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Review Article

Sustainable agronomic practices to increase climate resilience in rice-based cropping system: A review

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Abstract
Climate-resilient farming represents a sustainable strategy for transposing and redirecting agricultural methodology to uphold food safety in the context of the evolving challenges of climatic variability acquired through various adaptation and mitigation strategies. The consequences of climate change have an enormous effect on agricultural operations due to their responsiveness to fluctuations in multiple factors, including temperature, rainfall, natural phenomena, and calamities such as floods and droughts. On average, these extreme weather patterns have the potential to influence agricultural earnings. Furthermore, rice-based production systems also significantly contribute to climatic change by increasing greenhouse gas emissions significantly. The mitigation of challenges can be achieved by augmenting farmers' adaptability while enhancing the flexibility and efficiency of resource utilization in agricultural systems. Several agricultural practices such as integrated nutrient management, integrated weed management, direct seeded rice, System of rice intensification, conservation practices, bed planting, crop residue management, etc. adaptation in agricultural production systems are beneficial approaches to mitigate climatic variability and sustain long-term ecosystems. The review will help build up small-holding farming communities' capability to get the maximum possible yield with current climatic variability.

Keywords: Direct seeded rice, Greenhouse gas, Integrated nutrient management, Integrated weed management, System of rice intensification

INTRODUCTION

In India, rice (*Oryza sativa L.)* is the most notable cereal crop, accounting for over 104.80 mt of production at 43.86 Mha of land with a productivity of 2390 kg/ha; even with decent productivity compared to other rice-growing nations in the universe, rice is produced continuously in many climatic and soil conditions in India (Paramesh *et al*., 2023a). Presently, climate change is a drastic threat to agricultural production. The production ability of crop varieties is extremely reduced by the diverse weather conditions, creating the implementation of various adaptive approaches and diversified cropping mechanisms for agricultural production. Worldwide, agriculture practices have a crucial contribution to climate change;, crop and livestock production directly contributed to greenhouse gas (GHG) emissions at about 10 to 12 % of total global GHG emissions and another similar amount indirectly contributed through forestry and other land uses (Pasricha *et al*., 2023) . However, globally, 10-12% of greenhouse gases are emitted due to many man-made polluting substances directly connected to agriculture, especially rice cultivation practices (Baiswar *et al*., 2023). (Gupta *et al*., 2021) pointed out that the production of methane gas and nitrous oxide emissions are the major causes of greenhouse gas emissions from rice cultivated fields. Due to submerged or waterlogged conditions, anaerobic conditions produce excess amounts of methane and nitrous oxide gas. T*hese* are emitted from the rice field as a source of greenhouse gases (Rajbonshi *et al.*, 2024). It is predicted that the emission of GHG levels will increase in rice fields, impacting food demand worldwide (Habibi *et al.*, 2019). Globally, about 18% of the methane emissions and about 11% of nitrous oxide emissions are accounted for in rice farming; therefore, rice-based farming systems have major impacts on global climate change or global warming (Ahmed *et al.*, 2023). Furthermore, major rice-growing countries are using various nonrenewable resources to supply a significant quantity of energy and higher water sources, and excessive synthetic fertilizer inputs to achieve greater productivity (Paramesh *et al.*, 2017, Lal *et al.*, 2019); those play significant roles in the deterioration of soil health as well as water pollution (Habibi *et al.*, 2019).

Many factors contribute to greenhouse gas emissions in rice-based farming systems i.e. variability in length of cropping cycle, variability in seasonal moisture and temperature regimes, variability in crop production and productivity, proficiency in feedstock and energy use, application of various nutrients (fertilizer), carbon retention, residues, and others (Smith *et al.*, 2014). Subsequently, it creates critical ways to preserve environmental health and identify potential strategies for diminishing energy consumption and enhancing climatic resilience (Jena *et al.*, 2023). Hence, adaptation of energy-proficient rice-based cropping systems is essential to maintain sustainability with minimum environmental influences. Understanding the significance of environmental effects is also helpful in adopting long-term sustainable approaches related to rice-based cropping practices (Nabavi-Pelesaraei *et al.*, 2018). The impacts of climatic change necessitate the acclimatization of eco-friendly approaches to achieve climatic resilience in rice-based farming systems. Concerning adopting climate resilient agriculture, it is necessary to build up a capability in small-holding farming systems to survive pest infestation, droughts, severe weather conditions, erosion, flooding, and salinization; reduction of ecological degradation and greenhouse gas emissions; and specifying growing inequalities, bounded resources, social disruption, and economic ambiguity (Farooq *et al.*, 2023). Many agricultural technologies or agronomic practices are developed in agriculture that can significantly reduce GHG emissions and acclimate climate variability. Many eco-friendly land management practices include uses of green or brown manuring, agroforestry, bed planting, cover crops addition, zero/minimum tillage practices with crop residues, and uses of numerous soil-water conservation practices. They significantly enhance the capturing and sequestration of carbon from the earth's atmosphere to the soil or above the soil surface. Hence, adapting such kind of practices to get long-term benefits is essential to achieve greater yields, mitigate variability in production, and make more resilient systems to climatic change (Pathak, 2023). There are various types of sustainable approaches or technologies related to climate-resilient agriculture in the rice-based cropping system, i.e. INM (integrated nutrient management), IWM (integrated weed management), SSWM (site-specific weed management), FIRBS (furrow irrigated raised-based system), IFS (integrated farming system), agroforestry, crop diversification, conservation agriculture practices, LLL (laser land leveling), management of crop residues (Pathak and Das, 2016) as shown in Fig. 1.

Factors hindering climate change adaptation by the farming communities

Agriculture is the main source of livelihood for the majority of the farming community, but for the marginal landholding farmers, it is highly exposed and vulnerable to climate-related risks, such as droughts and floods. The lack of education, small landholdings and insufficient income sources are the major constraints that influence the farming communities to select appropriate strategies for climate change mitigation (Pangapanga *et al.*, 2012). Many factors act as barriers to farming communities' adoption of climate-resilient practices. These include lack of information regarding the effect of climate change, lack of knowledge regarding suitable adaptation strategies, insufficient money and credit services, unavailability of own land, scarcity of sufficient irrigation facilities and inadequate market access to the farmers (Marie *et al.*, 2020). According to Khan *et al.*, (2020), poor infrastructure, lack of technology, poor market access, lack of labour availability, low level of education, inadequate information regarding climate change, excessive practices of conventional farming, and lack of governmental support are the crucial factors that significantly effects on the selection of suitable strategies by the farming communities. Comprehensive strategies comprising government support, community involvement, education, and infrastructure and technology investment are needed to tackle these challenges.

Strategies to adopt climate-resilient agriculture

Integrated nutrient management (INM)

Since nitrous oxide and methane are the major two gases that have higher impacts on global warming than carbon dioxide (gradually 310 and 21 times more); adopting agriculture practices that have a greater potential to mitigate these two greenhouse gas (N_2O and CO_2) emissions. Hence, the adaptation of improved cropping patterns and nutrient management are necessary to raise the quality yield production of the crops to supply sufficient fiber, food, and biofuel for the world's expanding population; these management practices should be considered opportunities for the depletion of methane (CH_4) and nitrous oxide (N_2O) emissions es-

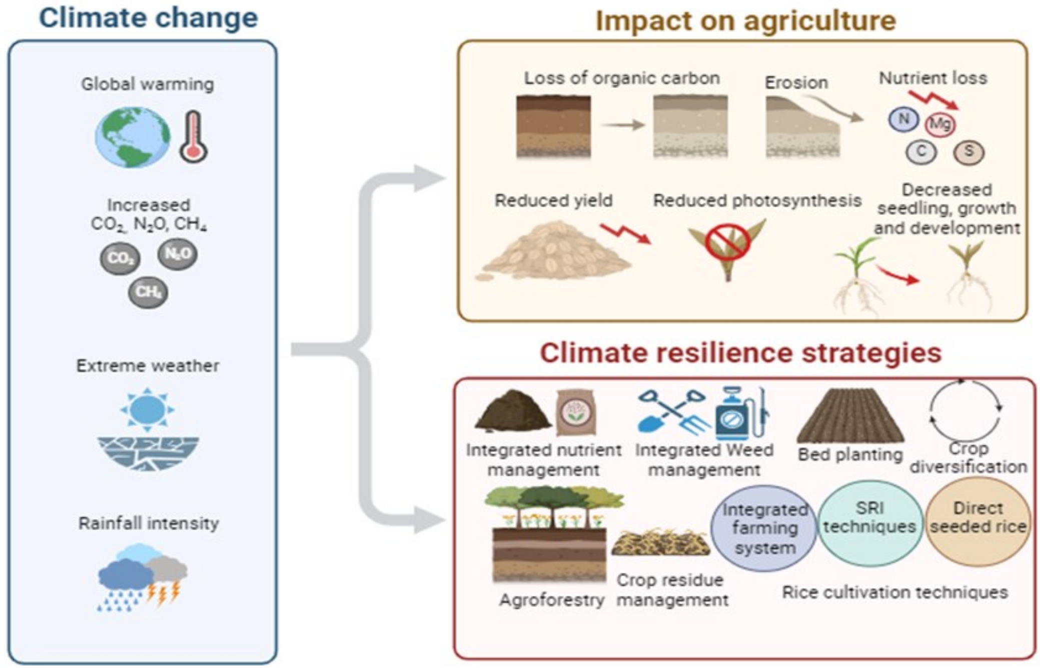

Fig. 1. *Impact of climate change and its mitigation approaches on rice based cropping system*

