

# **Re-Designing Energy-Efficient and Intensively Managed Cereal Based Cropping Systems for Reducing the Environmental Footprints of Production in North-West India: A Review**

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## **Authors' contributions**

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## **ABSTRACT**

Agriculture is a major contributor to India's environmental footprint, particularly through greenhouse gas (GHG) emissions. Sustainable agricultural systems are needed to produce high-quality and affordable food in sufficient quantity to meet the growing population need for food, feed, and fuel, and at the same time, farming systems must have a low impact on the environment. Achieving sustainability of the cereal system in the Indo-Gangetic Plains (IGP) of North West India under progressive climate change and variability necessitates adoption of practices and technologies that increase food production, adaptation and mitigation the environmental footprints of production in a sustainable way. But production is becoming unsustainable due to depletion or degradation of soil and water resources, rising production costs, decreasing input use efficiency, and increasing environmental pollution. In contrast, cereal production systems in the IGP are largely traditional,

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with low yields and farm income. This review paper mainly focus on the reduction of environmental footprint production in cereal systems such as greenhouse gas (GHG) emissions through the adoption of emerging conservation agricultural practices *i.e.*, re-designing energy-efficient, economically sustainable and intensively managed options for cereal systems. Adoption of re-designing energy-efficient, economically sustainable and intensively managed cereal systems could help in reducing the environmental footprints of production (EFP) while maintaining productivity and better resource utilization. In India could reduce its greenhouse gas emissions from agriculture by almost 18 percent through the adoption of mitigation measures. Several studies revealed that conservation agriculture (CA) practices and technologies implemented in the cereal systems of the IGP have positive impacts on crop yields, returns from crop cultivation, input use efficiency (water, nutrient and energy), adaptation to heat stress and reduction of GHGs emissions. Improved conservation technologies or packages of practices from intensive agriculture that reduce environmental impacts, such as laser-aided land leveling, reduced or zero tillage, conservation tillage operation, precise nutrient and water management, crop residues management, crop diversification improves resource use efficiency by decreasing losses of inputs to the surrounding environment. It indicates that the adoption of better soil, water, nutrient management practices, and technologies has enormous potential to reduce environmental foot print, such as GHG emissions from agriculture cereal systems, thereby contributing to the mitigation of climate change.

**Keywords:** *Re-designing energy-efficient; economically sustainable; intensively managed cereal systems and environmental footprints of production (EFP).*

## 1. INTRODUCTION

In South Asia, Billions of people depends on rice-wheat (RW) system (13.5 M ha) for their food security and livelihood [1]. Whereas, maize-wheat (MW) rotation is third most important cropping system (~1.86 M ha) [2] and has potential to expand in view of emerging water crisis in the Indo-Gangetic plains. Over time, the sustainability of the intensive rice-wheat systems of North-West (NW) India has become a major challenge owing to faster depletion of groundwater table, stagnating or declining productivity growth, degrading soil health and environmental quality, and diminishing farm profitability [3], Kumar et al. [4]. Achieving sustainability of the cereal system in the Indo-Gangetic Plains (IGP) of North West India under progressive climate change and variability necessitates adoption of practices and technologies that increase food production, adaptation and mitigation the environmental footprints of production in a sustainable way. But production is becoming unsustainable due to depletion or degradation of soil and water resources, rising production costs, decreasing input use efficiency, and increasing environmental pollution. In contrast, cereal production systems in the IGP are largely traditional, with low yields and farm income. Sustaining and increasing the production of cereal systems in the Indian states of Punjab, Haryana, and western Uttar Pradesh in the

northwest (NW) IGP, together known as the "breadbasket" of the country, are essential to meet the food requirement of India's burgeoning population, which is likely to increase from 1.3 billion in 2015 to 1.6 billion by 2050 [4].

The environmental footprint of production (EFP) is like as carbon footprint plays an important role in agricultural commodities at a time by increasing GHG gases emissions such as CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, Fluorinated gases etc., when climate change, an increasing population and competing demands for food, fiber and fuel are placing heavy demands upon the environment. By 2030, greenhouse gas emissions from the agricultural sector in India would be 515 MtCO<sub>2</sub>e per year. Indian agriculture has the potential to mitigate 85.5 Megatonne CO<sub>2</sub> equivalent (MtCO<sub>2</sub>e) per year without compromising food production and nutrition. Considering the 2012 estimates of 481 MtCO<sub>2</sub>e, that would represent a reduction of almost 18 percent [5]. The input intensive cereal production system in the IGP is responsible for significant amount of GHG emissions [6,7] reported that the emissions of GHGs from rice-wheat system in IGP has a global warming potential of 13-26 Mg CO<sub>2</sub> ha<sup>-1</sup> yr<sup>-1</sup>. Besides emission reduction through less energy and power use, Conservation agriculture also affects the soil flux of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O. Puddling and continuous flooding of rice field promote methanogenesis thereby increasing CH<sub>4</sub> emission whereas safe alternate wetting and

drying has been reported to reduce CH<sub>4</sub> emission effectively [8]. Foregoing puddling and tillage in rice-based production systems of IGP coupled with improved water management can reduce CH<sub>4</sub> emission [6]. Therefore, there is a need to increase the input-use efficiency through best management practices and applying balanced dose of fertilizers. Eliminating subsidies may enhance balanced use of fertilizers. Carbon trading is another strategy to offset CO<sub>2</sub> and promote adoption of best management practices. Burning of crop residues must be minimized, and residues used as mulch or compost to enhance soil properties [9].

**Table 1. Major cereal cropping systems (area in m ha and % of total area) in India [Jat et al., 2011] [46]**

Cereal cropping systems	India	
	M ha	%
Rice –Wheat	9.20	11.81
Rice – Rice	4.70	6.03
Rice – Rice – Rice	0.04	0.05
Rice – Maize	0.53	0.68
Rice – Pulses	3.50	4.49
Rice – Vegetables	1.40	1.80
Rice – Potato	-	-
Cotton – Wheat	1.39	1.78
Maize – Wheat	1.80	-
Millet – Wheat	2.44	3.13

In intensive managed cereal based systems of Indo-Gangetic plains of north-western India plays a major role in the food security and is a potential source for reducing the environmental footprints of production such as greenhouse gas (GHG) emission. Quantification of environmental footprints of production such as carbon footprint of this cropping system can be helpful in assessing the GHG emission due to crop production along with identification of low carbon options to improve the sustainability of the cereal cropping system. In conventional cereal based system, repeated tillage and crop residue burning are the two other major causes of concern for soil health deterioration and environmental pollution; the key indicators of sustainability. Conservation agriculture (CA) based innovative agronomic management practices like zero-tillage (ZT)/ No-tillage, crop establishment (smart seeding system/dry seeded rice), residue recycling, precision water and nutrient management etc. have been used as an alternative to conventional puddled transplanted rice (PTR) and CT wheat to improve farm productivity and farmers' profitability [10,3].

Looking to the constraints of water shortages in future, it is imperative that we put more focus on re-designing intensive cereal systems through developing efficient and remunerative practices for increasing water productivity and farmer's profitability in irrigated cereal systems in NW India [11]. Higher energy efficiency and the use of alternative energy sources as well as carbon sequestration by the avoidance of deforestation and better cropping systems are the main pathways to reduce the carbon emissions and environmental footprints of food production [12].

