

Transforming Indian agriculture through conservation agriculture

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Conservation Agriculture (CA) offers a transformative approach to Indian agriculture, addressing problems like soil degradation, scarcity of water, and climate variability. By adhering to the core principles of negligible soil disturbance, permanent soil cover, and diversified crop rotations, CA enhances soil health, improves water-use efficiency, and builds resilience against erratic weather patterns. The adoption of practices such as zero-tillage, mulching and crop rotation has demonstrated promising results in growing crop yields, decreasing water consumption, and mitigating environmental impacts. CA's potential to restore soil fertility, reduce dependence on chemical inputs, and promote long-term sustainability positions it as a key strategy for ensuring the future of Indian agriculture and improving the livelihoods of farmers.

Keywords: Crop rotation, Soil degradation, Soil health, Sustainable agriculture

CONVENTIONAL intensive farming systems have significantly contributed to the degradation of agricultural ecosystems. It is because of practices like repeated and deep tillage, monocropping, residue removal, and heavy reliance on chemical fertilisers and pesticides. Globally, around one third of agricultural soils are degraded due to erosion, compaction, salinisation, and loss of soil organic carbon, resulting in declining productivity and ecosystem services. In India, the problem is more acute, with about 44% of the land area affected by various forms of land degradation, particularly in intensively cultivated regions such as the Indo Gangetic Plains. Excessive and imbalanced fertiliser use has led to nutrient depletion, soil acidification, and declining factor productivity, while indiscriminate pesticide application has polluted soil and water resources and posed serious risks to biodiversity and human health. The pressure of pest infestation has also increased due to rising pesticide resistance, resulting in substantial

yield losses and rapid development of pesticide resistance. These environmental and agronomic challenges are further intensified by climate change, erratic rainfall, rising temperatures, and increasing water scarcity.

In this context, Conservation Agriculture (CA) has emerged as a promising and sustainable alternative to conventional intensive farming. CA is a farming system focused on improving soil health, enhancing productivity, and promoting environmental sustainability. It has three core principles: minimal soil disturbance, permanent soil cover and diversified crop rotations. In India, where agricultural productivity is affected by soil degradation, water scarcity, and climate variability, CA offers an effective pathway to sustainable intensification. Practices such as zero tillage, residue retention, cover cropping, and crop diversification improve soil structure, increase soil organic carbon, enhance water infiltration and retention, and promote soil biological activity. These practices reduce dependence

on chemical inputs, improve resource use efficiency, and build resilience against climate extremes such as droughts and irregular rainfall. By mitigating soil erosion, conserving water, and enhancing system stability, CA holds significant potential to ensure longterm sustainability, productivity, and improved livelihoods for Indian farmers.



Principles of conservation agriculture
(Source: Jayaraman *et al.* 2021)

CA practices

CA requires the simultaneous and integrated adoption of all three core principles. If the three principles are applied separately, they do not



Maize grown on permanent raised bed



Maize intercropped with greengram



Wheat grown with residue

constitute a CA system. Practices such as laser land levelling, bed planting, minimum or strip tillage, zero tillage, brown manuring with *Sesbania*, direct seeded rice (DSR), crop residue management, and crop diversification are important components or enabling practices of CA. When implemented in a holistic and complementary manner, these practices improve soil health, resource use efficiency, and system sustainability, thereby achieving the intended benefits of conservation agriculture.

Status of CA in India

In India, concerted efforts to advance CA research and development have been underway since the mid 1990s through a range of ecoregional, national, and international initiatives. Early momentum was generated through ecoregional programmes such as the Rice-Wheat Consortium (RWC), followed by major national initiatives including the National Agricultural Technology Project (NATP), National Agricultural Innovation Project (NAIP), the ICAR platform on Conservation Agriculture, and the National Innovation on Climate Resilient Agriculture (NICRA). These efforts were further strengthened through regional and bilateral collaborative programmes such as the Cereal Systems Initiative for South Asia (CSISA), the Sustainable and Resilient Farming Systems Initiative for the Eastern Gangetic Plains (SRFSI), CGIAR Research Programmes on Climate Change, Agriculture and Food Security (CCAFS), Wheat-Maize AgriFood

System programmes (WHEAT and MAIZE), and regional platforms like the Borlaug Institute for South Asia (BISA), involving a large number of national and international institutions.