pecially which are emitted per unit of fiber, food, and biofuel production (Mohanty *et al*., 2020). INM is defined as incorporating organic manures with synthetic fertilizers, which plays a vital role in mitigating synthetic fertilizer uses and reducing the emission of greenhouse gases (Pathak and Das, 2016). INM can help small farmers save a significant amount of their limited financial resources by reducing the amount of fertilizers they purchase. Hence, it makes sure that the biological nitrogen fixation (BNF) and soil microbial activity are improved, native soil nutrients are conserved and used effectively by plants, organic nutrient flows are recycled, and plant nutrients are added to the soil (Paramesh *et al*., 2023b). Additionally, INM lowers erosion, enhances soil aeration, water infiltration, and plant root growth, and lessens the possibility of downstream flooding (Gill *et al*., 2008). It may be possible to achieve a strong financial return and create favorable circumstances for a high yield of a cropping system based on rice by combining organic matter with synthetic fertilizers.

Integrated nutrient management (INM) is the technological and managerial element of implementing integrated plant nutrient systems (IPNS) goals in agricultural settings. It considers every aspect of managing crops and soil, including controlling inputs other than plant nutrition, water, and agricultural chemicals. The fundamental tenet of IPNS is the sensible and effective application of mineral fertilizers, organic matter, and biofertilizers to preserve soil fertility, preserve agricultural production, and increase farmers' profitability (Choudhary *et al*., 2022). In regard to maximizing productivity from a certain cropping system, INM aims to ensure the efficient and prudent usage of all relevant sources of essential plant nutrients in a holistic manner. In order to sustain the soil's chemical, biological, and physical properties, INM comprises all conceivable combinations of organic, inorganic, or biological sources (Dubey *et al*., 2014). The INM components are shown in Fig. 2. The two popular organic sources are green manuring and FYM, or compost. Due to the atmospheric N_2 fixing ability and organic matter addition potentiality, legumes can be used as a replacement for rice or as biomass to replenish the soil in rice-based cropping systems. Contrarily, a major source of organic nutrients is crop residue. In India, approximately 80.12 Mt of agricultural waste has a total nutritional potential of 1.61 Mt, equivalent to 0.80 Mt of synthetic fertilizers (Meena *et al*., 2019). Biofertilizers play a crucial role in IPNS because they contain living cells of various microorganisms that can biologically mobilize nutrients from unavailable to available forms. Phosphate-solubilizing bacteria, fungi, symbiotic and non-symbiotic bacteria, and N_2 fixers are all included in this category. These methods guarantee the viability of rice-based agricultural systems (Meena *et al*., 2022).

Conservation agriculture practices

Conservation agriculture (CA) is a self-sustainable approach comprising a no-tillage or zero-tillage system and crop waste recycling, offering a substitute for residue burning. The CA practices help improve soil health status by raising organic carbon (OC) and aggregation of soil, as well as conserving energy, soil, and water compared to traditional farming practices (Somasundaram *et al*., 2020). Thus, CA is an agricul-

Fig. 2. *Components of Integrated nutrient management*

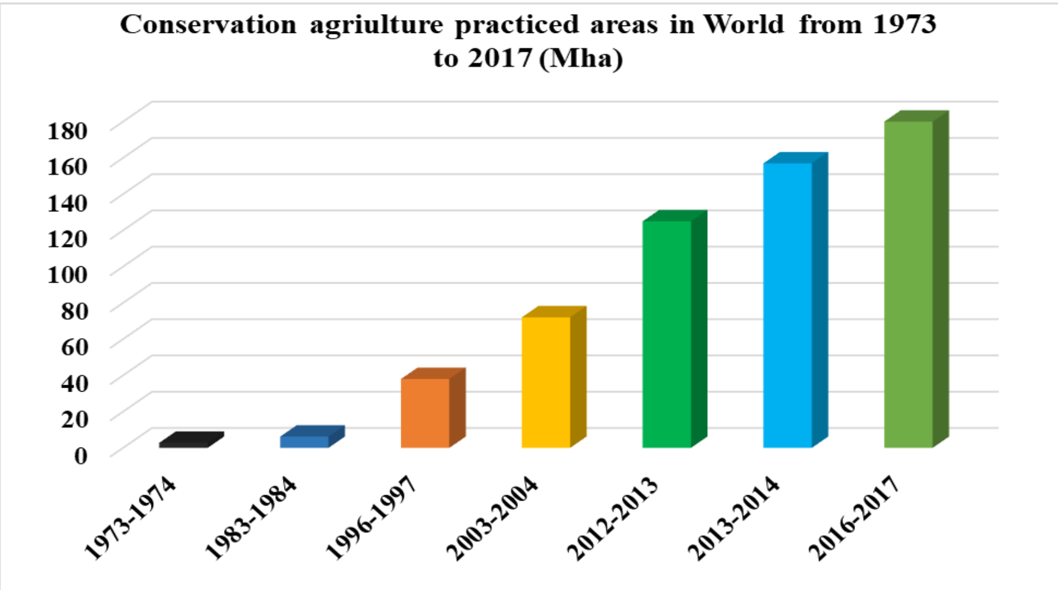

Fig. 3. *Adaptation of conservation agriculture (CA) worldwide year by year*

tural approach that meets farmers' demands in a sustainable manner (Sayre and Hobbs, 2004) and brings various benefits (Fig. 3). In contrast to conservation agriculture, conventional tillage consists of continuous intensive practices (deep tillage) with the repeated removal/burning of crop residues in similar crops. Fig. 4 shows the effects of tillage intensity on the agricultural ecosystem. The rising economic growth and growing population are creating huge pressure on natural resources and agricultural society, which are needed to meet ongoing and upcoming food demands and secure nutritional supply. The adaptation of conservation agriculture is one of the greater advantages of enhancing crop productivity and improving soil health status (Hobbs, 2007; Sayre and Govaerts, 2009. Recently, CA/no-tillage has been practiced for about 5 Mha in the Indo-Gangetic plains zone (IGP) of the Southern part of Asia (Derpsch *et al*., 2010). Recently, conservation agriculture (CA) has spread rapidly worldwide (Fig. 5). Globally, areas under CA were 2.8 Mha in 1973-1974 and enhanced by 6.2 Mha in 1983-1984; in 1996-1997 it reached 38 Mha, 72 Mha in 2003, 125 Mha in 2012 (Friedrich *et al*., 2011), 157 Mha in 2013-2014 (Kassam *et al*., 2014), and in 2016 it was 180 Mha (Kassam *et al*., 2019). However, exceptional appearances are held in India (328.2 Mha area with a cultivable land area of 141 Mha), where no-tillage practices have been adopted by Indian farmers basically in rice-wheat-based cropping system (less than 5 Mha) (Leharwan *et al*., 2023).