Agricultural systems in northwest and central IGP also produce large amounts of greenhouse gases (GHGs), particularly from flooded rice fields [13-16]. While emission of methane (CH<sub>4</sub>) from flooded rice systems can be reduced by adopting different water and crop management strategies [17,18], such changes, plus increased N fertilizer use, in intensive cereal systems would be likely to increase production of nitrous oxide (N<sub>2</sub>O), another GHG [19,20]. This trade-off between CH<sub>4</sub> and N<sub>2</sub>O emissions is a major limitation in devising an effective strategy for mitigating GHG emissions from the R–W system [10]. Burning of rice residues to clear the land for wheat also releases large amounts of CO<sub>2</sub> into the atmosphere [21]. Farm machinery, including the pumps used for irrigation, emitted 283–437 kg CO<sub>2</sub>-C/ha of rice and 33–58 kg CO<sub>2</sub>-C/ha of wheat in a R–W system [16]. Rice fields submerged with water are potential source of methane (CH<sub>4</sub>) and application of nitrogenous fertilizers is the main source of nitrous oxide (N<sub>2</sub>O) in fertilized soils [22]. Application of chemical fertilizers not only contributes to N<sub>2</sub>O emission but also has an impact on emission of CO<sub>2</sub> and CH<sub>4</sub> [23]. Soil management through tillage operations lead to emission of carbon dioxide (CO<sub>2</sub>) from soil through biological decomposition of soil organic matter [24]. Fuel use for various agricultural operations and burning of crop residues is a source of carbon dioxide emission. Burning of agricultural residues emit significant amount of CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub> with CO<sub>2</sub> accounting for 91.6% of the total emissions [25] and maximum were from Uttar Pradesh followed by Punjab and Haryana. Some of the major cereal cropping systems are followed in India is shown in Table 1. This review paper mainly focus on the reduction of environmental footprint of production in cereal systems such as greenhouse gas (GHG) emissions through the adoption of emerging conservation agricultural practices i.e., re-designing energy-efficient, economically

sustainable and intensively managed options in cereal systems for improving crop yields, water productivity, N and energy use efficiency, and farm profitability in NW India for a sustainable farming future.

## 2. METHODOLOGY

The systematic literature review related to the topic concerned, were collected and studied for gathering the concepts and research findings in support of this study.

## 3. RE-DESIGNING ENERGY-EFFICIENT CEREAL SYSTEMS

For reducing the environmental footprints of production, energy-efficient use is generally high in intensive cereal production systems. Of the total energy used for crop production, fertilizer and chemical energy inputs comprise 47% for wheat, 43% for rice [26], and 45% for maize [27]. About 60% of this is due to nitrogen (N) fertilizers alone. In the R-W system in northwest IGP most of the energy is used for land preparation—wet tillage and puddling for rice and preparatory tillage operations for wheat, pump irrigation, and combine harvesting. Conventional tillage is not only fuel- and cost-inefficient, it also contributes to a larger carbon footprint through increased emission of CO<sub>2</sub> [28]. The liberal or excessive use of natural resources and external inputs such as N fertilizers and other agrochemicals in the western and central regions of IGP has caused environmental and ecological degradation—soil degradation (salinity and alkalinity, soil erosion), depletion of soil organic matter due to oxidation of soil carbon under conventional tillage, depletion of groundwater in large areas, pollution of surface and groundwater, and leakage of reactive N into the environment [29]. In intensive irrigated RW cropping system of north-western IGP, zero-till wheat planting under rice straw mulch is spreading, with significant savings on farm energy use, cost of cultivation, and irrigation water use; increased wheat productivity and profitability; and improved soil and environmental quality. Further improvements in Happy Seeder are needed to reduce its power requirement and increase its working efficiency. Modifying combine harvester to uniformly distribute the residue in the field. Large volume and transport is a major bottleneck in using the residues where those are required. Machinery for volume reduction would facilitate

the process of residue use for Conservation Agriculture [30].

Appropriate agricultural practice can contribute to climate change mitigation through sequestration of carbon in soil and plant biomass as well as reducing fossil fuel combustion and soil related emissions. Since soil disturbance tends to stimulate soil carbon losses through enhanced decomposition and erosion of soil organic matter, zero-tillage in CA often results in soil carbon gain. However, the issue is still debatable. But, reduced power and energy requirements due to non-requirement of tillage in CA translates into less fuel consumption, lower working time and slower depreciation rates of equipment, all leading to emission reduction from farm operations as well as from the machinery manufacturing processes. While enhanced C sequestration, if any, will continue for a finite time, emission reduction from less fossil-fuel, energy and machinery use can continue indefinitely, as long as such practices are continued [31]. On an average, by adopting of zero tillage (ZT) for land preparation and crop establishment in rice-wheat system of the IGP, farmers could save 36 L diesel ha<sup>-1</sup> [32], equivalent to a reduction in 93 kg CO<sub>2</sub> emission ha<sup>-1</sup> yr<sup>-1</sup>. Further, retention of crop residues in the system adds carbon fixed in the crop biomass by means of photosynthesis to soil thereby improving soil health and fertility. This measure may reduce fertilizer use and associated GHG emission over time [33]. CA can also reduce emissions by saving irrigation water (CA requires less water). In North-West IGP, irrigation water is mainly pumped by using electricity whereas in eastern IGP diesel pumps are used, both the ways contributing to CO<sub>2</sub> emission [6]. Jat et al. [34] reported that in CA systems, crop residues contributed the maximum (~76%) in total energy input (167,995 MJ ha<sup>-1</sup>); however, fertilizer application (nonrenewable energy source) contributed the maximum (43%) in total energy input (47,760 MJ ha<sup>-1</sup>) in CT-based systems. CA-based cereal (rice/maize) systems recorded higher net energy and energy-intensiveness (EI) levels of 251% and 300%, respectively, compared with those of the CT-based rice-wheat system (RW/CT) (295, 217 MJ ha<sup>-1</sup> and 46.05 MJ USD<sup>-1</sup>), irrespective of mungbean integration. MWMb/ZT+R utilized 204% more input energy, which resulted in 14% higher net energy and 229% higher EI compared with RW/CT (rice-wheat/ conventional till). CA-based RW and MW (rice-wheat,

**Table 2. Estimated energy input (total, from tillage and crop establishment, irrigation, and fertilizer), energy output, net energy return, specific energy, fuel and electricity consumed in different scenarios during rabi (wheat), kharif (rice/maize), and at systems level in Karnal, India (based on 5-year average, 2009–14)**

Scenario	Total input energy CJ ha <sup>-1</sup>	Total output energy	Energy input for T & CE	Energy input for irrigation water	Energy input for fertilizer	Net energy return	Specific energy MJ kg <sup>-1</sup> grain	Fuel consumed L ha <sup>-1</sup>	Electricity consumed kWh ha <sup>-1</sup>
Wheat									
1	25.3a	165.6b	4.44a	5.4ab	11.4a	140b	5.1a	41a	450b
2	21.0b	160.0b	0.68b	5.4b	11.2b	139b	4.0b	12c	449b
3	20.9b	176.3a	0.80b	5.8a	10.6c	155a	3.5c	14b	485a
4	20.9b	179.2a	0.75b	5.7ab	10.7c	158a	3.6c	14b	478ab
Rice/ maize									
1	53.9a	217.0c	3.90a	35.4a	12.5a	163c	7.7a	57a	2925a
2	40.7b	244.9b	2.72b	25.5b	10.4c	204b	5.1b	54b	2107b
3	35.3c	182.3d	0.61c	20.5c	12.0b	147c	5.2b	23c	1693c
4	18.1d	289.8a	0.43d	3.4d	12.3a	272a	2.2c	8d	278d
System ( wheat + rice/maize + mungbean)									
1	79.2a	382.6d	8.34a	40.8a	23.9a	303d	6.6a	98a	3376a
2	65.5b	448.5b	3.78b	32.8b	21.6d	383b	5.0b	74b	2710b
3	59.6c	403.5c	1.79c	28.2c	22.6c	344c	4.6b	45c	2330c
4	42.3d	511.7a	1.55d	10.9d	23.0d	469a	3.1c	30d	906d

