-integrated approach towards addressing the state of natural farming is still lacking, even among the state-led initiatives; since, most of the flagship programmes are currently at a small scale, lacking cohesive macro-level intervention. Furthermore, the extensive certification process is expensive and cumbersome for small farmers. Also, the lack of risk coverage and low yield support for the farmers during the transition phase from traditional agriculture, pose yet another set of challenges toward the widescale adoption of ZBNF practices (Khurana and Kumar 2020).

Policy support is needed for capacity building and training for CA practices, similar to the self-organized pedagogical drive that was witnessed in Karnataka during the inception phase of ZBNF. An entirely different set of barriers hinders the scalability of CA; which demands a particular need to shift from a narrow goal of food security to livelihood security of the farmers, from a policy perspective. Bhan and Behera (2014), suggest for a "Lead Farmer Approach" to achieve such an extension. Furthermore, CA systems are often quite complex, hence greater linkages within the farming and research community are required for the effective tailored implementation of CA. In terms of policy support, credit and subsidy measures can be considered, along with higher support in terms of accessibility to CA equipment and maintenance. The practice of CA in India was primarily initiated in a mechanized form but that doesn't associate strictly with conventional industrialized practices. Hence, greater AE norms are to be envisioned in carrying forth due development in the future of CA practices.

The framework of objectives set by the CSA approach has brought forth a resurgence in the discussions pertaining to food security in the advent of climate change. Yet, the practices that are being introduced under CSA have to be broadened from the three-pronged goals and need to take into account aspects of long-term productivity, environmental sustainability, agroecological biodiversity, food sovereignty, and national security. This is where the distinctions between the blended differences of SAI and AEI are important. Thus, the cohesion between the objectives of CSA and the practices identified under AE holds relevance towards striking a balance between multidimensional aspects of agriculture. Furthermore, an economy-wide framework is certainly of great significance in encompassing the linkage effects of varying interventions and their effects on various sectors and household groups. But, for future studies, inter-regional SAM might be of great use, which is region specific and is considerate of the agroecological variations.

Appendix 1

Agricultural methane arises majorly from livestock rearing through enteric fermentation and through, anaerobic decomposition from water-intensive paddy fields that follow the traditional continuous submergence practice of rice cultivation (Heilig 1994; Bhatia et al. 2012). Nitrous oxide is produced naturally from the microbes present in the soil, but with increase in usage of nitrogenous fertilizer application there is an excess for microbial conversion (Reay et al. 2012). The potency of these emissions is calculated in terms of CO_2 equivalent (CO_2eq) or global warming potential (GWP), which is an index with CO_2 as base that indicates the number of times more warming the other GHGs cause over a given time horizon (generally taken to be 100 years); The Global Warming Potential (GWP) of CH_4 and N_2O are 25 and 298 times higher, than that of CO_2 (Brander and Davis 2012).

Appendix 2

Social accounting matrix of India 2017–18

The 2017–18 SAM created by the International Food Policy Research Institute (IFPRI), constitutes 112 sectors composed of 39 sectors belonging to agriculture and allied activities, 18 sectors relating to agriculture-based processing activities, 24 manufacturing sectors, 4 mining sectors, 3 utilities sector, 1 construction sector, and 23 service sectors. The factors' inputs are classified into labor, capital, and land. The labor has been classified into rural and urban, with the further division based on education level. Capital has been divided into 4 types; crop, live animal, mining, and other financial capital. Household has been divided into rural farm households, rural non-farm households, and urban households (Pal et al. 2020). The SAM entries show transaction flows among the sectors, where the columns indicate the expenditures, while the rows represent the receiving sectors, respectively. Furthermore, among the SAM sectors, the division of sectors is based on the activity and commodity of the respective sectors. Additional two sectors were split towards introducing interventions in rice and wheat crops.

See Table 8

Table 8 IFPRI SAM 2017–18 framework

	Activities	**Commodities**	**Factors**	**Enterprises**	**Households**	**Government**	**Taxes**	**Investment**	**Rest of the World**	**Total**
Activities		Marketed outputs			Private non-marketed consumption					Activity income
Commodities	Intermediate demand	Transaction costs			Private marketed consumption	Government consumption		Gross capital formation	Exports	Total demand
Factors	Value-added								Foreign transfers to factors	Factor income
Enterprises			Factor income to enterprises			Government transfers to enterprises			Foreign transfers to enterprises	Enterprise income
Households			Factor income to households	Enterprise transfers to households		Government transfers to households			Foreign transfers to households	Household income
Taxes	Taxes on producers	Taxes on products	Factor taxes	Corporate taxes	Household taxes					Tax income
Government				Enterprise transfers to government	Household transfers to government		Tax revenues paid to government		Foreign transfers to government	Government income
Savings				Enterprise savings	Household savings	Government savings			Foreign savings	Savings
Rest of the World		Imports	Factor payments abroad	Enterprise payments abroad	Household payments abroad	Government payments abroad				Foreign exchange outflow
Total	Activity expenditures	Total supply	Factor expenditures	Enterprise expenditures	Household expenditures	Government expenditures	Tax payments	Investment	Foreign exchange inflow	