Table 1. Benefit-cost ratio comparison between the conventional method and the DSR method of rice

Technology	Benefit: Cost	Reference
Conventional transplanted rice	2.88	Gautam *et al*. (2021)
DSR method	4.42	
Conventional transplanted rice	2.18	Mohanta *et al*. (2021)
DSR method	2.56	
Conventional transplanted rice	1.36	Kaur *et al*. (2022)
DSR method	1.83	
Conventional transplanted rice	2.06	Kumar *et al.* (2018)
DSR method	2.29	
Conventional transplanted rice	2.4	Ishfaq *et al*. (2020)
DSR method	3.3	

Direct seeded rice

In the present agriculture scenario, adopting profit-oriented technologies is more needful by shifting production-oriented practices for sustainable farming. In this direction, adopting conservation agriculture practices will be an effective way to sustain the production and security of food in the future. Direct-seeded rice production is one of the important alternatives to conservation agriculture (Jat *et al*., 2019). Direct seeding is a more efficient practice than transplanting because of less movement of soil, which often includes some part of the strip-tillage system (McDonald *et al*., 2022). Direct seed/ aerobic rice cultivation has the greater potential to diminish production costs, hazardous soil health, and negative effects on subsequent crops. Direct-seeded rice cultivation (DSR) requires less water than puddled transplanted rice (TPR) to prepare land/ puddling, saving overall water use or demand. DSR is a sustainable technology practice that saves labour, water, time, and fuel requirements (Yadav *et al*., 2020). Still, it yields a similar amount to TPR if weed populations are controlled effectively by the judicious application of herbicides (Raj and Syriac, 2017). The farming community can adopt DSR in various ecologies, i.e., lowland, upland, medium land, irrigated areas, and deep water areas, because it does not impact rice quality. DSR practice improved soil health properties and maximized water and fertilizer use efficiencies (30-40% irrigation water saving) (Bhatt *et al*., 2021). Moreover, DSR is a more technical and economical practice than TPR (Table 1). Normally, DSR in the wet season should be practiced before 10 to 12 days of monsoon onset. In northern India, summer mung bean can be cultivated without delay in rice sowing. It produces 8-10 quintals/ha grain yield and helps in addition to 40-60 kg of nitrogen per hectare of soil, minimizing nitrogen requirement for the succeeding crop (Pathak and Das, 2016).

System of rice intensification (SRI)

SRI refers to a farming technique that creates an ideal atmosphere for crop growth without hampering resources and helps increase productivity. In this method, yields of the crops are enhanced by 50-100%, with less water requirement (25-50%) and 80-90% less plant population compared to conventional practices. It does not require any improved varieties or uses of synthetic fertilizers (only compost is added to the soil), which helps to reduce cultivation costs and increases yield production (Table 2) and net economic benefits per hectare of land (Mboyerwa *et al*., 2022).

Important features of SRI (Thakur *et al*., 2016)

Reduced plant population

Transplanting of young seedlings

Maintenance of aerated conditions in soil

Adds a significant quantity of organic substances to the soil

Re-emphasize biology

Rediscover the potentiality of symbiosis and synergy

Bed planting

This planting method uses crop sowing on the beds or ridges. Depending on the crop types, bed height and width are maintained, which is about 15-20 cm in height and 40-70 cm in width. Moreover, wheat is cultivated around the width of 45 cm bed and normally, three rows of plants are sown in a bed, having a spacing of 15 cm. The width of the furrow is typically maintained at 25 cm (Du *et al*., 2022). During the last ten years, an adaptation of the bed planting method has emerged in the Indo-Gangetic plain at a magnificent pace. The major aims of adopting this method are to increase crop productivity and reduce the loss of irrigation water (Islam *et al*., 2022). Table 3 compares the bed method and flat method of sowing based on yield production efficiency. The advantages of the bed system include reduced waterlogging, decreased soil compaction through limited trafficking, better soil structure, and easier machinery operation due to improved surface drainage (Du *et al*., 2021). In dry areas, permanent beds act as a moisture conserver, providing moisture to plants in prolonged dry periods, and high precipitation areas, they facilitate a good drainage system. These bed systems also provided better opportunities for mechanical weeding and improved placement of fertilizers (Porwal and Verma, 2023). In rice-wheat cropping systems in Australia and Asia, permanent bed planting for water-logging-sensitive plants created diversification opportunities unsuited for conventional flat sowing methods. Generally, the bed planting method saves 18-50% of irrigation water for crop production (Sharma *et al*., 2022).

Agroforestry

Agroforestry is one type of land use system that helps to mitigate water and soil erosion and stabilizes crop productivity with better water management. Bushes and trees can produce fodder, firewood, fruits, building materials, fuel, etc., creating greater annual household income opportunities and mitigating risk (Quandt *et al*., 2023). Agroforestry also helps to enhance carbon sequestration below and above ground, mitigating greenhouse gas emissions (Ghale *et al*., 2022). The integration of trees with crops or pastures increases biomass production, which contributes to organic matter accumulation through the decomposition of leaf litter and roots into the soil, leading to greater carbon sequestration in the soil and an increment in the soil's microbial activity and fertility status (Lorenz and Lal, 2014). The silvi-pastoral practices sequestered 36.3% to 60% more amount of total organic carbon in the soil than only the tree system and more than 27.1%-70.8% organic carbon stock in the soil compared to the pastoral system alone (Mangalassery *et al*., 2014).

Alley cropping

It is an intercropping system, where crops and trees are grown together or agricultural crops are sown widely between alternate rows of the trees, having greater potentiality to mitigate nitrous oxide emissions and increase carbon sequestration potentiality in the agricultural fields (Jacobs *et al*., 2022). Many recent studies reported that tree-based intercropping systems created global opportunities to mitigate carbon dioxide accumulation in the Earth's atmosphere (Cardinael *et al*., 2017). In an alley cropping system, total organic carbon accumulation in the soil is much higher than in conventional monoculture practices because litterfall and pruning parts are integrated into the soil system (Hombegowda *et al*., 2022). This system enhances carbon storage in soil and reduces carbon loss to the earth's atmosphere (Sánchez-Navarro *et al*., 2022).

Integrated Farming System (IFS)

In an agricultural production system, greenhouse gas emission occurs mainly in various steps in a production chain. Moreover, evaluating different management strategies requires an integral assessment of GHG emissions covering the entire production chain, including the agro-inputs life cycle (Skinner *et al*., 2019). The conversion of the conventional method (application of chemical inputs) to the organic method by the IFS system resulted in a reduction in GHG emissions per ha of field and farm area. Integrating rice-duck, rice-duck-fish, or rice-fish methods significantly helped reduce synthetic inputs (fertilizers and pesticides), resulting in sustainable environmental health. The practices of diversified crops with other enterprises in IFS system provide a sustained and stable production system, which helps to minimize risk and resilience to climate change (Behera and France, 2016). The IFS system also helps recycle on-farm by-products within these enterprises and ensures economic stability (Table 4) for the farming community (Singh *et al*., 2020). From a specific perspective (considering worldwide enhancing food demand), assessing GHG emissions should be related to protein production for human nutrition (Sekaran *et al*., 2021). This strategy shows clearly that livestock production is a major factor in determining GHG emissions concerning food production. This happened because of direct emissions from animal wastes and the lower nitrogen efficiency of meat production. Hence, 80-95% of the nitrogen is excreted from taken feed through urine and dung. Moreover, reducing crop production for livestock husbandry without affecting human nutrition illustrates the most relevant measures for reducing GHG emissions in agriculture (Mujeyi *et al*., 2021).

Laser land leveling (LLL)

Laser land leveling is a basic technological strategy for adopting conservation agriculture systems like bed planting, zero tillage (Sapkal *et al*., 2019). This is also called laser-aided land leveling. Initially, LLL was introduced in India at the farm level in western parts of Uttar Pradesh in 2001. In South Asia, it is practiced by over 1.5 Mha. In the case of the traditional farming system, the average field has an undulation of 5 to 15 cm which often causes poor emergence of seedlings, a higher mortality rate of seedlings because of waterlogged conditions, and variability in primary growth stages of the crops (Pathak and Das, 2016). Adopting LLL provides uniform application of nutrients and water throughout the farmland, which facilitates synchronous crop stand and the maturity of the crops as a result of nutrient-water interactions (Aryal *et al*., 2020).