[Source: Kumar et al., 2018][4]

**Table 3. Estimated average GWP (total, due to diesel, electricity, fertilizer, pesticides, N<sub>2</sub>O, and methane emissions) of different scenarios during rabi (wheat) season, kharif (rice/maize) season, and at systems level based on 5-year average**

Scenario kg CO <sub>2</sub> equivalent ha <sup>-1</sup>	Total GWP	GWP by diesel	GWP by electricity	GWP by fertilizers	GWP by pesticides	N <sub>2</sub> O emissions	CH <sub>4</sub> emissions
<b>Wheat</b>							
1	1608a	111	448	801	17	231	0
2	1501b	32	447	782	17	223	0
3	1482b	37	482	740	17	211	0
4	1481b	37	475	736	17	210	0
<b>Rice/ maize</b>							
1	4713a	151	2908	862	62	409	320
2	3741b	143	2095	748	75	350	320
3	3209c	61	1683	854	71	401	140
4	2806d	20	276	882	51	1576	0
<b>System ( wheat + rice/maize + mungbean)</b>							
1	6321a	262	3355	1663	79	640	320
2	5402b	193	2693	1529	92	573	320
3	4861c	116	2316	1590	88	611	140
4	4455d	75	900	1622	68	1788	0

[Source: Kumar et al., 2018][4]

RW/maize–wheat, MW)) systems enhanced the crop productivity by 10 and 16%, water productivity by 56 and 33%, and profitability by 34 and 36%, while saving in irrigation water by 38 and 32%, compared with their respective CT-based systems, respectively. Hung et al. [35] reported that the rice cultivation with in-field burning rice straw is the worst option with lowest energy efficiency and highest air pollution emission, despite the added energy requirements in straw collection and transport, the utilization of rice straw removed from the field for mushroom production can increase the net energy obtained from rice production systems by 10–15% compared to burning straw in the field. Additionally, partial or complete removal of rice straw from the field reduces the GHGE by 30% and 40% compared to complete straw retention and incorporation, respectively.

Srivastava [36] reported that intensive tillage under conventional farmer practices which required about one-third of the total operational energy that could be saved without adversely affecting the yield with zero tillage. Ladha et al. [37] also found that intensive tillage for crop establishment, higher amount of irrigation water, higher labor and fertilizer inputs are the major factors for higher energy usage under business as usual scenario but least energy under improved management scenarios due to ZT coupled with precise nutrient and water

management practice. Kumar et al. [4] reported that the average seasonal Global Warming Potential (GWP) of ZT wheat in Scenarios 2–4 was 7–8% lower than that of CT wheat in Scenario 1 (Table 3). Diesel fuel (for land preparation and seeding), electricity (for irrigation water application), and fertilizers constitute the major share (78–82%) of the total GWP estimated for wheat, whereas emissions of GHGs (N<sub>2</sub>O and CH<sub>4</sub>) from the soil contributed only 14%. Diesel consumption was 27–29 L ha<sup>-1</sup> lower in scenarios with ZT (Table 2). The experiment-wide GWP of rice was almost three times higher than that of wheat (Table 3). During kharif, the GWP of Scenarios 2, 3, and 4 was lower by 21%, 32%, and 40%, respectively, than in Scenario 1 (Table 3). CH<sub>4</sub> emissions declined by 56% with the change in rice establishment from PTR in Scenario 1 or 2 to ZT-DSR in Scenario 3 as also reported by Padre et al. [38]. Moreover, CH<sub>4</sub> emissions were eliminated with kharif maize. In contrast, N<sub>2</sub>O emissions were almost four times higher in maize in Scenario 4 than in rice. Electricity and fertilizer contributed 75–80% of the total GWP in rice, whereas GHG emissions from the soil contributed only 15–18%. In maize, the major contributors to the total GWP were the emissions of N<sub>2</sub>O from the soil (56%) followed by fertilizer input (31%). The GWP from diesel consumption was 60% lower when rice was directly sown with ZT in Scenario 3 than in conventional PTR (Scenario

1), which became 87% lower when ZT maize was grown instead of rice in Scenario 4. Similarly, the GWP from electricity was 28%, 42%, and 91% lower in Scenarios 2, 3, and 4, respectively. These results imply that more research is needed on N management in maize to reduce the GWP of this crop. On an annual basis at the systems level and in contrast to Scenario 1, the total GWP was lower by 15%, 23%, and 30% in Scenarios 2, 3, and 4, respectively.

#### 4. ECONOMICALLY SUSTAINABLE CEREAL SYSTEMS

India is the world's third largest emitter of greenhouse gases. Contributing almost one-fifth to the national total, agriculture has been identified as a priority in the country's efforts to reduce emissions. However, these climate change mitigation benefits can only work if farmers take up the new practices, some of which require an initial investment (Fig. 1). Government policies and incentives will be crucial to help farmers take the first steps, ensure wide-scale adoption of these mitigation options, and help India meet its food security and greenhouse gas emission reduction goals [5]. Cereal Based farming systems need to be reconfigured worldwide for sustainable intensification. Cereal growers have already begun that transition by adopting key Save and Grow components and practices such as Conservation agriculture, Soil health, improved crops and varieties, efficient water management, integrated pest management. While each of those components contributes to sustainability, the maximum benefits will only be realized when all of them are integrated fully into save and grow farming systems [39]. Sustainable intensification, through save and grow, offers a range of productivity, socio-economic and environmental benefits to smallholder farmers and to society at large, including: high and stable production and profitability; higher farmer income and improved rural livelihoods; increased availability and consumption of the diverse range of foods necessary for a healthy diet; adaptation and reduced vulnerability to climate change and other shocks; enhanced ecosystem functioning and services; and reductions in agriculture's greenhouse gas emissions and carbon footprint [40].

