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# Conservation Agriculture for Climate Change Adaptation and Mitigation in India

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**ABSTRACT**

Conservation agriculture (CA) is an emerging intervention in agriculture that fosters natural ecological processes to improve crop productivity and sustainability through the three important basic principles of minimum soil disturbance, permanent soil cover and diversified crop rotation. A large number of studies suggest significant benefits of CA including yield advantage (5.2%), irrigation water savings (9.8%), reduction in costs of cultivation (14.2%) and increase net return (27.5%), reduction in global warming potential (12-33%) as well as other climate benefits in terms of adaptation gains. It is estimated that global warming potential of about 25 Mt $CO_2$ eq. i.e., about 15% of the emission from the crop sector (agricultural soil, rice cultivation and crop residue burning) is mitigated by the adoption of various CA practices and other mitigation technologies in India. Area under CA in India is increasing in irrigated as well rainfed areas. However, there are several barriers hindering the adoption of CA, which needs further innovations and policy incentives. Scalable and sustainable business models need to be developed for creating custom hiring centers, manufacturing hubs and enhanced capacity development of the stakeholders to realize the full benefits from CA.

**Key words:** Greenhouse gas, irrigated ecosystems, rainfed ecosystems, resource conservation technologies, zero tillage

## Introduction

Conservation agriculture (CA) is an ecosystem approach to regenerative agriculture and land management systems based on three interlinked principles: (1) continuous minimum mechanical soil disturbance using no-till or reduced tillage based crop establishment, (2) maintenance of permanent soil cover using crop residues and cover crops and (3) diversification of cropping system using economically, environmentally and socially adapted rotations including legumes and cover crops coupled with other complementary good agronomic management practices (FAO, 2014). Minimum soil disturbance aids in provision of several benefits such as maintaining optimum proportions of respiration gases at the root zone of plant, lesser oxidation of soil organic matter, porosity maintenance for water movement and limits the re-exposure of weed seeds to sunlight that restricts germination (Kassam and Friedrich, 2009). It also allows microbes to produce stable soil aggregates for efficient infiltration that referred as "biological tillage". A permanent soil cover is very much essential to protect the surface from deleterious impacts of exposure to rain and sunlight and to provide constant food supply to soil microbes and

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plant roots. As a result, there is an improvement in soil biodiversity, microbial activity, soil aggregation and carbon sequestration (Srinivasarao *et al.*, 2009, 2010, 2011a). Diversified crop rotations offer a diverse "diet" to the soil microorganisms and also helps in recycling the soil nutrients from deeper layers by the cultivation of different crops. Legume crops involved in cropping sequence and rotations help in biological nitrogen ($N_2$) fixation, minimum pest infestation and enhance the soil biodiversity (Srinivasarao *et al.*, 2013a, 2013b). Construed more broadly, it also encompasses natural resource management to upsurge the synergies between crop production and ecosystem conservation as it includes diversified farm practices such as agroforestry, watershed management, livestock and fodder management, improved fallows, and community protected areas. Along with the benefit as an agricultural development strategy, CA also deals with the climate related issues and plays a vital role in climate change mitigation i.e., greenhouse gas (GHGs) emission reductions or carbon sequestration, conservation of biodiversity and ecosystem services. The CA can sequester the atmospheric carbon dioxide ($CO_2$) into soil carbon at slower rate. Incorporation of crop residues, perennial woody biomass such as fruit trees, live fences, etc. in farms accelerates the C sequestration rates.