Source: (Pal et al. 2020)

Appendix 3

See Table 9

Table 9 Backward and Forward linkages of major cereals

Maize		Sorghum & Millets		Rice		Wheat	
Backward linkages of major cereals							
Maize	0.237	Sorghum & Millets	0.088	Rice	0.066	Wheat	0.053
Fertilizer	0.047	Petroleum	0.043	Electricity	0.060	Electricity	0.042
Electricity	0.039	Financial services	0.024	Fertilizer	0.050	Fertilizer	0.038
Petroleum	0.036	Insurances	0.021	Petroleum	0.036	Petroleum	0.020
Small ruminants	0.025	Electricity	0.021	Financial services	0.016	Financial services	0.016
Financial services	0.023	Fertilizer	0.020	Insurances	0.014	Other crops	0.015
Insurances	0.020	Small ruminants	0.011	Construction	0.011	Insurances	0.014
Other livestocks	0.017	Other livestocks	0.008	Small ruminants	0.010	Construction	0.009
Cattle	0.010	Construction	0.005	Other livestock	0.007	Small ruminants	0.005
Construction	0.007	Cattle	0.005	Wheat	0.005	Machinery	0.005
Machinery	0.001	Machinery	0.001	Machinery	0.005	Other livestock	0.004
Forward linkages of major cereals							
Maize milling	0.261	Sorghum & Millets Milling	0.176	Rice Milling	0.931	Eggs	0.283
Maize	0.237	Sorghum & Millets	0.088	Beverages	0.141	Poultry	0.273
Beverages	0.034	Beverages	0.010	Rice	0.066	Wheat milling	0.148
Fertilizer	0.005	Fertilizer	0.001	Public administration	0.027	Beverages	0.141
Chemicals	0.004	Chemicals	0.001	Other foods	0.008	Wheat	0.053
Pharmaceuticals	0.004	Pharmaceuticals	0.001	Grams	0.006	Small Ruminants	0.051
Public administration	0.002	Public administration	0.001	Flowers	0.005	Cattle	0.051
Aquaculture	0.002	Aquaculture	0.001	Cocoa	0.005	Public administration	0.048
Capture fishes	0.002	Capture fishes	0.001	Irish Potato	0.005	Other livestock	0.047
Flowers	0.001			Cassava	0.005	Restaurants	0.045

Source: Authors' calculations

The backward linkages presented here are column sums of the technical coefficients Aij, also known as direct backward linkages and can be considered as a measure of production dependency of the respective activity sector upon other commodities sector as inputs or interindustry supply. Similarly, the forward linkages here are the row sums of the technical coefficients Aij, known as direct forward linkages and can be considered as a simple measure of dependency of activity sector upon interindustry demand (Miller and Blair 2009)

Abbreviations

ACT	Activity
AE	Agroecology
AI	Agroecological intensification
BCM	Billion cubic meters
CSA	Climate smart agriculture
CA	Conservation agriculture
COM	Commodities
DSR-ZT	Direct seeded rice-zero tillage
FAC	Factor income
GHG	Greenhouse gases
GWP	Global warming potential

HHS	Households
KVK	Krishi vigyan kendras
IFPRI	International Food Policy Research Institute
IGP	Indo-gangetic plains
PDS	Public distribution system
RWCS	Rice wheat cropping system
SAM	Social accounting matrix
SWI	System of wheat intensification
SRI	System of rice intensification
SAI	Sustainable agricultural intensification
TRC	Trade and transport margins
ZBNF	Zero budget natural farming

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Author contributions

All authors contributed to the study conception and design, material preparation, data collection, and analysis. All authors read and approved the final manuscript.

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Availability of data and materials

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Declarations

Competing interests

The authors declare that they have no competing interests.