Despite substantial research investments and strong science based evidence demonstrating CA's multiple benefits, the overall uptake of CA in India has been relatively slow. Nevertheless, CA has emerged as one of the major frontiers of future farming, given its ability to contribute to several Sustainable Development Goals. Globally, CA was practiced on over 205 million hectares of cropland during 2018-19, representing approximately 15% of the world's cropland, with adoption reported across more than 100 countries. In contrast, India has around 3.5 million hectares under CA, accounting for only 2.5% of total cropland.

At the regional level, recent estimates indicated that nearly 2.5 million hectares in South Asia are under partial CA systems, where at least one crop is grown using no till practices, with or without residue retention. Of this area, about 80–90% (approximately 2 million hectares in India) is predominantly concentrated in the rice-wheat system dominating Indo Gangetic Plains especially Punjab and Haryana. Limited adoption is also observed in the Eastern Gangetic Plains and parts of southern India. Adoption is higher among large scale farmers due to better access to machinery, whereas smallholder farmers remain constrained despite government support through custom hiring services.

Advantages of CA

CA provides transformative benefits for sustainable farming in India by addressing major challenges such as soil degradation, water scarcity, and climate variability. A primary advantage of CA is the improvement of soil health. Practices like zero tillage and residue mulching enhance soil structure, microbial diversity, and nutrient cycling, counteracting the adverse effects of intensive tillage. Long term studies from Punjab and Haryana have reported significant increases in soil organic carbon under zero tillage systems, resulting in improved soil fertility and crop vigour. Water conservation is another critical benefit of CA, particularly in monsoon dependent and water stressed regions. Residue retention and reduced tillage lower evaporation losses and improve soil moisture retention. Research from Rajasthan and Madhya Pradesh indicated that CA practices can reduce irrigation water requirements by up to 30%, making them highly suitable for rainfed and semiarid regions. Productivity gains under CA become evident over time as soil quality improves. Zero tillage in wheat and rice systems has resulted in 10–15% higher yields compared to conventional tillage, supported by better root growth and nutrient uptake. CA also enhances climate resilience; for example, rice-wheat systems under CA in Uttar Pradesh showed a 25% increase in drought resilience. Additionally, CA can reduce production costs with reduced tillage, fuel, labour, and chemical inputs. Observations from all over the country have

Table 1. Advantages of conservation agriculture found in different regions of India

Location	Cropping system	Findings
New Delhi	Cotton–wheat	<ul style="list-style-type: none"> ↑ 52% and 16% mean cotton and wheat yield, respectively under permanent broad bed + residue with 100% N than conventional tillage (CT) ↑ 53% and 17% mean cotton and wheat yield, respectively under permanent flat bed + residue with 100% N than CT ↑ 27.5% and 56% total organic carbon stock and system water productivity, respectively under permanent broad bed + residue with 100% N compared to CT
New Delhi	Maize–wheat–greengram	<ul style="list-style-type: none"> ↑ 56% root length density in maize, 60% root length density in wheat and 26.5% root length density in greengram under permanent broad bed + residue with 100% N than CT ↑ 31.1% system productivity under permanent broad bed + residue with 100% N than CT
Haryana	Rice–wheat–mungbean	<ul style="list-style-type: none"> ↑ 36% system yield under zero-till DSR–wheat–mungbean than conventional system ↑ 67% total water productivity under zero-till DSR–wheat–mungbean than conventional system
Punjab	Six cropping systems	<ul style="list-style-type: none"> ↓ 4.4% bulk density in soybean–wheat–mungbean under permanent broad bed with residue than rice–wheat–mungbean under conventional tillage ↑ 45.6% infiltration rate in soybean–wheat–mungbean under permanent broad bed with residue than rice–wheat–mungbean under conventional tillage
Bihar	Rice–wheat	<ul style="list-style-type: none"> ↑ Soil organic carbon across all four fractions under zero tillage (ZT) + residue retention compared to continuous and rotational tillage ↑ CPI (Carbon pool index) and CMI (Carbon management index) under ZT + residue retention compared to continuous and rotational tillage ↓ LI (Lability index) under ZT + residue retention compared to continuous and rotational tillage
Telangana	Sorghum–blackgram	<ul style="list-style-type: none"> ↑ 12.32 and 5.21% grain yield in sorghum and blackgram, respectively under minimum tillage over conventional tillage ↑ 19.61 and 25.93% SYI (Sustainability yield Index) in sorghum and blackgram, respectively under minimum tillage over conventional tillage

shown that similar or higher yields can be obtained under CA as with conventional systems. Overall, CA is a vital strategy for resilient, profitable, and sustainable Indian agriculture.