## Conservation Agriculture in Different Ecosystems

### *Conservation agriculture in irrigated ecosystems*

During the past couple of decades, as an alternative to tillage-based inefficient conventional agriculture, CA with elements of site-specificity of component technologies with similar or higher yields, high profitability and use efficiency of external production inputs and natural resources, has emerged as major sustainable intensification strategy and practiced over 200 Mha globally. In South Asia, CA is relatively a new concept compared to leading CA adopting continents and countries, but estimates indicate that a partial CA-based system (at least one crop has no till, with or without residue retention) is spread to over 2.5 Mha in South Asia (Jat *et al.*, 2020). In South Asia/India, a systematic CA research was started during mid-1990's in rice-wheat system of Indo-Gangetic plains (IGP). Over past two and half decades, a significant advancement has been made in terms of development and refinement of tillage, crop establishment, crop residue management, CA machinery and associated component technologies (water, weed, nutrient, etc.) adapted to CA based management paradigm in major production systems of the region. Zero-till wheat has been adopted on a significant area in the rice-wheat system of IGP of South Asia, with positive impacts on wheat yield, profitability, and resource-use efficiencies, improvement in soil health and reduced greenhouse gases and air pollution. The synthesis of CA research jointly by CIMMYT-ICAR researchers using meta-analysis of large datasets across South Asia have generated evidence on the performance of CA on key parameters (yield, protein, water, profits, GHGs, soil health, adaptive capacity to climatic risks, etc.) which shows that CA not only has multiple benefits but also has potential to contribute to the UN Sustainable Development Goals through alleviating the multiple stresses including emerging social issues currently faced by agriculture in South Asia (Jat *et al.*, 2020). However, the response for different indicators varies under various management circumstances (cropping systems, soil types, etc.).

A large number of studies (both on-station and on-farm) have been carried out on various elements of CA or CA in tandem in major production systems and agro-ecologies of South Asia. The meta-analysis analysis (Jat *et al.*, 2020) suggests significant, if not transformative, benefits when CA component practices are implemented either separately or in tandem (Table 1). For example, zero tillage with residue retention had a mean yield advantage of 5.2%, irrigation water savings of 9.8%, reduction in costs of cultivation by 14.2% and increase net returns by 27.5%. Evidence also suggests a reduction of 12-33% in the global warming potential with full CA adoption. Results further suggest that CA and it's component technologies provide real benefits in the cereal systems of South Asia, especially for its potential for increasing net returns, and there are opportunities for improved technology targeting to maximize the expected benefits. The results of several studies on various aspects of CA on the key performance indicators such as crop/system productivity, economic profitability, water saving and climate benefits are summarized in Table 1.

**Table 1.** Evidences of climate-smart agricultural practices in South Asia

| Climate-smart technology | Crop/ cropping system | Productivity gain (kg $ha^{-1}$) | Profitability (USD $ha^{-1}$) | Water saving (%) | Adaptation to climatic risks | GHG mitigation (kg $CO_2$ eq $ha^{-1}$)[&] | Reference |
|---|---|---|---|---|---|---|---|
| 1. Laser land leveling (LLL) | Rice-wheat; maize-wheat | 350-645 | 150-220 | 15-20 | * | 400-600 | Jat *et al.* (2015); Kakraliya *et al.* (2018) |
| 2. Zero tillage (ZT) without residue | Wheat | 300-450 | 110-160 | - | * | 1000-1500 | Yadvinder-Singh *et al.* (2015); Thind *et al.* (2019) |
| 3. ZT with residue | Wheat | 410-660 | 153-232 | 6-10 | * # | 1500-2000 | Gathala *et al.* (2014); Aryal *et al.* (2016) Choudhary *et al.* (2018); Kakraliya *et al.* (2018) |
| 4. Direct seeded rice (DSR) | Rice | ±150-220 | 120-155 | 12-18 | *# | 1000-2250 | Gathala *et al.* (2014); Kakraliya *et al.* (2018); Chakraborty *et al.* (2017) |
| 5. Permanent beds | Maize-wheat | 450-950 | 220-350 | 65-70 | *# | 800-1000 | Jat *et al.* (2013; 2018); Das *et al.* (2018); Parihar *et al.* (2017 a,b); Jat *et al.* (2019) |
| | Maize-mustard | 400-1120 | 280-460 | 70-85 | * | - | Gora *et al.* (2020) unpublished |
| | Pigeonpea-wheat | 400-900 | - | 15-25 | - | - | Das *et al.* (2016) |
| 6. Site specific nutrient management (SSNM) | Rice-wheat; maize-wheat | 350-650 | 160-220 | - | # | 500-1000 | Singh *et al.* (2015); Sapkota *et al.* (2014) |
| 7. Sub-surface drip irrigation | Rice-wheat | 280-550 | 150-220 | 40-50 | *# | 500-1500 | Sidhu *et al.* (2019); Jat *et al.* (2019) |
| | Maize-wheat | 500-1020 | 320-580 | 70-85 | * | | Sidhu *et al.* (2019); Jat *et al.* (2019); Patra *et al.* (2021) |