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References

Abraham B, Araya H, Berhe T, Edwards S, Gujja B, Khadka RB, Verma A (2014) The system of crop intensification: reports from the field on improving agricultural production, food security, and resilience to climate change for multiple crops. Agric Food Secur 3(1):1–12. https://doi.org/10.1186/2048-7010-3-4

Abrol, I. P., Gupta, R. K., & Malik, R. K. (2005). Conservation agriculture: status and prospects. Centre for Advancement of Sustainable Agriculture. Retrieved from https://www.worldcat.org/title/conservation-agriculture-status-and-prospects/oclc/607659932

Aune JB (2012) Conventional, organic and conservation agriculture: production and environmental impact. In: Lichtfouse E (ed) Agroecology and strategies for climate change. Springer, Dordecht

Barrett CB, Moser CM, McHugh OV, Barison J (2004) Better technology, better plots, or better farmers? Identifying changes in productivity and risk among Malagasy rice farmers. Am J Agr Econ 86(4):869–888

Bhan S, Behera UK (2014) Conservation agriculture in India-problems, prospects and policy issues. Int Soil Water Conserv Res 2(4):1–12

Bharucha ZP, Mitjans SB, Pretty J (2020) Towards redesign at scale through zero budget natural farming in Andhra Pradesh, India. Int J Agric Sustain 18(1):1–20. https://doi.org/10.1080/14735903.2019.1694465

Bhatia A, Aggarwal PK, Jain N, Pathak H (2012) Greenhouse gas emission from rice- and wheat-growing areas in India: spatial analysis and upscaling. Greenh Gases: Sci Technol 2(2):115–125. https://doi.org/10.1002/ghg.1272

Bhattacharyya R, Das TK, Sudhishri S, Dudwal B, Sharma AR, Bhatia A, Singh G (2015) Conservation agriculture effects on soil organic carbon accumulation and crop productivity under a rice–wheat cropping system in the western Indo-Gangetic Plains. Eur J Agron 70(70):11–21. https://doi.org/10.1016/j.eja.2015.06.006

Birthal PS, Khan T, Negi DS, Agarwal S (2014) Impact of climate change on yields of major food crops in India: implications for food security. Agric Econ Res Rev 27(2):145–155

Biswas S (2020) Zero budget natural farming in India: aiming back to the basics. Int J Environ Clim Change 10(9):38–52. https://doi.org/10.9734/IJECC/2020/v10i930228

Biswas S, Das R (2021) System of wheat intensification (SWI). Agriculture & Food: E-Newsletter, Goundam

Brander, M., & Davis, G. (2012). Greenhouse gases, CO2, CO2e, and carbon: What do all these terms mean. Econometrica, White Papers. Retrieved from https://ecometrica.com/assets/GHGs-CO2-CO2e-and-Carbon-What-Do-These-Mean-v2.1.pdf

Breisinger C, Thomas M, Thurlow J (2009) Social accounting matrices and multiplier analysis: an introduction with exercises. International Food Policy Research Institute (IFPRI), Washington DC

Calzadilla A, Rehdanz K, Betts R, Falloon P, Wiltshire A, Tol RS (2013) Climate change impacts on global agriculture. Clim Change 120(1):357–374. https://doi.org/10.1007/s10584-013-0822-4

CEA (2023) All India electricity statistics. General review 2023. Central Electricity Authory, Ministry of Power, Government of India, New Delhi. https://cea.nic.in/wp-content/uploads/general/2022/GR_Final.pdf

CEIC. (2021). India Electricity: Consumption: Utilities: Agriculture. Retrieved from CEIC: https://www.ceicdata.com/en/india/electricity-consumption-utilities/electricity-consumption-utilities-agriculture#:~:text=India%20Electricity%3A%20Consumption%3A%20Utilities%3A%20Agriculture%20data%20was%20reported,at%20215%2C000.000%20GWh%20in%202021.

CSE (2019) Fertilizer—sector performance. Centre for Science and Environment, New Delhi

Davis KF, Chhatre A, Rao ND, Singh D, Ghosh-Jerath S, Mridul A, DeFries R (2019) Assessing the sustainability of post-green revolution cereals in India. Proc Natl Acad Sci 116(50):25034–25041. https://doi.org/10.1073/pnas.1910935116

DeFries R, Chhatre A, Davis KF, Dutta A, Fanzo J, Ghosh-Jerath S, Smith MR (2018) Impact of historical changes in coarse cereals consumption in India on micronutrient intake and anemia prevalence. Food Nutr Bull 39(3):377–392. https://doi.org/10.1177/2F0379572118783492

Dhar S, Barah BC, Vyas AK, Uphoff N (2016) Comparing system of wheat intensification (SWI) with standard recommended practices in the northwestern plain zone of India. Arch Agron Soil Sci 62(7):994–1006. https://doi.org/10.1080/03650340.2015.1101518