The beneficial features of uniform land leveling by using drag bucket equipment include (Bhatt *et al*., 2021):

It provides greater crop establishment

Enhances in cultivable area around 3-6%

It facilitates higher water use efficiency of about 50% or more

It provides higher efficiency in nutrient use

Increases the efficiency of weed control

Enhances water productivity and yields (15-25%) of the crops, and reduces losses of irrigation water (25-30%)

Table 3. The grain yield comparison between the flat method and bed method of sowing for the different crops in the rice -based cropping system

Crop Name	Method of sowing	Grain yield (kg ha^{-1})	Reference
Rice	Flat sowing	4242	Bakhsh *et al*. (2018)
	Bed sowing	5512	
Wheat	Flat sowing	3727	
	Bed sowing	4470	
Cotton	Flat sowing	3371	
	Bed sowing	3779	
Wheat	Flat sowing	1816	Majeed *et al*. (2015)
	Bed sowing	2100	
Green gram	Flat sowing	1967	Tripathi and Das (2017)
	Bed sowing	2199	
Wheat	Flat sowing	2810	Mollah *et al*., (2015)
	Bed sowing	3340	
Wheat	Flat sowing	5813.4	Du *et al*. (2022)
	Bed sowing	6692.4	

Table 4. Net profit comparison between different methods of IFS

Cropping System	Net Profit (USD)	Addition of IFS	Net profit (USD)	% Increment	Reference
Rice-rice	288	Rice+fish+poultry	648	125	Channabasavanna *et al*. (2007)
Rice-wheat	575	Rice-wheat+goat+duck+fish	2204	284	Kumar *et al*. (2012)
Rice-maize	780	Rice-maize+goat+duck+fish	2211	184	Kumar *et al*. (2012)
Rice-fallow	764	Rice+fish	979	28	Dey *et al*. (2019)
Rice-rice	227	Rice+vegetables+fish	2653	1067	Panda *et al*. (2016)

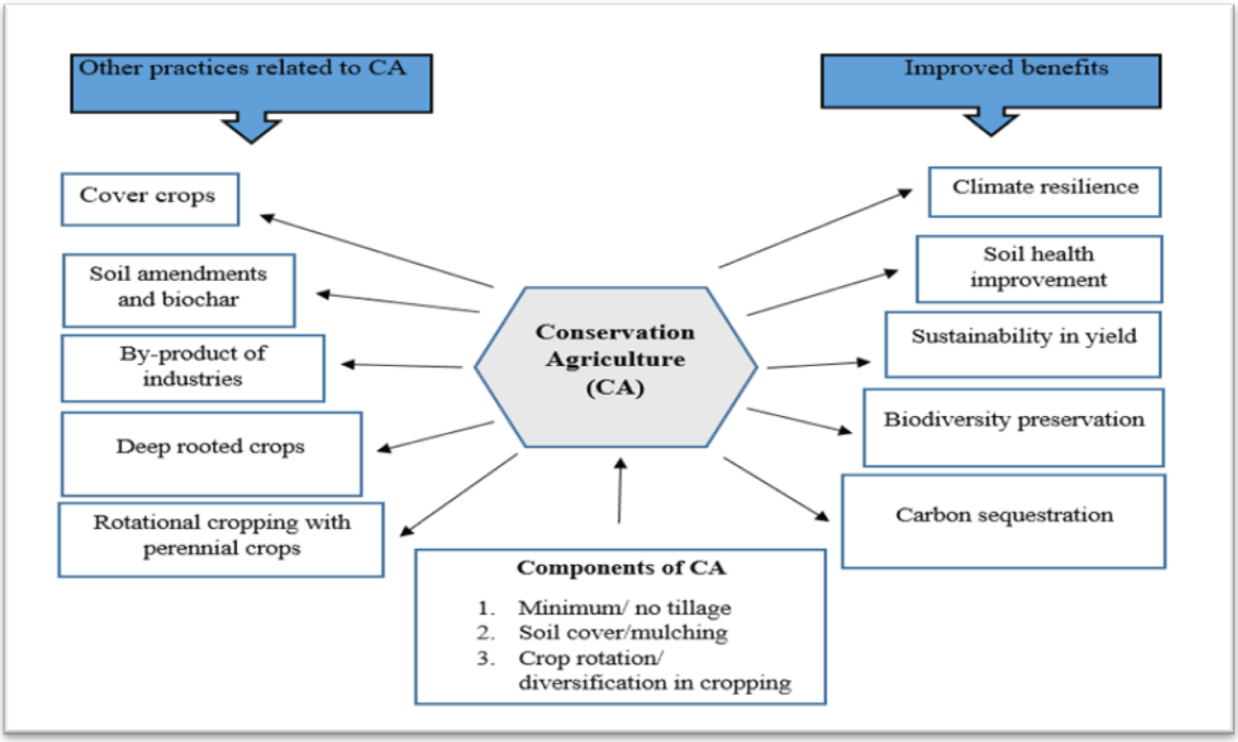

Fig. 4. *Beneficial effects of conservation agricultural practices*

The use of laser land leveling was found to be accelerating at several different rates and nowadays, around 0.2 Mha of farmland has adopted this practice in the Indo-Gangetic plain region, and significantly it saved irrigation water use, fuel, energy, and electricity along with greater yield potentiality in various crops and cropping system (Aryal *et al*., 2015). The average water productivity under LLL at Ludhiana, Punjab was 0.52 kg/m3 and under an unlevelled condition, it was 0.33 kg/m3. Furthermore, the water productivity under LLL at Modipuram, Uttar Pradesh was 0.91 kg/m3; compared to traditional practices, it was 2.15 times much higher. Moreover, (Jat *et al*., 2009) revealed that the production potentiality of rice is not affected by laser land leveling practices.

Crop diversification

Crop diversification is an important eco-friendly approach that helps to mitigate environmental stresses arising due to continuous monoculture practices (Barman *et al*., 2022). The addition of certain species of crops in intercropping and sequential cropping has been observed to decrease many obnoxious weed species to a greater extent, resulting in reduced herbicide necessity (Scott and Freckleton, 2022). Leaching nitrate is often a problem in most agricultural systems. Integrating a suitable cropping system and management strategies helped diminish nitrate leaching and improve nitrogen use efficiency (Eberly *et al*., 2024). Including legume crops in a cropping system has been observed to be workable in decreasing nitrate leaching into the lower profiles of the soil (Lapierre *et al*., 2022). Besides, crop rotation practice also plays a crucial role in weed and disease management practices. It becomes a part of the residue management strategies to keep the soil continually covered either in live crops or under residue mulch (Liu *et al*., 2022). According to Rautaray and Sucharita (2024), crop diversification adaptation plays many beneficial roles in agricultural system, such as

Interrupts the life cycles of weeds, insects and diseases, reducing their prevalence.

Efficiently distributes nutrients in the soil profile (through growing legume crops)

Adequate utilization of soil water by growing deep-rooted crops

Decreases economic risk by adopting a multiple cropping system

Permits a balance in the production of crop residues

In the rice-wheat-based cropping system of IGP regions, fields remain fallow between harvesting (wheat) and the next crop planting (rice) for more than 70 to 80 days. The strategy was to establish additional crops in this fallow period with short life spans such as summer mungbean (60 days to 65 days). Summer mungbean cultivation not only contributes additional income but also helps to incorporate a certain amount of nitrogenous nutrients into the soil via biological nitrogen fixation (Gora *et al*., 2022). Besides, the pigeon peas variety 'ICPL 88039' (extra-short duration) can also be grown to diversify rice-wheat-based cropping (Sharma *et al*., 2023). Table 5 represents the advantage of crop diversification over conventional practices.

Management of crop residues

Long-lasting or partially permanent crop residues cover the soil, may be dead or live mulch, have a crucial role in preserving soil health from rain, wind, and sun, and supply feed for soil biota that helps to maintain tillage functionalities and nutrient balancing (Jat *et al*., 2019). Incorporation of agricultural residue under a no-tillage system is more advantageous than residue retention

Table 5. Advantages of crop diversification with their example

Conventional cropping system	Crop diversification	Advantages of adopting crop diversification	References
Transplanted boro rice-transplanted aman rice	Wheat-mungbean-Transplanted aman rice with full tillage Wheat-mungbean- dry seeded aman rice with strip tillage	Increased land and water productivity; Enhanced profitability of rice-based cropping system	Alam *et al*. (2017)
Maize-fallow	Maize-rajmash Maize-toria Maize–buckwheat Maize (green cobs)-urdbean–buckwheat	Enhanced system production efficiency, land use efficiency, grain quivalent yield, and relative production efficiency.	Babu *et al*. (2016)
Transplanted aman rice-Potato-Transplanted boro rice	Transplanted aman rice-Potato -cucumber-Transplanted aus rice	Higher productivity and profitability compared to conventional cropping system; Improved sustainability	Alam *et al*. (2021)