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|---|---|---|---|---|---|---|---|---|
| 8. | Legumes inclusion (Mungbean) | Rice-wheat; maize-wheat | 320-350 | 180-250 | - | # | 65-120 | Gathala *et al.* (2014); Choudhary *et al.* (2018); Thind *et al.* (2019) |
| 9. | Crop diversifi-cation | Wheat and mustard based systems | 400-1050 | 250-450 | 15-75 | *# | Significant but varied widely depending on different crops | Gora *et al.* (2020) unpublished |
| 10. | Portfolios of climate smart practices (LLL + ZT + Mulch + SSNM) | Rice-wheat | 110-220 | 280-360 | 15-20 | *# | 2800-3000 | Kakraliya *et al.* (2018) |

*Adaptation to extreme climate events such as excess rainfall during season
#Adaptation to extreme climate events such as terminal heat stress during season
[&]These are both life cycle analysis as well as soil respiration under various studies

### *Conservation agriculture in rainfed ecosystems*

Rainfed ecosystems in India occupy about 55% total cultivable area and produce 40% food in the country. The predominant rainfed states are Andhra Pradesh, Telangana, Maharashtra, Karnataka, Rajasthan, Orissa, Tamil Nadu, MP and others. Soils are degraded with multi-nutrient deficiencies and poor in soil organic carbon (SOC). As agriculture is rain dependent, sustainability is directly associated with the amount and distribution of rainfall (Srinivasarao *et al.*, 2011c, d). Past decades witnessed the decrease in rainy events though total amount of rainfall is not varied. This leads to increased frequency of mid-season droughts, which lead to crop failure and overall uncertainty in the food production systems of this region. Therefore, resource conservation technologies (RCTs) covering water, soil, carbon and nutrient conservation technologies are much focused in the recent past. Conservation agriculture in true sense with three principles no-tillage or minimum tillage, legume in rotation and crop residue cover provide multiple benefits of resource conservation but implementation in true spirit is often difficult due to the need of in-situ rain water conservation, need of tillage for surface crusting management for optimum germination and introduction of legume with mono-cropping. This is the reason that the RCTs are more practical and implementable depending upon rainfall, soil type and other ecosystem properties (Srinivasarao *et al.*, 2011b, 2012a).

Experiments in rainfed Alfisols showed that introduction of legume crop (horsegram) is possible when sufficient terminal rainfall is received in maize (*kharif*)-horsegram (post-rainy season). This scenario of taking second crop in predominantly mono cropped regions is purely dependent on with optimal monsoon distribution (Srinivasarao *et al.*, 2016, 2019a) (Fig. 1). Another important constraint in crop residue recycling in typical CA in rainfed agriculture is due to lower biomass production and its competing uses for animal feed. If implemented successfully, CA systems resulted in improved system productivity, SOC status, reduced soil erosion and improved biological activity in soil; which broadly dependent on proper rainfall distribution in crop growing season.