Dhawan V (2017) Water and agriculture in India. German Asia-Pacific Business Association, Hamburg. https://www.oav.de/fileadmin/user_upload/5_Publikationen/5_Studien/170118_Study_Water_Agriculture_India.pdf

FAO. (2009). Food Security and Agricultural Mitigation in Developing Countries: Options for Capturing Synergies. Rome: Food and Agriculture Organization of the United Nations. Retrieved from https://www.fao.org/agrifood-economics/publications/detail/en/c/122847/

FAO. (2018). Climate-Smart Agriculture Case Studies 2018, Successful approaches from different regions. Rome: Food and Agriculture Organization of the United Nations. Retrieved from https://www.fao.org/3/CA2386EN/ca2386en.pdf

FAO. (2020). FAOSTAT Emissions Database. Retrieved from Food and Agriculture Organization of the United Nations (FAO): http://www.fao.org/faostat/en/#data/GT

FAO. (2020). The state of food security and nutrition in the world 2020. Retrieved from Food and Agriculture Organization of the United Nations: https://www.fao.org/3/ca9692en/online/ca9692en.html#chapter-Key_message

FAOSTAT. (2022). Food and Agriculture Organization of the United Nations (FAO). Retrieved from FAOSTAT Database: https://www.fao.org/faostat/

Fischer G, Shah MN, Tubiello F, Van Velhuizen H (2005) Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080. Phil Trans Royal Soc B Biol Sci 360(1463):2067–2083. https://doi.org/10.1098/rstb.2005.1744

Ghosh M (2019) Climate-smart agriculture, productivity and food security in India. J Dev Policy Pract 4(2):166–187. https://doi.org/10.1098/rstb.2005.1744

GOI (2016) Indian organic sector vision 2025. Government of India, New Delhi

GOI (2021) Indian petroleum and natural gas statistics 2020–21. Ministry of Petroleum and Natural Gas, Government of India, New Delhi

GOI (2022) International year of millets (IYoM)-2023. Ministry of Agriculture & Farmers Welfare, Government of India, New Delhi

GOI. (2021). Report of Task Force on Organic and Non-Chemical Farming. Recommendations on strategy to promote Organic and non-chemical farming in India. New Delhi: Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India. Retrieved from http://ums.rvskvv.net/TaskForce/D_R_B.pdf

GOI. (2022). Agricultural Statistics at a glance 2021. New Delhi: Ministry of Agriculture & Farmers Welfare, Government of India. Retrieved from https://eands.dacnet.nic.in/PDF/Agricultural%20Statistics%20at%20a%20Glance%20-%202021%20(English%20version).pdf

GOI. (2022). Urea Pricing Policy Section. Retrieved from Department of Fertilizers, Government of India: https://fert.nic.in/urea-pricing-policy-section#:~:text=The%20MRP%20of%20urea%20is,%2FPSUs%2FCooperatives%20and%20Rs.

GOI. (2020). Agricultural Statistics at a Glance 2019. New Delhi: Government of India, Ministry of Agriculture and Farmers Welfare, Department of Agriculture, Cooperation and Farmers Welfare. Retrieved from https://eands.dacnet.nic.in/PDF/At%20a%20Glance%202019%20Eng.pdf

Gupta N, Pradhan S, Jain A, Patel N. (2021). Sustainable Agriculture in India 2021 – What we know and how to scale up. New Delhi: Council on Energy, Environment and Water. Retrieved from https://www.ceew.in/sites/default/files/CEEW-Sustainable-Agricultre-in-India-2021-ES-21May21.pdf

Hashim SR. (1971). Inter-linkages and the changes in the pattern of commodity flows in India: 1950–51 to 1959–60. Indian Economic Journal, 19(2), 187. Retrieved from https://www.proquest.com/openview/cf6c51eff7872e3d8a0f9398dba2eb7e/1?pq-origsite=gscholar&cbl=1819379

Havinga IC, Sarmad K, Hussain F, Badar G, Mohammad F (1987) A social accounting matrix for the agricultural sector of Pakistan [with Comments]. Pak Dev Rev 26(4):627–641

Hayden C, Round JI (1982) Developments in social accounting methods as applied to the analysis of income distribution and employment issues. World Dev 10(6):451–465. https://doi.org/10.1016/0305-750X(82)90002-X

Hazari BR (1970) Empirical identification of key sectors in the Indian economy. Rev Econ Stat 52(3):301–305. https://doi.org/10.2307/1926298

Heilig GK (1994) The greenhouse gas methane (CH 4): sources and sinks, the impact of population growth, possible interventions. Popul Environ 16(2):109–137. https://doi.org/10.1007/BF02208779