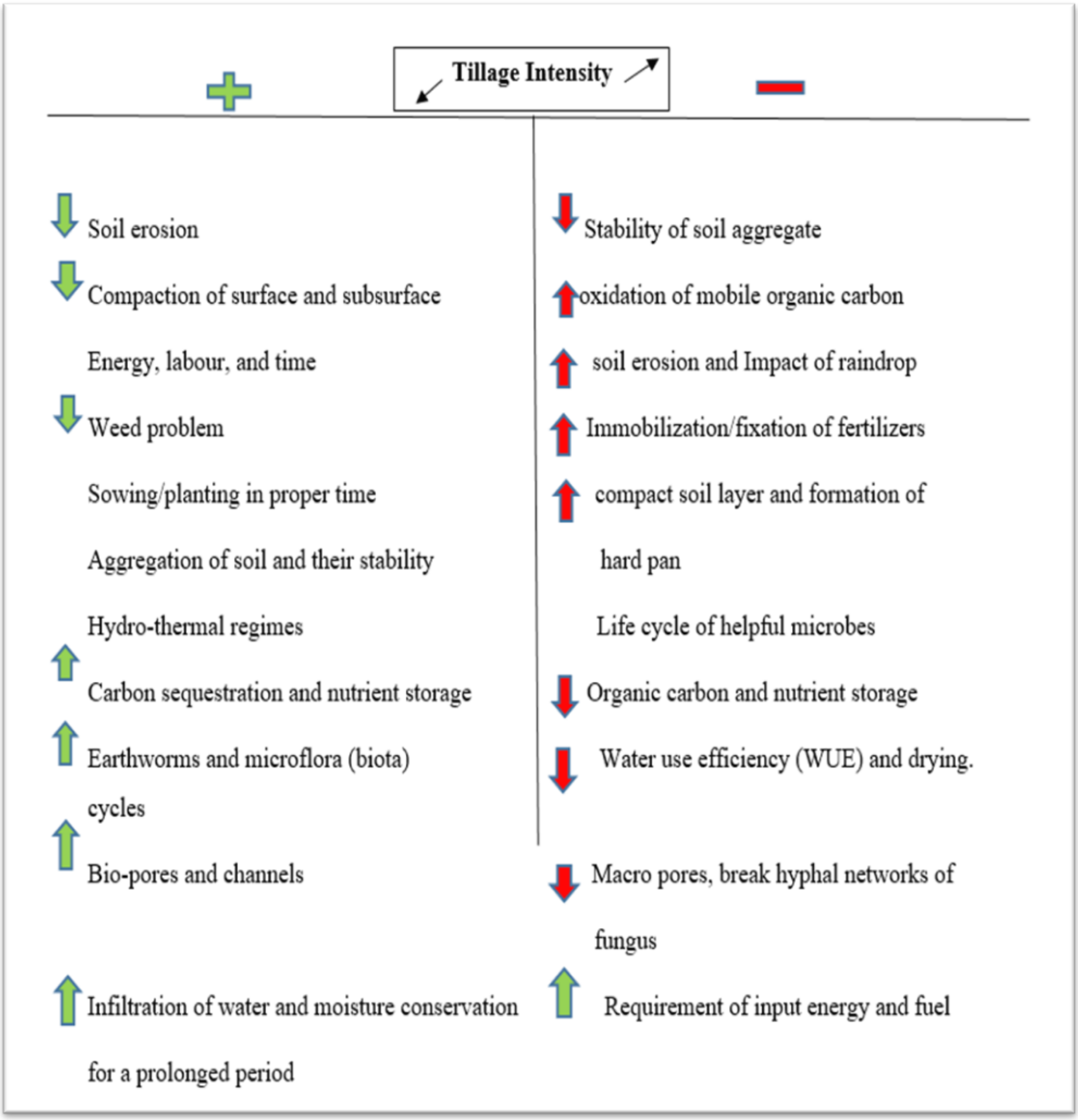

Fig. 5. *Effectiveness of conservation agriculture*

under a conventional tillage system (Lal *et al*., 2019). It preserves soil moisture, increases organic carbon, maintains soil temperature, reduces weed infestation, and provides nutrients to the soil, eventually reducing irrigation water necessity and increasing crop productivity status and net benefit (Goswami *et al*., 2020). Crop residues remarkably help sustain soil health and increase water retention by reducing evaporation losses, water erosion, wind erosion, and increasing water infiltration rate (Kumar *et al*., 2023). The suitable management practices of crop residues will exclude straw burning, increase water and nutrient utilization efficiency, improve organic carbon in the soil, and it will have the capability to diminish GHG emissions (Raza *et al*., 2022).

Integrated Weed Management (IWM)

Weed population and management of weeds are being influenced by global warming and the continuous rise of carbon dioxide concentration in the air (Siddiqui *et al*., 2022). Many recent research evidence proved that higher concentrations of CO_2 in the surrounding atmosphere enhance the growth and development of weeds, especially C3 weeds (Ziska, 2016). Further, global warming supports many weed species in spreading their ranges and establishing new areas. Higher carbon dioxide levels and warming may also antagonise several herbicides' efficacy (Rastgordani *et al*., 2023). Adapting mechanical and cultural practices is crucial in limiting the expanded weed population. Hence, the integration of physical (hand weeding), mechanical (cono weeder, Robocrop intra-row cultivator), cultural (intercropping, cover crops, competitive cultivars, crop rotation, mulching), and biological methods along with chemical herbicide application is the best strategy to control weeds effectively under this changing climate (Steiner *et al*., 2023; Rao and Chandrasena, 2022).

Conclusion

Strengthening the adaptability of agriculture to address fluctuations in weather patterns and global climate shifts is a blessing for the economic stability of countless small-scale and low-income farmers worldwide. Climate-adaptive farming practices result in sustainable agricultural output production and income over the long term by enhancing the management of crops and livestock, even in the face of diverse climate fluctuations. This approach provides a way for farmers to deal with the problems triggered by climate change. However, despite the apparent advantages, the level of acceptance among small-scale farmers varies significantly. If governmental and other accountable entities take proactive measures to encourage the implementation of climate-adaptive farming practices, it becomes more feasible to inhibit the consequences of climate change.

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Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

1. Ahmed, Z., Gui, D., Qi, Z., Liu, J., Ali, A., Murtaza, G. & Ahmad, S. (2023). Greenhouse gas emissions and mitigation strategies in rice production systems. *In Global Agricultural Production: Resilience to Climate Change* (pp. 237-265). Cham: Springer International Publishing. DOI: https://doi.org/10.1007/978-3-031-14973-3_8
2. Alam, M. J., Al-Mahmud, A., Islam, M. A., Hossain, M. F., Ali, M. A., Dessoky, E. S. & Hossain, A. (2021). Crop diversification in rice—based cropping systems improves the system productivity, profitability and sustainability. *Sustainability*, 13(11), 6288.
3. Alam, M. J., Humphreys, E. & Sarkar, M. A. R. (2017). Intensification and diversification increase land and water productivity and profitability of rice-based cropping systems on the High Ganges River Floodplain of Bangladesh. *Field Crops Research*, 209, 10-26.
4. Aryal, J. P., Khatri□Chhetri, A., Sapkota, T. B., Rahut, D. B. & Erenstein, O. (2020). Adoption and economic impacts of laser land leveling in the irrigated rice□wheat system in Haryana, India using endogenous switching regression. *Nat. Resour. Forum.,* 44(3), 255-273. DOI: https://doi.org/10.1111/1477-8947.12197
5. Aryal, J. P., Mehrotra, M. B., Jat, M. L. & Sidhu, H. S. (2015). Impacts of laser land leveling in rice–wheat systems of the north–western indo-gangetic plains of India. *Food Security*, 7(3), 725-738. DOI: https://doi.org/10.1007/s12571-015-0460-y
6. Babu, S., Singh, R., Avasthe, R. K., Yadav, G. S. & Rajkhowa, D. J. (2016). Intensification of maize (Zea mays)–based cropping sequence in rainfed ecosystem of Sikkim Himalayas for improving system productivity, profitability, employment generation and energy-use efficiency under organic management condition*. Indian Journal of Agricultural Sciences*, 86(6), 778-84.
7. Baiswar, A., Yadav, J. S., Sain, K., Bhambri, R., Pandey, A., & Tiwari, S. K. (2023). Emission of greenhouse gases due to anthropogenic activities: an environmental assessment from paddy rice fields. *Environmental Science and Pollution Research*, 30(13), 37039-37054. DOI: https://doi.org/10.1007/s11356-022-24838-0
8. Bakhsh, A., Chauhdary, J. N. & Ahmad, N. (2018). Improving crop water productivity of major crops by adopting bed planting in Rechna Doab Pakistan. *Pakistan J. Agric. Sci*., 55, 965-972.
9. Barman, A., Saha, P., Patel, S. & Bera, A. (2022). Crop diversification an effective strategy for sustainable agriculture development. *IntechOpen.* DOI: http://dx.doi.org/10.5772/intechopen.102635
10. Behera, U. K. & France, J. (2016). Integrated farming systems and the livelihood security of small and marginal farmers in India and other developing countries. *Advances in agronomy*, 138, 235-282.
11. Bhatt, R., Singh, P., Hossain, A. & Timsina, J. (2021). Rice–wheat system in the northwest Indo-Gangetic plains of South Asia: issues and technological interventions for increasing productivity and sustainability. *Paddy and Water Environment*, 19(3), 345-365. DOI: https://doi.org/10.1007/s10333-021-00846-7
12. Cardinael, R., Chevallier, T., Cambou, A., Béral, C., Barthès, B. G., Dupraz, C. & Chenu, C. (2017). Increased soil organic carbon stocks under agroforestry: A survey of six different sites in France. *Agriculture, Ecosystems & Environment*, 236, 243-255. DOI: https://doi.org/10.1016/j.agee.2016.12.011
13. Channabasavanna, A. S. & Biradar, D. P. (2007). Relative performance of different rice-fish-poultry integrated farming system models with respect to system productivity and economics. *Karnataka Journal of Agricultural Sciences*, 20 (4), 706.
14. Choudhary, S., Choudhary, S., Baghel, S. S., Upadhyay, A. K., Singh, A. & Yadav, S. (2022). Performance of rice under IPNS-STCR based nutrients management strategy. *The Pharma Innovation Journal*, 11(2), 183-186.
15. Derpsch, R., Friedrich, T., Kassam, A. & Li, H. (2010). Current status of adoption of no-till farming in the world and some of its main benefits. *International journal of agricultural and biological engineering*, 3(1), 1-25.
16. Dey, A., Sarma, K., Kumar, U., Mohanty, S., Kumar, T. & Bhatt, B. P. (2019). Prospects of rice-fish farming system for low lying areas in Bihar, India. *Organic agriculture*, 9, 99-106. DOI: https://doi. org/10.1007/s13165-017-0204-8
17. Du, X., He, W., Gao, S., Liu, D., Wu, W., Tu, D. & Xi, M. (2022). Raised bed planting increases economic efficiency and energy use efficiency while reducing the environmen-