**Table 2.** Efficient inter-cropping systems in rainfed drylands for resource conservation in India

| System | Target domain | Adoption rate |
|---|---|---|
| 1. Groundnut + pigeonpea (7:1) | Rayalaseema, Andhra Pradesh | 70% |
| 2. Cotton + sorghum + pigeonpea + sorghum (6:1:2:1) | Vidarbha, Maharashtra | 40% |
| 3. Maize + pigeonpea (1:1) | Odisha | 40% |
| 4. Sorghum + pigeonpea (2:1) | Telangana | 40% |
| 5. Fingermillet + pigeonpea (10:1) | South Karnataka | 20% |
| 6. Pearlmillet + pigeonpea (2:1) | Solapur, Maharashtra | 35% |
| 7. Maize –wheat + raya (2:1) | Kandi region of Punjab | 38% |
| 8. Maize + blackgram (2:2) | Southern Rajasthan | 63% |
| 9. Pearlmillet + castor (2:1) | North Gujarat | 15% |

Another important technology for resources conservation in rainfed drylands is land treatments coupled with intercropping system. Land treatments such as ridge-furrow, semi-permanent raised beds and furrow etc. will allow the conservation of rain water, which is critical for sustainable agriculture in rainfed system but also reduces soil and nutrient loss. If land treatments and legume intercropping systems are done together provides ample opportunity for climate change adaptation and mitigation (Srinivasarao *et al.*, 2014, 2017, 2019a). Promising intercropping systems for different rainfed ecosystems are presented in Table 2.

As soils are poor in SOC and fertility, improving SOC with integrated nutrient management (INM) practices is viable option which conserves more water by improved water retention in soil and also improves nutrient availability in rainfed drylands (Srinivasarao *et al.*, 2020a). Important strategy for implementing INM in rainfed agriculture to generate organic resources on-farm with legume cover crops with off-season rainfall or introduction of legumes in fallow period. Various organic resources such as glyricidia green leaf manure, legume cover crops, farm yard manure, crop residues and other green manure crops are being added to the soil in different rainfed ecosystems of India. This improves SOC in soil and contributes to climate change adaptation by protecting the crop during mid-season droughts by improved soil moisture retention (Srinivasarao *et al.*, 2012a, b, c, d, e f). Each ton of SOC stocks in soil improved productivity of various rainfed crops such as groundnut, finger millet, sorghum, pearl millet, cluster bean, soybean, safflower, rainfed rice and lentil to the range of 40 to 160 kg $ha^{-1}$ (Fig. 1). However, in rainfed dryland systems, as there are limited options are available in terms of water availability and implementation of various available technologies in holistic manner results in adaptation to the climate change, reduced GHG emission and overall positive carbon foot print at village level (Srinivasarao *et al.*, 2015a).

## Conservation Agriculture for Mitigating GHG Emission

Agriculture contributes to greenhouse effect primarily through the emission and consumption of GHGs such as $CH_4$, $N_2O$ and $CO_2$. Rice fields submerged under water are the potential source of $CH_4$ production. Nitrous oxide is produced in soils through nitrification and denitrification processes. The source of $CO_2$ is the soil management practices such as tillage. Use of fuel for various agricultural operations, burning of crop residues and manufacturing of farm implements, fertilizers and pesticides are the other sources of carbon dioxide. Resource-conserving technologies have potential to enhance input use efficiency and mitigating GHGs emissions. The GHG mitigation as well as adaptive capacity of various RCTs to climatic risks is presented in Table 1. A few of them are discussed below.

Zero tillage (ZT) is an intervention used in conservation agriculture system intensification (CASI) reported to enhance soil organic carbon (SOC) storage and other soil-quality parameters