Hill, S. (1985). Redesigning the food system for sustainability. Alternatives: Global, Local, Political, 12(3), 32–36. Retrieved from https://www.researchgate.net/publication/285538508_Redesigning_the_food_system_for_sustainability

Hobbs PR, Sayre K, Gupta R (2008) The role of conservation agriculture in sustainable agriculture. Phil Trans Royal Soc B Biol Sci 363(1491):543–555. https://doi.org/10.1098/rstb.2007.2169

Hobbs P, Gupta R, Jat RK, Malik RK (2019) Conservation agriculture in the indogangetic plains of India: past, present and future. Exp Agric 55(2):339–357. https://doi.org/10.1017/S0014479717000424

IFPRI. (2020). Social Accounting Matrix for India 2017/18. doi:https://doi.org/10.7910/DVN/NYVJX8

IPCC (2013) Summary for policymakers. In: Stocker TF, Qin D, Plattner G-K, Tignor MM, Allen SK, Boschung J, Midgley PM (eds) Climate change 2013. The physical science basis. Summary for policymakers, technical summary and frequently asked questions. Intergovernmental Panel of Climate Change, Geneva

Jackson, M. T. (2009). Revitalizing the Rice-Wheat Cropping Systems of the Indo-Gangetic Plains: Adaptation and Adoption of Resource-Conserving Technologies in India, Bangladesh, and Nepal. Final Report. IRRI Ref. No. DPPC2007–100. Retrieved from https://pdf.usaid.gov/pdf_docs/Pdacp630.pdf

Jain N, Dubey R, Dubey DS, Khanna M, Pathak H, Bhatia A (2014) Mitigation of greenhouse gas emission with system of rice intensification in the Indo-Gangetic Plains. Paddy Water Environ, 12(3):355–363. https://doi.org/10.1007/s10333-013-0390-2

Jat ML, Singh B, Gerard B (2014) Nutrient management and Use efficiency in wheat systems of South Asia. Adv Agron 125:171–259. https://doi.org/10.1016/B978-0-12-800137-0.00005-4

Jat ML, Chakraborty D, Ladha JK, Rana DS, Gathala MK, McDonald A, Gerard B (2020) Conservation agriculture for sustainable intensification in South Asia. Nat Sustain 3(4):336–343. https://doi.org/10.1038/s41893-020-0500-2

Jovial N (2022) India uses more groundwater than US and China combined. The Week. https://www.theweek.in/theweek/specials/2022/08/13/india-uses-more-groundwater-than-us-and-china-combined.html

Kapil, S. (2021). Agri share in GDP hit 20% after 17 years: Economic Survey. Retrieved from Down to Earth: https://www.downtoearth.org.in/news/agriculture/agri-share-in-gdp-hit-20-after-17-years-economic-survey-75271

Kashyap D, Agarwal T (2020) Food loss in India: water footprint, land footprint and GHG emissions. Environ Dev Sustain 22(4):2905–2918. https://doi.org/10.1007/s10668-019-00325-4

Kashyap D, Agarwal T (2021) Carbon footprint and water footprint of rice and wheat production in Punjab, India. Agric Syst. https://doi.org/10.1016/j.agsy.2020.102959

Kassam A, Friedrich T, Derpsch R, Kienzle J. (2015). Overview of the worldwide spread of conservation agriculture. Field Actions Science Reports The Journal of Field Actions, 8. Retrieved from https://journals.openedition.org/factsreports/3966

Kayatz B, Harris F, Hillier J, Adhya T, Dalin C, Nayak D, Dangour AD (2019) "More crop per drop": exploring India's cereal water use since 2005. Sci Total Environ 673:207–217. https://doi.org/10.1016/j.scitotenv.2019.03.304

Khadse A, Rosset PM, Morales H, Ferguson BG (2018) Taking agroecology to scale: the zero budget natural farming peasant movement in Karnataka, India. J Peasant Stud 45(1):192–219. https://doi.org/10.1080/03066150.2016.1276450

Khan HA, Thorbecke E (1989) Macroeconomic effects of technology choice: multiplier and structural path analysis within a SAM framework. J Policy Model 11(1):131–156

Khurana, A., & Kumar, V. (2020). State of Organic and Natural Farming: Challenges and Possibilities. New Delhi: Centre for Science and Environment (CSE). Retrieved from https://cdn.cseindia.org/webinar/State-Organic-amit.pdf