tal footprint for wheat after rice production. *Energy*, 245, 123256. DOI: https://doi.org/10.1016/j.energy.2022.123256

18. Du, X., He, W., Wang, Z., Xi, M., Xu, Y., Wu, W. & Kong, L. (2021). Raised bed planting reduces waterlogging and increases yield in wheat following rice. *Field Crops Research*, 265, 108119. DOI: https://doi.org/10.1016/j.fcr.2021.108119
19. Dubey, R., Sharma, R. S. & Dubey, D. P. (2014). Effect of organic, inorganic and integrated nutrient management on crop productivity, water productivity and soil properties under various rice-based cropping systems in Madhya Pradesh, India. *International Journal of Current Microbiology and Applied Sciences*, 3(2), 381-389.
20. Eberly, J. O., Hammontree, J. W., Fordyce, S. I., Jones, C. A. & Carr, P. M. (2024). Changes in biological soil health properties in response to increased crop diversity in a dryland wheat-based cropping system. *Communications in Soil Science and Plant Analysis*, 1-17. DOI: https://doi.org/10.1080/00103624.2024.2345153
21. Farooq, A., Farooq, N., Akbar, H., Hassan, Z. U., & Gheewala, S. H. (2023). A critical review of climate change impact at a global scale on cereal crop production. *Agronomy*, 13(1), 162. DOI: https://doi.org/10.3390/agronomy13010162
22. Friedrich, T., Derpsch, R. & Kassam, A. (2011). Global overview of the spread of conservation agriculture. In Proceedings from the 5th World Congress on Conservation Agriculture, Brisbane, Australia (pp. 26-30).
23. Gautam, A., Singh, V. & Aulakh, G. S. (2021). Performance of paddy cultivation under different methods in South-Western part of Punjab, India. *Indian Journal of Extension Education*, 57(4), 131-134.
24. Ghale, B., Mitra, E., Sodhi, H. S., Verma, A. K. & Kumar, S. (2022). Carbon sequestration potential of agroforestry systems and its potential in climate change mitigation. *Water, Air, & Soil Pollution*, 233(7), 228.
25. Gill, M. S., Pal, S. S. & Ahlawat, I. P. S. (2008). Approaches for sustainability of rice (Oryza sativa)-wheat (Triticum aestivum) cropping system in Indo-Gangetic plains of India–A review. *Indian Journal of Agronomy*, 53(2), 81-96.
26. Gora, M. K., Kumar, S., Jat, H. S., Kakraliya, S. K., Choudhary, M., Dhaka, A. K. & Jat, M. L. (2022). Scalable diversification options delivers sustainable and nutritious food in Indo-Gangetic plains. *Scientific reports*, 12(1), 14371. DOI: https://doi.org/10.1038/s41598-022-18156-1
27. Goswami, S. B., Mondal, R. & Mandi, S. K. (2020). Crop residue management options in rice–rice system: a review. *Archives of Agronomy and Soil Science*, 66(9), 1218-1234. DOI: https://doi.org/10.1080/03650340.2019.1661994
28. Gupta, K., Kumar, R., Baruah, K. K., Hazarika, S., Karmakar, S., & Bordoloi, N. (2021). Greenhouse gas emission from rice fields: a review from Indian context. Environmental Science and Pollution Research, 28(24), 30551-30572. DOI: https://doi.org/10.1007/s11356-021-13935-1
29. Habibi, E., Niknejad, Y., Fallah, H., Dastan, S. & Tari, D. B. (2019). Life cycle assessment of rice production systems in different paddy field size levels in north of Iran. *Environmental monitoring and assessment*, 191(4), 202. DOI: https://doi.org/10.1007/s11270-022-05689-4
30. Hobbs, P. R. (2007). Conservation agriculture: what is it and why is it important for future sustainable food production?. *The Journal of Agricultural Science*, 145(2), 127. DOI: https://doi.org/10.1017/S0021859607006892
31. Hombegowda, H. C., Adhikary, P. P., Jakhar, P. & Madhu, M. (2022). Alley Cropping Agroforestry System for Improvement of Soil Health. In *Soil Health and Environmental Sustainability:* Application of Geospatial Technology. *Cham: Springer International Publishing.* 529-549. DOI: https://doi.org/10.1007/978-3-031-09270-1_23
32. Ishfaq, M., Akbar, N., Anjum, S. A. & Anwar-Ijl-Haq, M. (2020). Growth, yield and water productivity of dry direct seeded rice and transplanted aromatic rice under different irrigation management regimes. *Journal of Integrative Agriculture*, 19(11), 2656-2673.
33. Islam, M. A., Bell, R. W., Johansen, C., Jahiruddin, M., Haque, M. E. & Vance, W. (2022). Conservation agriculture practice influences soil organic carbon pools in intensive rice□based systems of the Eastern Indo□Gangetic Plain. *Soil Use and Management*, 38(2), 1217-1236.
34. Jacobs, S. R., Webber, H., Niether, W., Grahmann, K., Lüttschwager, D., Schwartz, C. & Bellingrath-Kimura, S. D. (2022). Modification of the microclimate and water balance through the integration of trees into temperate cropping systems. *Agricultural and Forest Meteorology*, 323, 109065. DOI: https://doi.org/10.1016/j.agrformet.2022.109065
35. Jat, H. S., Datta, A., Choudhary, M., Sharma, P. C., Yadav, A. K., Choudhary, V. & McDonald, A. (2019). Climate Smart Agriculture practices improve soil organic carbon pools, biological properties and crop productivity in cereal-based systems of North-West India. *Catena*, 181, 104059. DOI: https://doi.org/10.1016/j.catena.2019.05.005
36. Jat, M. L., Gathala, M. K., Ladha, J. K., Saharawat, Y. S., Jat, A. S., Kumar, V. & Gupta, R. (2009). Evaluation of precision land leveling and double zero-till systems in the rice–wheat rotation: Water use, productivity, profitability and soil physical properties. *Soil and Tillage Research*, 105(1), 112-121. DOI: 10.1016/j.still.2009.06.003
37. Jena, B. K., Barik, S. R., Moharana, A., Mohanty, S. P., Sahoo, A., Tudu, R., ... & Pradhan, S. K. (2023). Rice production and global climate change. Biomedical *Journal of Scientific and Technical Research*, 48(1), 39075-39095. DOI: https://dx.doi.org/10.26717/BJSTR.2023.48.007592
38. Kassam, A., Friedrich, T. & Derpsch, R. (2019). Global spread of conservation agriculture. *International Journal of Environmental Studies*, 76(1), 29-51. DOI: https://doi.org/10.1080/00207233.2018.1494927
39. Kassam, A., Friedrich, T., Shaxson, F., Bartz, H., Mello, I., Kienzle, J. & Pretty, J. (2014). The spread of conservation agriculture: Policy and institutional support for adoption and uptake. Field Actions Science Reports. *The journal of field actions*, 7. DOI: http:// factsreports.revues.org/3720
40. Kaur, K., Singh, G. & Aulakh, C. S. (2022). Effect of various crop establishment methods on the crop performance and water use efficiency of rice (Oryza sativa). *Crop Research*, 57(1and2), 15-20. DOI: http://dx.doi.org/10.31830/2454-1761.2022.003
41. Khan, I., Lei, H., Shah, I. A., Ali, I., Khan, I., Muhammad, I. & Javed, T. (2020). Farm households' risk perception, attitude and adaptation strategies in dealing with climate change: Promise and perils from rural Pakistan. *Land use*