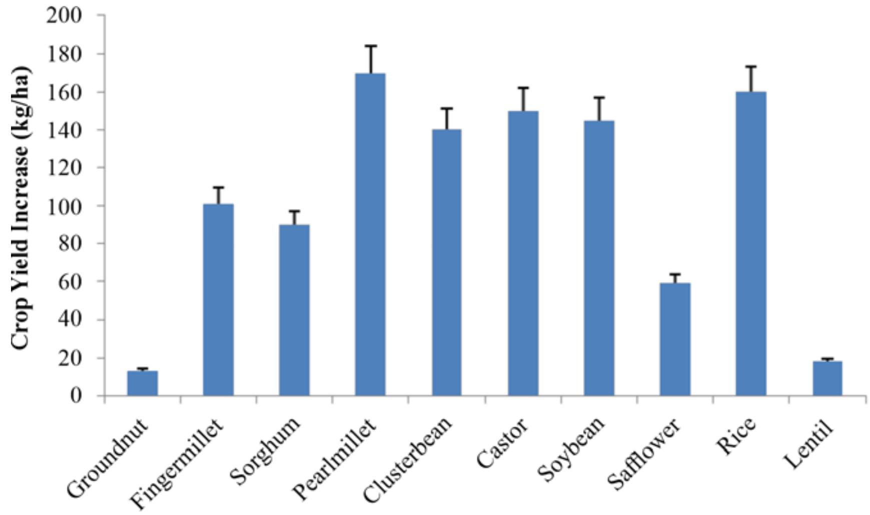


**Fig. 1.** Increase in crop yield for every ton per hectare increase in soil organic C stock in the root zone in different rainfed production systems

as compared with conventional tillage (CT) system (Gathala *et al.*, 2011; Day *et al.*, 2020; Parihar *et al.*, 2018; Sapkota *et al.*, 2017). No-tillage systems eliminate all pre-planting mechanical seedbed preparation thereby reducing the fossils fuel burning and reduces sequester the carbon in the soil that ultimately reduces GHGs emissions. Intensive tillage operations involved in CT exacerbate the problems of soil degradation and oxidation of soil organic matter (SOM) (Lal, 2015). Rate of SOC increase under ZT in the Indo-Gangetic Plains (IGP) could be around 0.3 Mg C $ha^{-1}$ $yr^{-1}$ in a 0–30 cm soil layer in the tropical regions (Powlson *et al.*, 2016). As per the estimation of Grace *et al.* (2003), the $CO_2$ emissions from CT plots of rice–wheat cropping system would be about 29 Mg $CO_2$ $yr^{-1}$ if applied to 1 million hectares of IGP; while this can be lowered to 14 Mg $CO_2$ $yr^{-1}$ under ZT system with residue retention. In India, rice–wheat system has the potential to sequester 44,100 Gg C over 20 years under ZT practice (Grace *et al.*, 2012). A study conducted by Aryal *et al.* (2015) revealed that adoption of ZT under wheat cultivation reduced the GHG emissions by 1.5 Mg $CO_2$ eq $ha^{-1}$ $yr^{-1}$. Direct-seeded rice (DSR) is the best alternative for conventional puddle transplanted rice (TPR) that emits enormous amounts of methane ($CH_4$) and other GHGs. Pathak *et al.* (2013) observed that DSR has the total global warming potential of 1.3 to 2.9 t$CO_2$e $ha^{-1}$ while it is 2.0 to 4.6 t $CO_2$e $ha^{-1}$ for TRP. Burning of crop residues can efficiently reduce by CA practice. That means, it also results in lowering the emission of $N_2O$ and $CH_4$ (each ton of crop residue emits 40 g of $N_2O$ and 2.3 kg of $CH_4$) (Grace *et al.*, 2003).

Direct-seeded rice has potential for minimizing the cost of production, soil health hazards, GHG mitigation and the negative impacts on the succeeding crops (Das *et al.*, 2013; Chakarborty *et al.*, 2017). Reduction in $CH_4$ emission from rice fields is due to aerobic condition or intermittent wetting and drying. Parihar *et al.* (2018) reported reduction in nitrous oxide emissions in addition to increased storage of soil organic and inorganic fractions under conservation agriculture based maize-wheat rotation in north-west India.