Korav S, Dhaka AK, Chaudhury A, M S (2020) Review- zero budget natural farming a key to sustainable agriculture: challenges, opportunities and policy intervention. Indian J Pure Appl Biosci 8(3):285–295. https://doi.org/10.1878/2582-2845.8091

De Laulanié, H. (1993). Le système de riziculture intensive malgache. Tropicultura, 11(3), 110–114. Retrieved from http://www.tropicultura.org/text/v11n3/110.pdf

Laxmi, V., Erenstein, O., & Gupta, R. K. (2007). Impact of zero tillage in India's rice-wheat systems. International Maize and Wheat Improvement Center. Retrieved from https://www.researchgate.net/publication/46471795_Impact_of_Zero_Tillage_in_India's_Rice-Wheat_Systems

Lewis BD, Thorbecke E (1992) District-level economic linkages in Kenya: evidence based on a small regional social accounting matrix. World Dev 20(6):881–897

Linquist BA, Adviento-Borbo MA, Pittlekow CM, van Kessel C, van Groenigen KJ (2012) Fertilizer management practices and greenhouse gas emissions from rice systems: a quantitative review and analysis. Field Crop Res 135:10–21. https://doi.org/10.1016/j.fcr.2012.06.007

Lipper L, Zilberman D (2018) A short history of the evolution of the climate smart agriculture approach and its links to climate change and sustainable agriculture debates. In: Lipper L, McCarthy N, Zilberman D, Branca AS (eds) Climate smart agriculture: building resilience to climate change. Springer, Cham

Maheswarappa HP, Srinivasan V, Lal R (2011) Carbon footprint and sustainability of agricultural production systems in India. J Crop Improv 25(4):303–322. https://doi.org/10.1080/15427520902969906

Mall RK, Singh R, Gupta A, Srinivasan G, Rathore LS (2006) Impact of climate change on Indian agriculture: a review. Clim Change 78(2):445–478. https://doi.org/10.1007/s10584-005-9042-x

Mekonnen MM, Hoekstra AY. (2011). National water footprint accounts: The green, blue and grey water footprint of production and consumption. Delft, Netherlands: Daugherty Water for Food Global Institute. Retrieved from https://digitalcommons.unl.edu/wffdocs/85/

Mendelsohn R (2008) The impact of climate change on agriculture in developing countries. J Natl Resour Policy Res 1(1):5–19. https://doi.org/10.1080/19390450802495882

Michler JD, Baylis K, Arends-Kuenning M, Mazvimavi K (2019) Conservation agriculture and climate resilience. J Environ Econ Manag 93:148–169. https://doi.org/10.1016/j.jeem.2018.11.008

Miller RE, Blair P (2009) Input-output analysis: foundations and extensions. Cambridge University Press, Cambridge

Mishra JS, Poonia SP, Kumar R, Dubey R, Kumar V, Mondal S, Bhaskar S (2021) An impact of agronomic practices of sustainable rice-wheat crop intensification on food security, economic adaptability, and environmental mitigation across eastern Indo-Gangetic Plains. Fields Crops Res. https://doi.org/10.1016/2Fj.fcr.2021.108164

Mizik T (2021) Climate-smart agriculture on small-scale farms: a systematic literature review. Agronomy 11(6):1096. https://doi.org/10.3390/agronomy11061096

Mockshell J, Kamanda J (2018) Beyond the agroecological and sustainable agricultural intensification debate: is blended sustainability the way forward? Int J Agric Sustain 16(2):127–149. https://doi.org/10.1080/14735903.2018.1448047

Mythili G, Harak N (2012) Sectoral linkages, multipliers, and the role of agriculture. In: Dev SM (ed) India development report 2012–13. Oxford University Press, Oxford

Nayar, V., Ravichandran, V. K., Barah, B. C., & Uphoff, N. (2020). Sustainable SRI and rice production: Learnings from an irrigated agriculture management project in Tamil Nadu. Economic and Political Weekly, 55(2), 46–51. Retrieved from https://www.epw.in/journal/2020/2/special-articles/sustainable-sri-and-rice-production.html

Nirmala B, Tuti MD, Mahender Kumar R, Waris A, Muthuraman P, Parmar B, Vidhan Singh T (2021) Integrated assessment of system of rice intensification vs. conventional method of transplanting for economic benefit, energy efficiency and lower global warming potential in India. Agroecol Sustain Food Syst 45(5):745–766. https://doi.org/10.1080/21683565.2020.1868648

Pal BD, Pradesha A, Thurlow J (2020) 2017/18 Social Accounting Matrix for India. A Nexus Project SAM. International Food Policy Research Instittute, Washington DC. https://doi.org/10.2499/p15738coll2.134178

Palekar S. (2005). The philosophy of spiritual farming I, 2nd ed. Amravati, Maharashtra, India: Amravati: Zero Budget Natural Farming Research, Development & Extension Movement.