policy, 91, 104395.
42. Kumar, N., Chaudhary, A., Ahlawat, O. P., Naorem, A., Upadhyay, G., Chhokar, R. S. & Singh, G. P. (2023). Crop residue management challenges, opportunities and way forward for sustainable food-energy security in India: A review. *Soil and Tillage Research*, 228, 105641. DOI: https://doi.org/10.1016/j.still.2023.105641
43. Kumar, P., Kumar, S., Mouriya, A. K. & Kumar, V. (2018). Productivity and economics of direct seeded rice. *Int. J. Sci. Environ. Technol*, 7, 2033-2039.
44. Kumar, R., Raj, M., Lal, K. & Ranjan, A. (2021). Impact of SRI Components on Growth and Productivity of Conventional Transplanted Rice. *Biological Forum–An International Journal,* 13(3), 196-199.
45. Kumar, S., Subash, N., Shivani, S., Singh, S. S. & Dey, A. (2012). Evaluation of different components under integrated farming system (IFS) for small and marginal farmers under semi-humid climatic environment. *Experimental agriculture*, 48(3), 399-413. DOI: https://doi. org/10.1017/S0014479712000087
46. Lal, B., Gautam, P., Nayak, A. K., Panda, B. B., Bihari, P., Tripathi, R. & Meena, B. P. (2019). Energy and carbon budgeting of tillage for environmentally clean and resilient soil health of rice-maize cropping system. *Journal of Cleaner Production*, 226, 815-830. DOI: http://doi.org/10.1016/j.jclepro.2019.04.041
47. Lapierre, J., Machado, P. V. F., Debruyn, Z., Brown, S. E., Jordan, S., Berg, A. & Wagner-Riddle, C. (2022). Cover crop mixtures: A powerful strategy to reduce post-harvest surplus of soil nitrate and leaching. *Agriculture, Ecosystems & Environment*, 325, 107750.
48. Leharwan, M., Kumar, Y., Kumar, R., Kumar Saraswat, P., Kumar, R., Kumar Thaliyil Veetil, A., & Kumar, S. (2023). Assessing the effects of conservation tillage and in-situ crop residue management on crop yield and soil properties in rice–wheat cropping system. *Sustainability*, 15(17), 12736. DOI: https://doi.org/10.3390/su151712736
49. Liu, C., Plaza-Bonilla, D., Coulter, J. A., Kutcher, H. R., Beckie, H. J., Wang, L. & Gan, Y. (2022). Diversifying crop rotations enhances agroecosystem services and resilience. *Advances in Agronomy*, 173, 299-335. DOI: https://doi.org/10.1016/bs.agron.2022.02.007
50. Lorenz, K.,& Lal, R. (2014). Soil organic carbon sequestration in agroforestry systems. A review. *Agronomy for Sustainable Development*, 34, 443-454.
51. Majeed, A., Muhmood, A., Niaz, A., Javid, S., Ahmad, Z. A., Shah, S. S. H. & Shah, A. H. (2015). Bed planting of wheat (Triticum aestivum L.) improves nitrogen use efficiency and grain yield compared to flat planting. *The crop journal*, 3(2), 118-124.
52. Marie, M., Yirga, F., Haile, M. & Tquabo, F. (2020). Farmers' choices and factors affecting adoption of climate change adaptation strategies: evidence from northwestern Ethiopia. *Heliyon*, 6(4).
53. Mangalassery, S., Dayal, D., Meena, S. L. & Ram, B. (2014). Carbon sequestration in agroforestry and pasture systems in arid northwestern India. *Current Science*, 1290 -1293.
54. Mboyerwa, P. A., Kibret, K., Mtakwa, P. & Aschalew, A. (2022). Lowering nitrogen rates under the system of rice intensification enhanced rice productivity and nitrogen use efficiency in irrigated lowland rice. *Heliyon*, 8(3). DOI: https://doi.org/10.1016/j.heliyon.2022.e09140
55. Mboyerwa, P. A., Kibret, K., Mtakwa, P. & Aschalew, A. (2022a). Rice yield and nitrogen use efficiency with system of rice intensification and conventional management practices in mkindo irrigation scheme, Tanzania. *Frontiers in Sustainable Food Systems*, 6, 802267.
56. McDonald, A. J., Keil, A., Srivastava, A., Craufurd, P., Kishore, A., Kumar, V. & Malik, R. K. (2022). Time management governs climate resilience and productivity in the coupled rice–wheat cropping systems of eastern India. *Nature Food*, 3(7), 542-551.
57. Meena, B. L., Raja, R., Dotaniya, M. L., Nanda, G., & Meena, R. S. (2019). Integrated nutrient management for sustainable rice-based cropping systems and soil quality. *Sustainable Agriculture; Meena, RS, Ed.; Scientific Publishers (India): Jodhpur, India*, 1.
58. Meena, S. K., Dwivedi, B. S., Meena, M. C., Datta, S. P., Singh, V. K., Mishra, R. P. & Meena, V. S. (2022). Impact of Long-Term Nutrient Supply Options on Soil Aggregate Stability after Nineteen Years of Rice–Wheat Cropping System. *Land*, 11(9), 1465.
59. Mohanta, S., Banerjee, M., Malik, G. C., Shankar, T., Maitra, S., Ismail, I. A. & Hossain, A. (2021). Productivity and profitability of kharif rice are influenced by crop establishment methods and nitrogen management in the lateritic belt of the subtropical region. *Agronomy*, 11(7), 1280.
60. Mohanty, S., Nayak, A. K., Swain, C. K., Dhal, B. R., Kumar, A., Kumar, U. & Behera, K. K. (2020). Impact of integrated nutrient management options on GHG emission, N loss and N use efficiency of low land rice. *Soil and Tillage Research*, 200, 104616.
61. Mollah, M. I. U., Bhuiya, M. S. U., Hossain, M. S. & Hossain, S. M. A. (2015). Growth of wheat (Triticum aestivum L.) under raised bed planting method in rice-wheat cropping system. *Bangladesh Rice Journal*, 19(2), 47-56.
62. Mujeyi, A., Mudhara, M., & Mutenje, M. (2021). The impact of climate smart agriculture on household welfare in smallholder integrated crop–livestock farming systems: evidence from Zimbabwe. *Agriculture & Food Security*, 10, 1-15. DOI: https://doi.org/10.1186/s40066-020-00277-3
63. Nabavi-Pelesaraei, A., Rafiee, S., Mohtasebi, S. S., Hosseinzadeh-Bandbafha, H. & Chau, K. W. (2018). Integration of artificial intelligence methods and life cycle assessment to predict energy output and environmental impacts of paddy production. *Science of the total environment*, 631, 1279-1294. DOI: http://doi.org/10.1016/j.scitotenv.2018.03.088
64. Nirmala, B., Tuti, M. D., 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. *Agroecology and Sustainable Food Systems*, 45(5), 745-766.
65. Panda, N. (2016). Back yard poultry-a viable option for poverty alleviation. Root and tuber crops based integrated farming system: A way forward to address climate change and livelihood improvement, 133.
66. Pangapanga, P. I., Jumbe, C. B., Kanyanda, S. & Thangalimodzi, L. (2012). Unravelling strategic choices towards droughts and floods' adaptation in Southern Malawi. *International Journal of Disaster Risk Reduction*, 2, 57-66.