Crop residue retention under zero-tillage is more beneficial than residue incorporation in conventional tillage. It reduces weeds, conserves soil moisture and organic carbon, regulates soil temperature and supplies nutrients, which ultimately reduces irrigation need and increases crop yield and net returns. Crop residues help in enhanced water infiltration, reducing evaporation, and wind and water erosion. Residue management will avoid straw burning, improve soil organic C, enhance input-use efficiency and have the potential to mitigate GHGs emission. New variants of zero-till seed-cum-fertilizer drill such as happy seeder, turbo seeder and rotary-disc drill can do direct drilling of seeds in the presence of surface residues (loose and anchored up to 10 t $ha^{-1}$). India produces about 500 Mt of crop residues both on-farm and off-farm (MoA, 2012). India, amount of surplus crop residues is 90-140 Mt, which is burnt on-farm (Pathak *et al.*, 2011). With CA technologies, the residues can be used for improving soil health, increasing crop productivity, reducing pollution and enhancing sustainability and resilience of agriculture.

## Quantification of Mitigation Potential of Conservation Agriculture Practices

Conservation practices mainly bring about two modifications: (i) minimal soil disturbance and (ii) retention of plant residues in soils (Parihar *et al.*, 2018). These two factors cause changes in soil properties and processes, physico-chemically as well as biologically. Under absence of intense soil disturbances, moisture retention improves, aggregates are stabilized, organic matter is protected and microbial communities are less disturbed (Bhattacharya *et al.*, 2018). Increased resistance to gaseous diffusivity under ZT causes low mobility of gases along the soil profile, thus affecting gaseous transport (Gupta *et al.*, 2016). Under reducing conditions, residue incorporation tends to make soil more anaerobic since organic compounds usually serve as electron donors. The $CH_4$ emission rates are generally higher under continuous no-tilled than in continuously tilled soils. However, $N_2O$ and $CO_2$ emission rates are higher in alternately tilled soils due to residue incorporation coupled with intermediate soil disturbances. Alterations of drainage regimes and residue incorporation in rice production systems can reduce $CH_4$ emissions. Crop management practices that increase SOC in semi-arid region generally reduce $CH_4$ emissions (Feng *et al.*, 2018). However, wetting and drying of soils may also enhance $N_2O$ emissions and soil C mineralization, thereby reducing net GHG mitigation potential. Zhao *et al.* (2016) in a meta-analysis study indicated that the higher $N_2O$ emission could be mitigated by adopting no-tillage (NT) within alkaline soils, for long-term duration, and with less N fertilization input when compared to conventional tillage (CT).

A study was conducted by Pathak *et al.* (2012) in two regions broadly classified as the upper and lower Indo-Gangetic Plains (IGP) to assess the potential and cost of low carbon technologies. The upper IGP comprised of states like Punjab, Haryana and western Uttar Pradesh, while eastern Uttar Pradesh, Bihar and West Bengal comes under the lower IGP. In both these regions GHG emission was calculated for rice and wheat crops using the InfoRCT simulation model (Pathak *et al.*, 2011). Twenty different technologies were selected in rice and ten in wheat, to study their GHG mitigation potential in respective crops. In rice crop grown in the upper-IGP, maximum reduction in GWP has been observed in C sequestration technology where rice straw was used as a construction material. Zero tillage also has a high global warming potential (GWP) reduction strength of 83.9%. In case of wheat, GWP reduction strength of the technologies ranged from 6 to 204% in the upper-IGP and 5 to 252% in the lower-IGP.

A preliminary estimate suggests that global warming potential of about 25 Mt $CO_2$ eq. is mitigated annually with adoption of various RCTs in India (Table 3). The crop sector of Indian agriculture (agricultural soil, rice cultivation and crop residue burning) emits about 172 Mt $CO_2$ eq. (Pathak, 2015). Thus, about 15% of the emission from the crop sector is mitigated by the various mitigation technologies. However, there are uncertainties in assessing the impacts of the RCTs on GHGs mitigation and climate change adaptation under different agro-climatic and management conditions. Incomplete and incorrect implementation of the RCTs may even have risks of enhancing GHGs emission and adverse impacts on adaptation.