Problems hindering adoption of CA in India

CA is a highly specialised and knowledge intensive production system that requires favourable conditions, adequate resources, and technical expertise for its successful adoption. Effective implementation of CA demands the simultaneous and holistic application of its core principles. However, there are instances where reduced yields have also been adopted. This is caused by following constraints in complete CA adoption:

- Deep-rooted implementation of conventional methods by farmers and other stakeholders
- Low productivity at initial transition stage
- Unavailability of specialised machinery
- Lower risk-bearing capability
- Incomplete implementation of CA principles
- Fragmented and small landholdings

- Limited technical knowledge
- Poor pest control
- Monocropping and practice of same cropping system/crop rotation over the years
- Limited availability of crop residue, hindering principle of permanent crop cover

Future prospects of CA in India

Conservation agriculture-based technologies have been developed and validated across diverse agroecological regions of India, demonstrating substantial benefits in terms of enhanced productivity, profitability, soil health, and climate resilience. Longterm studies and field experiences indicate that CA can significantly improve resource use efficiency, reduce production costs, and increase the sustainability of cropping systems. Despite these proven advantages, the adoption of CA technologies in India has remained limited due to farmers' apprehensions, lack of confidence, inadequate motivation, and several operational constraints. Nevertheless, CA offers immense potential for bringing large tracts of fallow and degraded lands under profitable cropping systems,

thereby improving farm incomes and national food security.

Wider adoption of CA requires a coordinated and multi stakeholder approach involving policymakers, researchers, extension agencies, private sector players, and farmers. Large scale awareness campaigns, on farm demonstrations, and farmer to farmer learning platforms are essential to showcase the tangible benefits of CA under real field conditions. In addition, timely access to suitable farm machinery, particularly for zero tillage, residue management, and precision input application must be ensured to facilitate smooth adoption.

A systematic analysis of the factors limiting adoption and acceptance of zero tillage (ZT) and CA practices is urgently needed. Insufficient understanding of the individual and interactive effects of minimal soil disturbance, permanent residue cover, planned crop rotations, and integrated weed management often hampers adoption. Although considerable information has been generated through research trials, there is a strong need to expand onfarm research and participatory

development programmes. Active farmer involvement in experimentation, validation, and demonstration is critical for accelerating CA diffusion.

Conservation agriculture presents both challenges and opportunities for researchers, demanding strong multidisciplinary approach. Agronomists and resource management scientists must pull efforts to refine CA technologies through integrated onstation and onfarm research, ensuring reduced costs, improved yields, enhanced produce quality, and sustained soil health. Scientists adopting and demonstrating CA in farmers' fields



will be pivotal in transforming India's agricultural landscape.

SUMMARY

Conservation agriculture (CA) revolves around three core principles i.e. minimal soil disturbance (zero-tillage), permanent soil cover (mulching) and crop diversification. Thus, it mitigates crop failure risks, reduce input costs, and restore ecological balance. CA promotes soil fertility, water-use efficiency, and resilience to climate extremes. Studies show 10–20% higher crop yields, 30–40% improved water retention, and reduced erosion. It offers a sustainable pathway


to transform Indian farming by addressing soil degradation, water scarcity, and climate variability. Despite advantages, its adoption faces hurdles including high initial costs, lack of awareness, lack of expertise and resources, etc. To scale CA, region-specific initiatives at farm level are essential. With growing support from farmers, researchers, and policymakers, CA holds strong prospects to secure food security, improve rural livelihoods, and promote climate-smart, sustainable agriculture across India.

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HANDBOOK OF HORTICULTURE

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HANDBOOK OF HORTICULTURE

Volume 1 & 2

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