Palekar S. (2006). The principles of spiritual farming II. Amravati, Maharashtra, India: Zero Budget Natural Farming Research, Development & Extension Movement.

Pandey S. (2021). How Sri Lanka's overnight flip to total organic farming has led to an economic disaster. Retrieved from The Print: https://theprint.in/world/how-sri-lankas-overnight-flip-to-total-organic-farming-has-led-to-an-economic-disaster/728414/

Pardikar, R. (2019). Thermal power plants in India using more water than permitted limit: RTI. Retrieved from Business Standard: https://www.business-standard.com/article/current-affairs/thermal-power-plants-in-india-using-more-water-than-permitted-limit-rti-119091300136_1.html

Pathak H, Aggarwal PK (2012) Low carbon technologies for agriculture: a study on rice and wheat systems in the Indo-Gangetic Plains. Indian Agricultural Research Institute, New Delhi

Pathak H, Bhatia A, Jain N (2014) Greenhouse gas emission from Indian agriculture: trends, mitigation and policy needs. Indian Agricultural Research Institute, New Delhi

Perman, R., Ma, Y., Common, M., Maddison, D., & McGilvray, J. (2011). Natural Resource and Environmental Economics (4th). Pearson. Retrieved from https://www.pearson.com/uk/educators/higher-education-educators/program/Perman-Natural-Resource-and-Environmental-Economics-4th-Edition/PGM848461.html

PIB. (2015). Fact Sheet on Agriculture Demand Side Management (AgDSM). Retrieved from Press Information Bureau, Ministry of Power, Government of India: https://pib.gov.in/newsite/PrintRelease.aspx?relid=128572

Pradan. (2008). Promoting SWI in the Mountain Farms. NewsReach. Retrieved from https://www.pradan.net/images/Media/sept_09.pdf

Pradhan, B., & Sahoo, A. (1996). Poverty in a linear modelling framework under alternative market regimes: a case study of rural India. Journal of Development Economics. Retrieved from https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/32519/117380.pdf?sequence=1

Prasad CS (2006) System of rice intensification in India; innovation history and institutional challenges. WWF International—ICRISAT Dialogue Project, Hyderabad

Prasad R, Nagarajan S (2004) Rice–wheat cropping system–food security and sustainability. Curr Sci 87(10):1334–1335

Praveen D, Ramachandran A (2020) The current policies and practices behind scaling up climate-smart agriculture in India. In: Venkatramanan V, Shah S, Prasad R (eds) Global climate change: resilient and smart agriculture. Springer, Singapore

Puranik S, Kam J, Sahu PP, Yadav R, Srivastava RK, Ojulong H, Yadav R (2017) Harnessing finger millet to combat calcium deficiency in humans: challenges and prospects. Front Plant Sci. https://doi.org/10.3389/2Ffpls.2017.01311

Pyatt G (1988) A SAM approach to modelling. J Policy Model 10(3):327–352

Pyatt G, Round JI (1977) Social accounding matrices for development planning. Rev Income Wealth 23(4):339–364. https://doi.org/10.1111/j.1475-4991.1977.tb00022.x

Pyatt G, Round JI (1979) Accounting and fixed price multipliers in a SAM framework. Econ J 89(356):850–873

Pyatt G, Round J (1985) Social accounting matrices: a basis for planning. World Bank, Washington DC

Rana L, Banerjee H, Ray K, Sarkar S (2017) System of wheat intensification (SWI)–a new approach for increasing wheat yield in small holder farming system. J Appl Natl Sci 9(3):1453–1464

Reay DS, Davidson EA, Smith KA, Smith P, Melillo JM, Dentener F, Crutzen PJ (2012) Global agriculture and nitrous oxide emissions. Nat Clim Chang 2(6):410–416. https://doi.org/10.1038/nclimate1458

Ritchie, H., & Roser, M. (2020). CO_2 and Greenhouse Gas Emissions. Retrieved from Our World in Data: https://ourworldindata.org/ghg-emissions-by-sector

Roland-Holst DW, Sancho F (1995) Modelling prices in a SAM structure. Rev Econ Stat 77(2):361–371

Round J (2003) Social accounting matrices and SAM-based multiplier analysis. In: Bourguignon F, Pereira da Silva L (eds) Techniques and tools for evaluating the poverty impact of economic policies. World Bank and Oxford University Press, Oxford