Climate and soil characteristics determine where no-till management can store carbon in soils and mitigate GHGs emissions (Ogle *et al.*, 2019). Arid regions can benefit the most from conservation agriculture by achieving a win-win

**Table 3.** Estimates of area under various conservation agriculture practices and their impacts on greenhouse gas mitigation and yield

| Greenhouse gas | Mitigation technology | Area under mitigation technology (Mha) | Emission in conventional practice (kg ha$^{-1}$) | Emission in mitigation technology (kg ha$^{-1}$) | Total mitigation (Mt $CO_2$ eq.) | Yield (% of conventional practice) |
|---|---|---|---|---|---|---|
| Methane | Intermittent wetting and drying | 7.5 | 100 | 30 | 4.7 | 95 |
| | Dry direct-seeded rice | 4.0 | 100 | 40 | 3.4 | 90 |
| Nitrous oxide | Leaf colour chart | 40.0 | 1 | 0.15 | 1.9 | 110 |
| | Neem-coated urea | 120.0 | 1 | 0.15 | 5.6 | 105 |
| Carbon dioxide | Zero tillage with residue | 2.5 | 2000 | 600 | 1.5 | 105 |
| | Integrated nutrient management | 25.0 | 2000 | 300 | 7.5 | 110 |

outcome of enhanced C sequestration and increased crop yield (Sun *et al.*, 2020, Hunt *et al.*, 2020). Carbonell-Bojollo *et al.* (2021) reported the tilled system had a substantially greater environmental cost than no tilled systems. The soils under the conventional tillage were found to be emitting 67% more $CO_2$ emission than soils under the conventional tillage in a four-year conservation experiment growing different crops in rotation, however, the environmental conditions influenced the $CO_2$ emissions. Feng *et al.* (2018) in a global meta-analysis study observed that NT/ reduced tillage (RT) significantly mitigated the overall global warming potential (GWP) of $CH_4$ and $N_2O$ emissions by 6.6% as compared with conventional tillage (CT). Plaza-Bonilla *et al.* (2020) observed that (NT), being key for the enhancement of several ecosystem services, can present benefits in terms of GHG mitigation if combined with best management practices adapted to the specific conditions of NT soils. Alam *et al.* (2019) reported that non-puddled transplanting with increased crop residue retention was an effective GHG mitigation option in wetland rice production.

## Climate Change Adaptation with Conservation Agriculture

The CA practices bring many benefits for climate change adaptation including adaptation to extreme climate events such as excess rainfall and terminal heat stress (Table 1). In rainfed dryland ecosystems, CA systems with contributed to improvement of soil organic carbon, soil biodiversity, reduced soil erosion with crop residue cover, reduced tillage and legumes in the cropping sequence or rotation. With improved soil organic carbon, the water retention was increased thus the crops adapted to mid-season droughts in maize-horsegram system (Kundu *et al.*, 2013) and in pigeonpea systems (Indoria *et al.*, 2017) in Alfisols of Southern India. Due to crop residues, soil loss was minimized in rainfed pigeonpea-castor based systems besides improved soil moisture storage in semi-arid tropics (Pratibha *et al.*, 2015, 2016). Other co-benefits of CA in rainfed systems are reduced nutrient losses along eroded soil with high intensity rainy events. Studies on effect of long-term tillage and sources of nitrogen on crop yields of sorghum- sunflower rotation and soil carbon sequestration in rainfed Vertisols also showed the similar advantages of climate change adaptation during variable rainfall situations North Karnataka (Prasad *et al.*, 2013). A fruit-based cropping system is the most suitable for sustainable production as it conserves soil and water and brings stability in production and income. Among the different intercropping systems tried, the mango + guava + cowpea system resulted in improvement in the water holding capacity of soil to the extent of 30% and improved organic carbon contents in soil profiles. Similar benefits of climate change adaptation and mitigation with land use changes/resource conservation technologies in diverse agro ecosystems (Ramesh *et al.*, 2019).