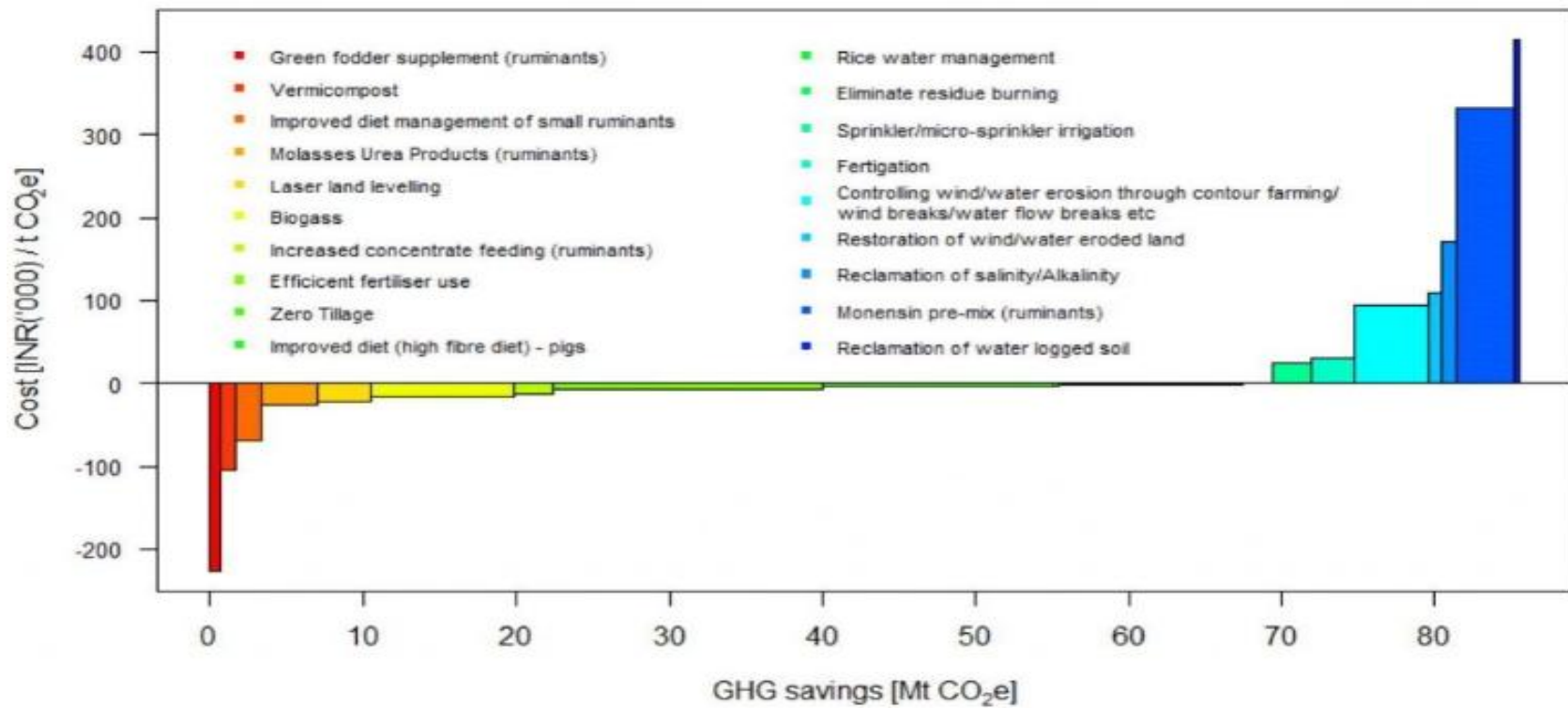
Aryal et al. [41] assessed the on-farm economic and environmental impacts of zero tillage (ZT) wheat in Haryana state of North-West India. He

reported that shifting from Conventional tillage (CT) to zero tillage (ZT) wheat production system reduces the farmers total input cost per ha by 20% (USD 79 ha<sup>-1</sup>) and increases net revenue per ha by 28% (USD 97.5 ha<sup>-1</sup>). If the target of the government of Haryana to increase the area under ZT wheat production system to about 1 million ha by 2015 can be realized, it would save about USD 79 million per wheat season through a reduction in the cost of production and this will bring approximately USD 97.5 million additional net revenue to wheat farmers in Haryana. Our estimations clearly showed the GHG mitigation benefits of ZT based wheat production as this reduces CO<sub>2</sub> emission by 1.5 Mg ha<sup>-1</sup> season<sup>-1</sup>. This means adopting ZT to about 1 million ha under wheat production in Haryana will reduce GHG emission of about 1.5 million tonne of CO<sub>2</sub> equivalent.

Jat et al. [42] reported the higher cost of cultivation (tillage, sowing/transplanting, fertilizer, irrigation water, pesticides, harvesting and threshing etc.) was associated with CT based RW system (ScI) compared to CA and CA+ based systems (ScII and ScV) during both the years. In ScI, 12.6% of total cost was incurred in tillage operation for seed bed preparation. Almost 15% of the total cost was associated with fertilizer use across the scenarios (Fig. 2A). Harvesting and threshing contributed ~39% share in CA based maize systems and ~22% in CA based rice systems irrespective of irrigation management. The SDI system with subsidy (80%) and irrigation shared ~4% each to the total cost of cultivation (Fig. 2A). However, the SDI system without subsidy incurred ~17% to the total cost of cultivation (Fig. 2B) and the irrigation contributes merely 6 and 2% of total cost in CA+ ScV and ScVI, respectively.

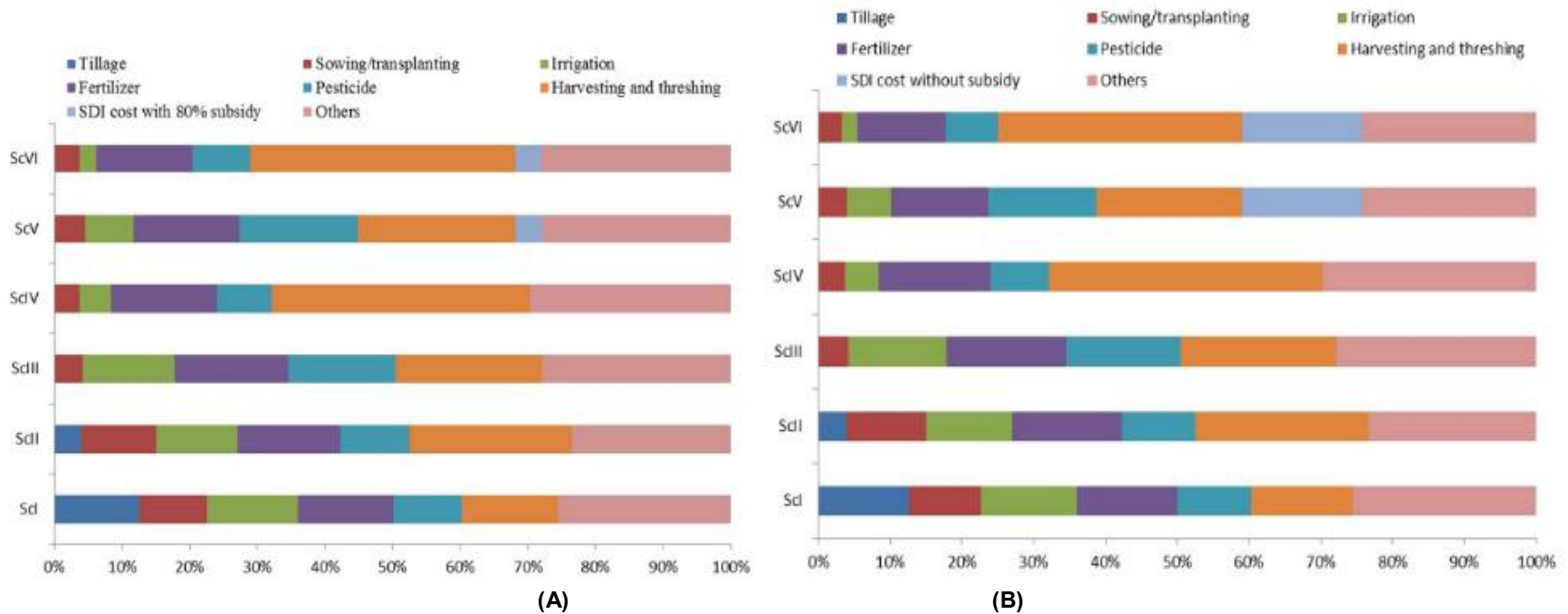
#### 5. INTENSIVELY MANAGED CEREAL SYSTEMS

Intensive irrigated cereal production systems of the northwest and central IGP combine CA practices with efficient water, nutrient, and pest management. Land management, crop establishment, and crop management practices employed include land leveling, ZT, direct/drill seeding, deep placement of fertilizer N, residue mulch, and diverse crop sequences/rotations. The systems achieve land productivity of 70–90% of site yield potential for major crops; water productivity of 0.8 to 1.0 kg grain/m<sup>3</sup> water for rice and 2.0–2.5 kg grain/m<sup>3</sup>