Sah D, Devakumar AS (2018) The carbon footprint of agricultural crop cultivation in India. Carbon Manag 9(3):213–225. https://doi.org/10.1080/17583004.2018.1457908

Saj S, Torquebiau E, Hainzelin E, Pages J, Maraux F (2017) The way forward: an agroecological perspective for climate-smart agriculture. Agr Ecosyst Environ 250:20–24. https://doi.org/10.1016/j.agee.2017.09.003

Sarkar H, Subbarao SV (1981) Social accounting matrix for India for 1980–81. National Council of Applied Economic Research, New Delhi

Saxena A, Upadhyay T, Rai D, Varshney AC, Saxena M (2019) System of wheat intensification study using hydroponically raised wheat seedling–a new approach towards farmer's welfare. Int J Adv Agric Sci Technol 6(1):24–40

Sen S (2018) If 80% water consumption in India is for agriculture, why is it unregulated and inefficient? Observer Research Foundation. http://20.244.136.131/expert-speak/if-80-water-consumption-in-india-is-for-agriculture-why-is-it-unregulated-and-inefficient

Shahbandeh, M. (2022). Leading countries based on the production of milled rice in 2020/2021 (in million metric tons). Retrieved from Statista: https://www.statista.com/statistics/255945/top-countries-of-destination-for-us-rice-exports-2011/

Sun P, Elgowainy A, Wang M, Han J, Henderson RJ (2018) Estimation of U.S. refinery water consumption and allocation to refinery products. Fuel 221:542–557. https://doi.org/10.1016/j.fuel.2017.07.089
Suresh NS, Ravuri S, Bose A, Haritha H, Shanker A, Lakshmi PA (2020) Life Cycle Assessment of ZBNF and Non-ZBNF. A preliminary study in Andhra Pradesh. Centre for Study of Science, Technology and Policy, Bengaluru. https://apcnf.in/wp-content/uploads/2020/05/LIFE-CYCLE-ASSESSMENT-OF-ZBNF-AND-NON-ZBNF-A-STUDY-IN-ANDHRA-PRADESH.pdf
Thakur AK, Uphoff NT (2017) How the system of rice intensification can contribute to climate-smart agriculture. Agron J 109(4):1163–1182. https://doi.org/10.2134/agronj2016.03.0162
Thiyagarajan, T. M. (2002). Experiments with a Modified System of Rice Intensification in India. Assessments of the System of Rice Intensification (SRI): Proceedings of an International Conference held in Sanya. (pp. 137–139). Retrieved from http://sri.ciifad.cornell.edu/proc1/sri_30.pdf
Timsina J, Connor DJ (2001) Productivity and management of rice-wheat cropping systems: issues and challenges. Field Crop Res 69(2):93–132. https://doi.org/10.1016/S0378-4290(00)00143-X
Tirol-Padre A, Rai M, Kumar V, Gathala M, Sharma PC, Sharma S, Ladha J (2016) Quantifying changes to the global warming potential of rice wheat systems with the adoption of conservation agriculture in northwestern India. Agric Ecosyst Environ 219(219):125–137. https://doi.org/10.1016/j.agee.2015.12.020
Townsend RF, McDonald S (1998) Biased policies, agriculture and income distribution in South Africa: a social accounting matrix approach. J Stud Econ Econom. https://doi.org/10.1080/03796205.1998.12129119
UNFCCC (2021) India: third biennial report to the United Nations framework convention on climate change. United Nations Framework Convention on Climate Change, Bonn
Vasudha. (2022). Vasudha Power info hub. Retrieved from Vasudha Power: https://vasudhapower.in/
Vetter SH, Sapkota TB, Hillier J, Stirling CM, Macdiarmid JI, Aleksandrowicz L et al (2017) Greenhouse gas emissions from agricultural food production to supply Indian diets: Implications for climate change mitigation. Agric Ecosyst Environ 237:234–241. https://doi.org/10.1016/j.agee.2016.12.024
Wezel A, Soboksa G, McClelland S, Delespesse F, Boissau A (2015) The blurred boundaries of ecological, sustainable, and agroecological intensification: a review. Agron Sustain Dev 35(4):1283–1295. https://doi.org/10.1007/s13593-015-0333-y
Wheeler T, Von Braun J (2013) Climate change impacts on global food security. Science 341(6145):508–513. https://doi.org/10.1126/science.1239402
World Bank. (2022). Fertilizer consumption (kilograms per hectare of arable land) - India, World. Retrieved from The World Bank Group: https://data.worldbank.org/indicator/AG.CON.FERT.ZS?locations=IN-1W

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