67. Paramesh, V., Kumar, P., Bhagat, T., Nath, A. J., Manohara, K. K., Das, B. & Prasad, P. V. (2023a). Integrated nutrient management enhances yield, improves soil quality, and conserves energy under the lowland rice–rice cropping system. *Agronomy*, 13(6), 1557. DOI: https://doi.org/10.3390/agronomy13061557
68. Paramesh, V., Kumar, P., Parajuli, R., Francaviglia, R., Manohara, K. K., Arunachalam, V. & Toraskar, S. (2023b). A Life Cycle Assessment of Rice–Rice and Rice–Cowpea Cropping Systems in the West Coast of India. *Land*, 12(2), 502. DOI: https://doi.org/10.3390/land12020502
69. Paramesh, V., Ravisankar, N., Das, B., Reddy, K. V., & Singh, N. P. (2017). Energy Budgeting and Sensitivity Analysis of Rice (Oryza sativa)—Wheat (Triticum aestivum) Cropping System in Indogangentic Plains of India. *Int. J. Curr. Microbiol. Appl. Sci*., 6, 1534–1544.
70. Pasricha, N. S., Ghosh, P. K. & Singh, R. (2023). Agriculture-related green house gas emissions and mitigation measures. *Advances in Agronomy*, 179, 257-376. DOI: https://doi.org/10.1016/bs.agron.2023.01.005
71. Pathak, H. & Das, T. K. (2016). Climate Resilient Agronomic Practices for Rice-Wheat Cropping System of the Indo-Gangetic Plains, Indian Society of Agronomy, Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi 110 012.
72. Pathak, H. (2023). Impact, adaptation, and mitigation of climate change in Indian agriculture. *Environmental Monitoring and Assessment*, 195(1), 52.
73. Porwal, M. & Verma, B. (2023). Agronomic interventions for the mitigation of climate change. *Emrg. Trnd. Clim. Chng.*, 2(1), 27-39. DOI: http://dx.doi.org/10.18782/2583-4770.122
74. Quandt, A., Neufeldt, H. & Gorman, K. (2023). Climate change adaptation through agroforestry: opportunities and gaps. *Current Opinion in Environmental Sustainability*, 60, 101244. DOI: https://doi.org/10.1016/j.cosust.2022.101244
75. Rajbonshi, M. P., Mitra, S., & Bhattacharyya, P. (2024). Agro-technologies for greenhouse gases mitigation in flooded rice fields for promoting climate smart agriculture. Environmental Pollution, 350, 123973. DOI: https://doi.org/10.1016/j.envpol.2024.123973
76. Raj, S. K. & Syriac, E. K. (2017). Weed management in direct seeded rice: A review. Agricultural Reviews, 38(1), 41-50. DOI: https://doi.org/10.18805/ag.v0iOF.7307
77. Ramesh, T. & Rathika, S. (2020). Evaluation of rice cultivation systems for greenhouse gases emission and productivity. Int. J. Ecol. Environ. Sci, 2, 49-54.
78. Rao, A. N. & Chandrasena, N. R. (2022). The Need for Climate-Resilient Integrated Weed Management (CRIWM) under future Climate Change. *Weeds-Journal of the Asian-Pacific Weed Science Society*, 4(2), 1-20.
79. Rastgordani, F., Oveisi, M., Mashhadi, H. R., Naeimi, M. H., Hosseini, N. M., Asadian, N. & Müller-Schärer, H. (2023). Climate change impact on herbicide efficacy: A model to predict herbicide dose in common bean under different moisture and temperature conditions. *Crop Protection*, 163, 106097. DOI: https://doi.org/10.1016/j.cropro.2022.106097
80. Rautaray, S. K. & Sucharita, S. (2024). Crop diversification for a sustainable agriculture. *Indian Farming*, 74(2), 19-22.
81. Raza, M. H., Abid, M., Faisal, M., Yan, T., Akhtar, S. & Adnan, K. M. (2022). Environmental and health impacts of crop residue burning: Scope of sustainable crop residue management practices. *International Journal of Environmental Research and Public Health*, 19(8), 4753. DOI: https://doi.org/10.3390/ijerph19084753.
82. Sánchez-Navarro, V., Shahrokh, V., Martínez-Martínez, S., Acosta, J. A., Almagro, M., Martínez-Mena, M. & Zornoza, R. (2022). Perennial alley cropping contributes to decrease soil CO2 and N2O emissions and increase soil carbon sequestration in a Mediterranean almond orchard. *Science of the Total Environment*, 845, 157225. DOI: https://doi.org/10.1016/j.scitotenv.2022.157225
83. Sapkal, S., Kamble, B. H., Kumar, P., Kar, A. & Jha, G. K. (2019). Impact of laser land levelling in rice-wheat systems of the North-Eastern indo-gangetic plains of India. Journal of *Pharmacognosy and Phytochemistry*, 8(1), 764-769.
84. Sayre, K. D. & Govaerts, B. (2009). Conservation agriculture for sustainable wheat production. *Wheat facts and futures*, 62-69.
85. Sayre, K. D., & Hobbs, P. R. (2004). The raised bed system of cultivation for irrigated production conditions. *Sustainable agriculture and the international rice-wheat system* (pp. 354-372). CRC press.
86. Scott, D. & Freckleton, R. P. (2022). Crop diversification and parasitic weed abundance: A global meta-analysis. *Scientific Reports*, 12(1), 19413. DOI: https://doi.org/10.1038/s41598-022-24047-2
87. Sekaran, U., Lai, L., Ussiri, D. A., Kumar, S. & Clay, S. (2021). Role of integrated crop-livestock systems in improving agriculture production and addressing food security–A review. *Journal of Agriculture and Food Research*, 5, 100190. DOI: https://doi.org/10.1016/j.jafr.2021.100190
88. Sharma, J., Sharma, B. C., Bharti, V., Kumar, R., Sharma, A., & Jamwal, S. (2022). Novel resource conservation technologies for increasing the production and productivity of rice-wheat cropping system in Indo-Gangetic plains of India. 235-242. DOI: http://dx.doi.org/10.5958/2582-2683.2022.00047.8
89. Sharma, T., Das, T. K., Maity, P. P., Biswas, S., Sudhishri, S., Govindasamy, P. & Rathi, N. (2023). Long-Term Conservation Agriculture Influences Weed Diversity, Water Productivity, Grain Yield, and Energy Budgeting of Wheat in North-Western Indo-Gangetic Plains. Sustainability, 15 (9), 7290. DOI: https://doi.org/10.3390/su15097290
90. Siddiqui, A. O., Yazlık, A. & Jabran, K. (2022). Weed management and climate change. *Building Climate Resilience in Agriculture: Theory, Practice and Future Perspective*, 211-223.
91. Singh, V. K., Rathore, S. S., Singh, R. K., Upadhyay, P. K. & Shekhawat, K. (2020). Integrated farming system approach for enhanced farm productivity, climate resilience and doubling farmers' income. *The Indian Journal of Agricultural Sciences*, 90(8), 1378-1388.
92. Skinner, C., Gattinger, A., Krauss, M., Krause, H. M., Mayer, J., Van Der Heijden, M. G. & Mäder, P. (2019). The impact of long-term organic farming on soil-derived greenhouse gas emissions. *Scientific reports*, 9(1), 1702. DOI: https://doi.org/10.1038/s41598-018-38207-w
93. Smith Jr, W. J., Liu, Z., Safi, A. S. & Chief, K. (2014). Climate change perception, observation and policy support

in rural Nevada: A comparative analysis of Native Americans, non-native ranchers and farmers and mainstream America. *Environmental Science & Policy*, 42, 101-122. DOI: http://doi.org/10.1016/j.envsci.2014.03.007

94. Somasundaram, J., Sinha, N. K., Dalal, R. C., Lal, R., Mohanty, M., Naorem, A. K. & Chaudhari, S. K. (2020). No-till farming and conservation agriculture in South Asia–issues, challenges, prospects and benefits. Critical Reviews in Plant Sciences, 39(3), 236-279.
95. Steiner, J. L., Lin, X., Cavallaro, N., Basso, G. & Sassenrath, G. (2023). Climate change impacts on soil, water, and biodiversity conservation. *Journal of Soil and Water Conservation*, 78(2), 27A-32A. DOI: https://doi.org/10.2489/jswc.2023.0208A
96. Thakur, A. K., Uphoff, N. T. & Stoop, W. A. (2016). Scientific underpinnings of the System of Rice Intensification (SRI): What is known so far?. *Advances in agronomy*, 135, 147-179. DOI: https://doi.org/10.1016/bs.agron.2015.09.004
97. Tomar, R., Singh, N. B., Singh, V. & Kumar, D. (2018). Effect of planting methods and integrated nutrient management on growth parameters, yield and economics of rice. *Journal of Pharmacognosy and Phytochemistry*, 7(2), 520-527.
98. Tripathi, S. C. & Das, A. (2017). Bed planting for resource conservation, diversification and sustainability of wheat based cropping system. *Journal of Wheat Research*, 9(1), 1-11.
99. Yadav, G. S., Babu, S., Das, A., Mohapatra, K. P., Singh, R., Avasthe, R. K. & Roy, S. (2020). No-till and mulching enhance energy use efficiency and reduce carbon footprint of a direct-seeded upland rice production system. *Journal of Cleaner Production*, 271, 122700. DOI: https://doi.org/10.1016/j.jclepro.2020.122700
100. Ziska, L. H. (2016). The role of climate change and increasing atmospheric carbon dioxide on weed management: herbicide efficacy. *Agriculture, Ecosystems & Environment*, 231, 304-309. DOI: https://doi.org/10.1016/j.agee.2016.07.014