**Fig. 1. Marginal abatement cost curve of Indian agriculture**  
(Source: CIMMYT. 2018)[5]





**Fig. 2. Cultivation cost (%) with subsidy on SDI system under different management scenarios in (A) rice/maize based cropping systems (B) rice/maize based cropping systems**  
[Jat et al., 2019] [42]

water for maize and wheat; agronomic N use efficiency of 20–25 kg additional grain/kg N applied for rice and wheat and 25–30 kg additional grain/kg N applied for maize; crop N recovery efficiency of significantly more than 50%; reduce farm energy use by 40–50%; reduce methane and N<sub>2</sub>O emission by 40–50%; and increase soil organic matter to 2–3% in most soils except in sandy soils. The systems are thus highly productive and profitable, efficient in resource use and conservation, enhance ecological efficiency and climatic resilience, improve soil quality, preserve biodiversity, and have minimal environmental footprints [43,1]. Such systems currently occupy some 4 million hectares of land in the IGP [44]

Conservation agricultural (CA) practices involving minimum soil disturbance, permanent soil cover and diversified crop rotations provides opportunities for obtaining sustainable crop yield, increasing input use efficiency, improving soil properties and also mitigating greenhouse gas (GHG) emissions [45]. CA based resource conserving technologies (RCTs) are being practiced over 3.9 M ha area of South Asia [46]. Technologies such as zero tillage (ZT), raised bed planting, laser leveling, direct seeded rice, direct drilling of crop residues, brown manuring, crop diversification, site specific nutrient management, etc are such crop management options which are based on the principles of CA [47].

## 6. TILLAGE PRACTICES

Tillage disturbance is the dominant factor reducing soil carbon stabilization within micro-aggregates in the clayey soil, whereas conservation practices increase soil organic carbon contents. In some cases, reduced tillage in combination with additional carbon input from cover crops significantly improved the soil organic carbon content [48]. During tillage operation soil aggregates are broken, increasing oxygen supply which promotes the decomposition of organic matter and evolution of more CO<sub>2</sub> from a tilled than an undisturbed soil [49]. On the other hand conservation tillage leads to organic carbon enrichment of soils [50]. Zero tilled wheat (ZTW) is an best option which allows earlier planting of the crop helps in controlling weeds, reduces CO<sub>2</sub> emission, saves water and fuel and enhances soil carbon stock [51], Abdalla et al. [52].

According to Hu et al. [53] reported that wheat-maize intercropping under reduced tillage with

stubble retention increased crop yield by 8% and reduced greenhouse gas emissions by 7% compared with conventional tillage. However, soil organic carbon can be gained or lost depending on soil type and land use practices. Soil disturbance affects the quantity and quality of plant residues entering the soil, their seasonal and spatial distribution, and the ratio between above- and belowground inputs (Pinheiro et al., [48]). CA based tillage practices led to enhancement in yield and C sustainability index value in all the cereal based cropping systems. However the C sustainability index was lower in rice than wheat and maize crop (Jat et al.,) [46].

Nelson et al. [54] reported that zero tillage could reduce the oxidation of soil organic matter to CO<sub>2</sub> and this may help in mitigating soil emissions and increase soil organic carbon. Gupta et al. [55] analyzed the GWP of rice-wheat cropping system under different management practices. It concluded that zero tilled wheat followed by direct seeded rice (ZTW-DSR) had significantly lower GWP than other management practices. GHG intensity (kg CO<sub>2</sub> eq kg<sup>-1</sup> yield) was lowest (0.11 kg CO<sub>2</sub> eq kg<sup>-1</sup> produce) in ZTW-DSR cropping system showing that adopting ZTW followed by DSR in place of conventional tilled wheat (CTW) followed by transplanted rice (TPR) can be an efficient low carbon option in the IGP (Fig. 3).

Continuous monitoring of GHGs by using static chamber method in a rice-wheat production system of northwest India, found much higher emission of CH<sub>4</sub> from rice production in puddle transplanted field with continuous flooding compared to direct seeded production system (50-250 mg CH<sub>4</sub> m<sup>-2</sup> d<sup>-1</sup> in puddle transplanted vs. <50 mg CH<sub>4</sub> m<sup>-2</sup> day<sup>-1</sup> in direct seeded rice). In this experiment, total cumulative GHGs emissions (soil flux of CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub>) in terms of CO<sub>2</sub>-equivalent was about 27% higher in the conventional tillage-based rice-wheat system (PuTPR-CTW) than in CA-based systems (ZTDSR-ZTW+R) (Fig. 4a). This difference mainly came through higher soil CO<sub>2</sub> flux from CT-based rice-wheat than from ZT based rice-wheat and higher CH<sub>4</sub> emission from CT-based rice than ZT-based rice. Higher CO<sub>2</sub> emission in CT based productions was probably due to enhanced decomposition because of tillage-induced disturbances. No detectable level of CH<sub>4</sub> emission was observed under ZT-based rice both with and without residue retention probably because of higher redox potential of soil thereby arresting methanogenesis process.

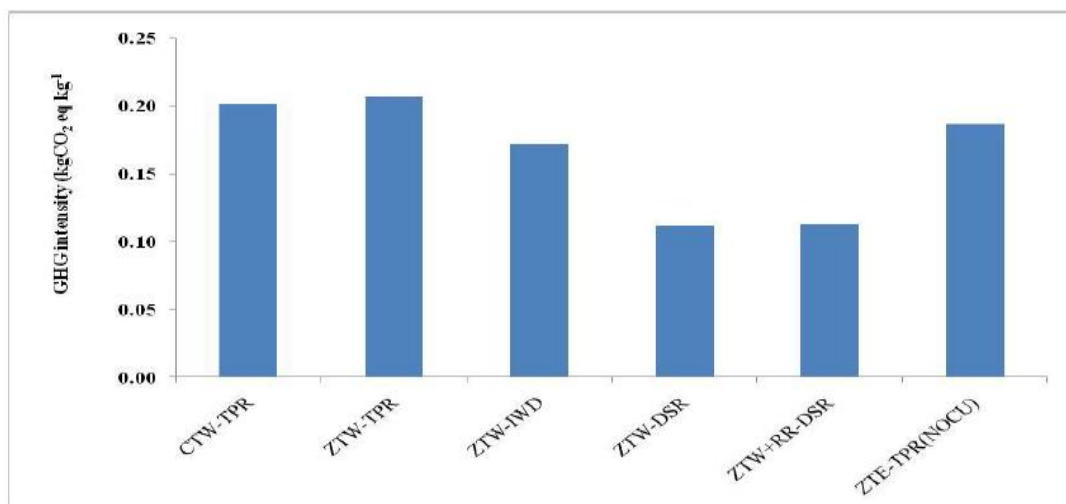
Through life-cycle analysis of wheat production in northwest India by using Cool Farm Tool, we found that global warming potential per unit of wheat yield was 10 times higher in CT-based production ( $\sim 400 \text{ kg CO}_2\text{-eq Mg}^{-1}$  wheat yield) than in ZT-based production ( $\sim 35 \text{ kg CO}_2\text{-eq Mg}^{-1}$  wheat yield) (Fig. 4b) [56].