Climatic variability, especially rainfall variability (i.e. both drought and excess rainfall) and end-of-season high temperatures severely impact wheat production in India. Many studies have demonstrated negative effects of high temperature during wheat maturity period, i.e. "terminal heat" in India (Jat *et al.*, 2009; Lobell *et al.*, 2012; Samra and Singh, 2004; Gupta *et al.*, 2010). A large number of studies in irrigated production systems of India indicates that CA based management practices helps to enhance the resilience of agriculture to climate variability through better adaptation to climate change (Jat *et al.*, 2016). A recent study (Aryal *et al.*, 2016) in Haryana, India showed that CA better copes with climatic extremes than the conventional tillage-based wheat production system (CT). The study found that wheat yield during the bad year (defined in terms of untimely excess rainfall during grain development) was 4.89 Mg $ha^{-1}$ under CA while it was only 4.23 Mg $ha^{-1}$ under CT.

## Lessons Learnt

Conservation agriculture has been shown to have multiple benefits for soils, crop yield and the environment, and consequently, no-till, the central practice of conservation agriculture, needs to be rapidly expanded (Jat *et al.*, 2020). There are several barriers that hinder the adoption of CA in India with three principles which includes burning of crop residues for the timely sowing of next crop, larger demand of crop residues for livestock feed and fuel, insufficient weed control measures and mechanization for CA implementation in small farm holdings, lack of supportive policies and adequate networks for distribution of machinery, termite management in rainfed agriculture to retain soil cover for longer period and surface crusting and strong need of rain water conservation with land treatments. There has been number of innovations taken place on CA, but their adoption has somehow been slow. However, lack of a common platform for sharing the knowledge and capacity development besides needed policy support is the major deterrent in accelerating the pace of adoption of CA in South Asia. In addition, one of the critical factors for success of CA is commercial availability of scale appropriate machinery, which is lacking in many regions specially in rainfed and hill farming systems in general and irrigated eastern India, limiting the adoption of CA in large chunk. For accelerated adoption of CA, there is a need to develop scalable and sustainable business models specially through Motivating and Attracting Youth in Agriculture (MAYA) and empowering women for creating effective custom hiring centers as well as manufacturing hubs. Enhanced capacity development of all stakeholders involving farmers service providers-scientists-to policy makers should be an integral part of such models. There is also need for policy re-orientation for transitioning from a classical 'push' to creating 'push' through incentivizing efficiency and sustainability and contributing to larger goals rather than quick fixes.

## Conclusions

Conservation agriculture offers a new paradigm for agricultural research and development, which mainly aimed at achieving food production targets in India while solving the problems of natural resource degradation. Developing and promoting CA practice on wider scale will be highly demanding in terms of the knowledge base. However, the maximum benefits of climate change mitigation are likely to be realized by linking CA as an efficient and sustainable livelihood strategy to deal with ecosystem degradation. Such management often requires deeper engagement in political, social, and governance issues. Standardization of the equipment for sowing, fertilizer placement and harvesting operations that ensures the less soil disturbance under residue cover will be a key to success of CA. There is a great need for policy analysis to obtain the knowledge on how CA technologies integrate with other technologies. Strengthening of knowledge and information sharing mechanisms are highly essential. Educating the farmers regarding the detrimental impacts of residue burning is crucial. Moreover, adoption tracking of CA in India is largely missing and concerted efforts should be made to track and quantify the area and the benefits achieved. Policy support is required for capacity building of farmers by organizing training on CA. To achieve the sustainability in CA technology, it is critical to institutionalize CA into relevant government ministries and departments and regional institutions. For the successful adoption of CA at global level, provision of credit to farmers to purchase equipment, machinery, and inputs through banks and credit agencies at reasonable interest rates is very much essential. Support is needed to adapt and validate the CA technologies in local environments in rainfed systems. Partnership of scientists, farmers, extension agents, policy makers and other stakeholders in the private sector is important to develop and promote CA at local, national and global levels.

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