## 7. WATER MANAGEMENT IN FIELD CROPS

Better water management in rice farming such as adopting alternate wetting and drying in rice fields that are currently continuously flooded can offer mitigation of about 12 MtCO<sub>2</sub>e per year. Other water management techniques in major cereals, such as laser-levelling of fields, or using sprinkler or micro-sprinkler irrigation and fertigation together, also provide important greenhouse gas emissions savings, with a reduction of around 4 MtCO<sub>2</sub>e per year for laser levelling alone [5]. A study conducted in Karnal, Haryana showed that yield of transplanted rice was 10-12% higher than DSR but practicing DSR caused labor and cost saving of 97% and 80% [57]. Intermittent wetting and drying (IWD) of soil in rice also saves irrigation water and reduces CH<sub>4</sub> emission [14]. Continuous flooding of rice fields (42.25 million ha) resulted in annual net emissions of 1.07–1.10, 0.038–0.048 and 21.16–60.96 Tg of CH<sub>4</sub>-C, N<sub>2</sub>O-N and CO<sub>2</sub>-C,

respectively, with a cumulated global warming potential (GWP) of 130.93–272.83 Tg CO<sub>2</sub> equivalent. Intermittent flooding of rice fields reduced annual net emissions to 0.12–0.13 Tg CH<sub>4</sub>-C and 16.66–48.80 Tg CO<sub>2</sub> 15-C while N<sub>2</sub>O emission increased to 0.056–0.060 Tg N<sub>2</sub>O-N. The GWP, however, reduced to 91.73–211.80 Tg CO<sub>2</sub> equivalents [58].

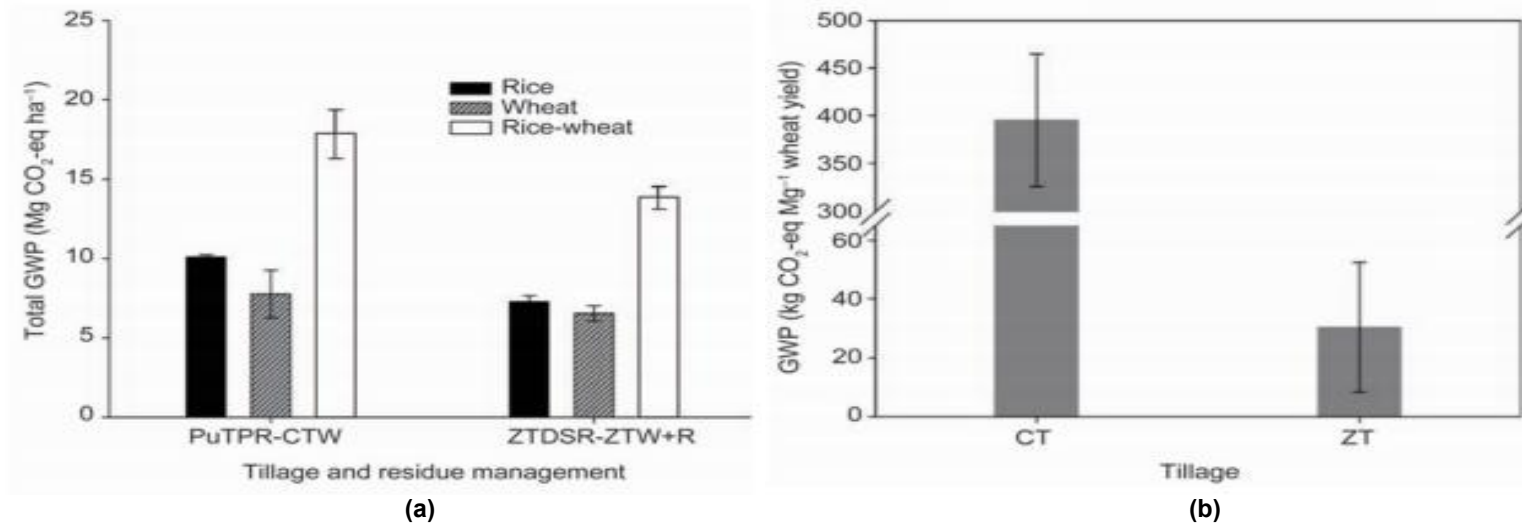
Chauhan and Opena [59] reported that puddling in transplanted rice consumes up to 30% of the total rice water requirement. In DSR, seeds are directly sown in soil and do not require puddling hence this technology is reported to reduce CH<sub>4</sub> emission and save labour and water. It has got better adaptive capacity to climate change, and growing DSR could reduce methane emission as fields are not continuously submerged with water [49]. Richards and Sander [60] estimated that global CH<sub>4</sub> emissions will be reduced by 4.1 Mt per year if continuously flooded rice fields are drained at least once during the crop growth period. Gupta et al. [61] quantified the GWP of rice-wheat cropping system using modeling approach and concluded that the GWP of conventional technologies of Haryana was higher than that of Bihar due to high CO<sub>2</sub> emission from electric pump used for irrigation purpose. Among different technologies studied RCTs like DSR, SRI, DSR and ZTW had lower GWP than conventional practices (Figs. 5a & 4b).



**Fig. 3. GHG intensity of different management practices in rice-wheat cropping system**

(Source: Gupta et al., 2016)[55]

[CTW-TPR: conventionally tilled wheat followed by transplanted rice; ZTW-TPR: zero tilled wheat followed by transplanted rice; ZTW-IWD: zero tilled wheat followed by rice with intermittent wetting and drying; ZTW-DST: zero tilled wheat followed by direct seeded rice; ZTW+RR-DSR: zero tilled wheat with rice residue retention followed by direct seeded rice; ZTW-TPR (NOCU): zero tilled wheat with neem coated urea application followed by transplanted rice with neem coated urea applied.]



**Fig. 4. a: Tillage and residue management effect on total GHGs emission from rice-wheat production system in North West IGP, 2011-12 (n=12).** PuTPR-CTW=puddle transplanted rice followed by conventional tilled wheat, ZTDSR-ZTW+R = Zero tilled direct seeded rice followed by zero-tilled wheat with crop residue retention. **b: Estimated global warming potential of conventional tillage (CT) and zero-tillage (ZT) based wheat production in North-West India (n=200).** Vertical bars in both figures indicate the standard errors of the means  
(Source: Sapkota et al., 2014)[56]

## 8. NUTRIENT MANAGEMENT IN FIELD CROPS

Efficient use of fertilizer not only lowers emissions at the field, but also reduces the need for fertilizer and the emissions associated with production and transportation. It also represents savings for the farmer. Mitigation options would include applying fertilizer at the right time and the right place for plant uptake, or using slow-release fertilizer forms or nitrification inhibitors. "Efficient fertilizer use in the agriculture sector in India has potential to reduce around 17.5 MtCO<sub>2</sub>e per year" [5]. Application of chemical fertilizers not only contributes to N<sub>2</sub>O emission, but may also have impact on CO<sub>2</sub> and CH<sub>4</sub> emission contributing towards enhanced global warming [23]. Hence improved fertilizer application techniques, are needed to reduce GHG emission and enhance crop yield. Bhatia et al. [22] reported that, leaf colour chart (LCC) based urea application caused reduction in N<sub>2</sub>O emission in rice and wheat crop. Site-specific nutrient management in rice has been found to be more efficient than the conventional methods in reducing nutrient losses and improving nutrient

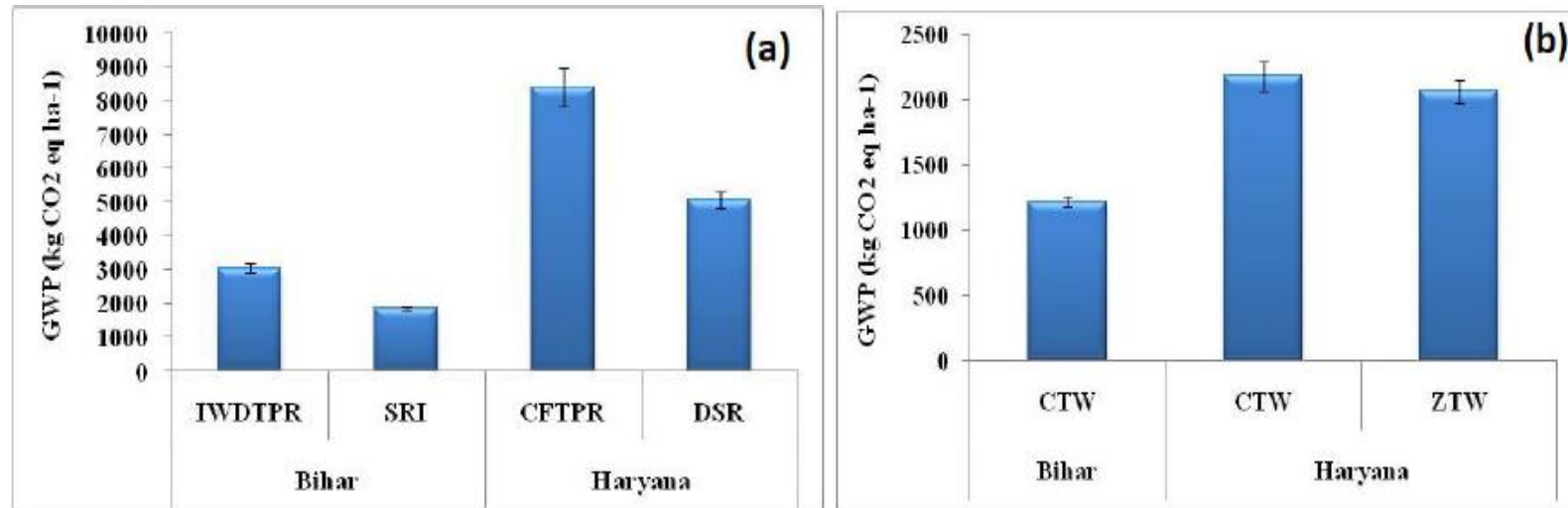
use efficiency [62]. Gan et al. [63] reported that improved crop management practices in wheat such as soil test based fertilization, reduction in summer fallow and rotation with grain legumes could lower CFP by 256 kg CO<sub>2</sub>eqha<sup>-1</sup> yr<sup>-1</sup> and sequester 0.027–0.377 kg CO<sub>2</sub> eq in the soil. Pathak and Aggarwal [47] estimated the GWP of rice and wheat crop under different management practices in the IGP. Some technologies such as direct seeded rice, mid-season drainage, nitrification inhibitor, site-specific nutrient management and use of leaf color chart based nitrogen application were able to reduce GHG emission while in lower IGP, zero tillage, sprinkler irrigation, nitrification inhibitor, site-specific nutrient management reduced GWP (Fig. 6). But some of these technologies required additional cost while some were found to be economically feasible.

## 9. CROP RESIDUES MANAGEMENT AS CONSERVATION PRACTICES

The field burning of Crop residues is a major contributor to reduced air quality (particulates, greenhouse gases), and impacts human and

**Table 4. Carbon footprint of rice-wheat cropping system under different management practices at New Delhi [22,14]**

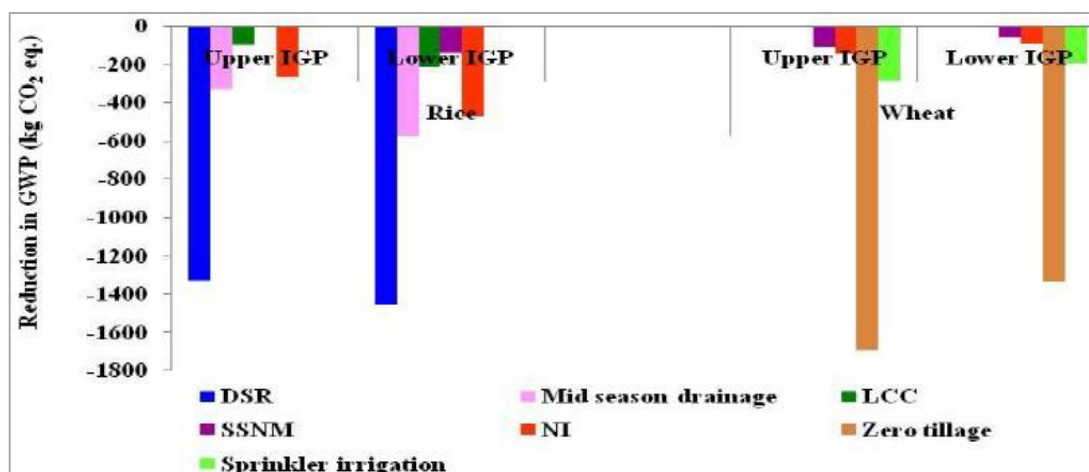
Crop management		CFP (kg CO <sub>2</sub> eq kg <sup>-1</sup> produce)		
		Rice	Wheat	Rice + Wheat
N management				
Dose (kg ha <sup>-1</sup> )	Source & No. of splits			
0	0	0.25	0.04	0.15
120	Urea (3)	0.19	0.06	0.13
120	Urea (4) (LCC based)	0.15	0.04	0.10
150	Urea (5) (LCC based)	0.14	0.04	0.10
Water & N management				
Rice		Wheat		
Saturated	100% Urea	5 Irrigations	100% Urea	0.14 0.04 0.36
	50% Urea + 50 % FYM		50% Urea + 50 % FYM	0.21 0.04 0.39
	90% Urea + 10% DCD (NI)		90% Urea + 10% DCD (NI)	0.09 0.03 0.34
	No N		No N	0.18 0.03 0.38
	100% Urea	3 Irrigations	100% Urea	0.14 0.04 0.34
IWD (Intermittent wetting and drying)	50% Urea + 50 % FYM		50% Urea + 50 % FYM	0.18 0.04 0.37
	90% Urea + 10% DCD (NI)		90% Urea + 10% DCD (NI)	0.08 0.03 0.33
	No N		No N	0.09 0.03 0.34



**Fig. 5. Global warming potential of different technologies in rice and wheat in Bihar and Haryana**

(Source: Dipak et al, 2015)

[IWDTPR: intermittent wetting and drying in transplanted puddled rice; SRI: system of rice intensification; CFTPR: continuous flooded puddled transplanted rice; DSR: direct-seeded rice; CTW: conventional tillage wheat; ZTW: zero tillage wheat]



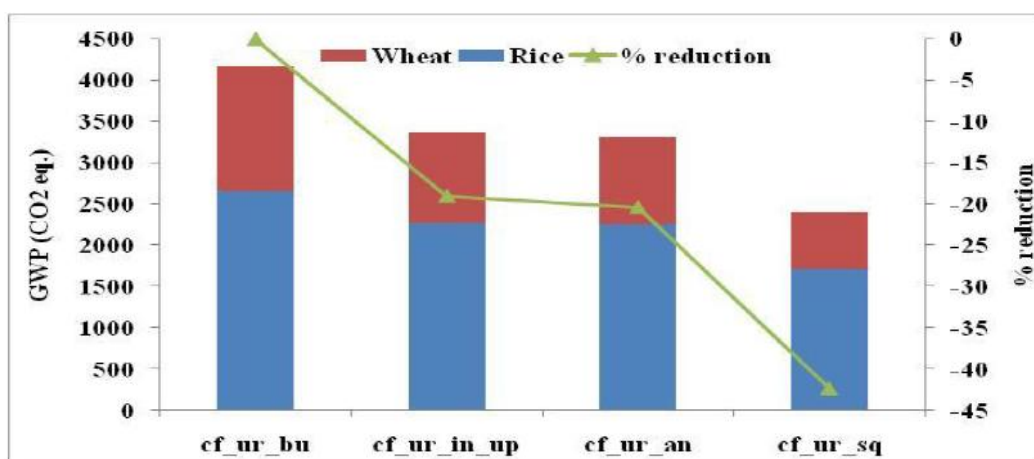
**Fig. 6. Reduction in GWP over conventional practice in rice and wheat under different technologies**

(Source: Pathak and Aggarwal, 2012)[47]

animal health both medically, and by traumatic road accidents due to restricted visibility in NW India. Besides, burning of CRs leads to a loss of organic matter and precious nutrients, especially N and S [30]. In India, one fourth of the total residue produced from rice-wheat cropping system [64]. Rice residue management is a tedious task since there are very less time gap between rice harvesting and sowing of next wheat crop. Besides this rice residue is not used as animal feed due to its high in silica content. Hence it is burnt on field to save time and cost of removal. Burning of crop residue causes emission of GHGs like CO<sub>2</sub> (70%) and N<sub>2</sub>O (2.09%) which can alter the radiation balance of the atmosphere [25]. Residue incorporation in soil is the easiest and successful method to improve water productivity, retain soil moisture, suppress weeds and regulate soil temperature [65-66]. Now a day's Happy Seeder Planter is keeping a pace in residue management by following conservation agricultural practices [67]. Haque et al. [68] carried an experiment in Jinju, South Korea and found that intermittent wetting and drying along with biomass incorporation is an effective strategy for GWP mitigation in rice crop.

Adoption of zero tillage farming and residue management, maintaining crop residues on the soil surface to protect the ground from erosion, in rice, wheat, maize, cotton and sugarcane was shown to reduce emissions by about 17 MtCO<sub>2</sub>e per year (CIMMYT. [5]). Rice is a leading cause, as well as a victim, of climate change, and its production impacts many natural systems. Rice

is responsible for about the same greenhouse gas emissions particularly from methane, which is emitted from rotting vegetation in inundated paddy fields. At the same time, rice yields and nutritional values are significantly reduced by rising temperatures, and production must increase by 25% by 2050 to meet global demand. Practices such as removing rice straw can reduce methane emissions by up to 70%, but farmers currently lack awareness, training, policy and market support (Hodge [69]). Incorporation of cereal residues into paddy fields at optimum time before rice transplanting can help in minimizing the adverse effect on rice growth and CH<sub>4</sub> emissions. The incorporation of wheat straw before transplanting of rice showed no significant effect on N<sub>2</sub>O emission due to immobilization of mineral N by high C/N ratio of the straw incorporated (Ma et al. [70]). Pathak and Wassman [71] used the modelling tool Techno GAS and assessed the GHG mitigation potential of different technologies in rice and wheat crop in Haryana, Results showed that 13 technologies have the potential to reduce the GWP compared to current farmers' practice in rice crop. Up scaling of the estimates showed that modifications in nutrient, water, and rice straw management could reduce the GWP by 15–41% in Haryana. According to the study proper management of rice straw can help in reducing the GWP of rice-wheat cropping system. Incorporation of straw in upland crops, straw fed to cattle and straw sequestered as construction material will help in reducing GWP by 19.1, 20.4 and 42.4% respectively as compared to conventional system (Fig. 7).



**Fig. 7. Global warming potential of rice-wheat cropping system under different management practices**

(Source: Pathak and Wassman, 2007) [71]

[*ncf\_ur\_bu*: continuous flooding, urea application and straw burnt; *cf\_ur\_in\_up*: continuous flooding, urea application and straw incorporated in upland crop; *cf\_ur\_an*: continuous flooding, urea application and straw fed to cattle; *cf\_ur\_sq*: continuous flooding, urea application and straw sequestered as construction material]

## 10. CROP DIVERSIFICATION AND CARBON FOOTPRINTS

Diversification of cropping system can help in reducing the Carbon Footprint of crops by 32% to 315% [72-74] reported that in durum wheat, diversification of cropping system with oilseeds and legumes lowered the carbon footprint. Durum wheat grown in a pulse-pulse-durum system had carbon footprint  $0.27 \text{ kg CO}_2 \text{ eq kg}^{-1}$  which is 34% lower than that of cereal-cereal-durum systems. Bhatia et al. [22] reported that an experiment was conducted at IARI, New Delhi to evaluate the CFP of rice-wheat cropping system under different management practices. Leaf colour chart (LCC) based N application lowered CFP from  $0.13 \text{ kg CO}_2 \text{ eq kg}^{-1}$  grain to  $0.10$  and  $0.10 \text{ kg CO}_2 \text{ eq kg}^{-1}$  grain in rice wheat cropping system (Table 3). Pathak et al. [13,14] also reported that the effect of both water as well as nitrogen management on GWP of rice-wheat cropping system was studied in IARI, New Delhi. Lower CFP values were observed under intermittent wetting and drying conditions as compared to saturated rice cultivation (Table 4). This is attributed to the fact that less  $\text{CH}_4$  emission in IWD condition than saturated one lowered the CFP. Substitution of inorganic N with organic sources increased  $\text{CH}_4$  emission resulting in higher CFP whereas application of nitrification inhibitor (NI) caused lower  $\text{N}_2\text{O}$  emission thereby reducing the CFP values.

## 11. CONCLUSIONS

Adoption of re-designing energy-efficient, economically sustainable and intensively managed cereal systems could help in reducing the environmental footprints of production (EFP) while maintaining productivity and better resource utilization. In India could reduce its greenhouse gas emissions from agriculture by almost 18 percent through the adoption of mitigation measures. Intensively crop management options for reduction of environmental footprint of production in cereal systems such as conservation tillage operation, precise nutrient and water management, crop residues management, crop diversification improves resource use efficiency by decreasing losses of inputs to the surrounding environment would account for more than half of these emission reductions in cereal systems. Moreover, the conservation practices are expected to raise land and water productivity, improve resource use efficiency, reduce risks and vulnerability of cereal cropping systems to climate change, diversify farm income, and improve family nutrition and livelihood. Farmers play a key role in ensuring the provision of low-emission materials to the food chain. There are huge gaps between the development of new cropping technologies and the implementation of the technologies in farming operations. With relevant agro-environmental policies in place, along with the adoption of improved agronomical tactics,



increasing food production with no cost to the environment can be achieved effectively, efficiently and economically.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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