



Prospects and Issues in the Adoption of Conservation Agriculture in India

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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

Conservation agriculture involves practices such as crop rotations, minimal soil disturbance, and maintaining permanent soil cover through crop residues or cover crops. Despite various challenges to its widespread adoption, India has made significant progress over the past two decades in developing, refining, and promoting conservation-based agricultural technologies. Notable advancements have been made in the Indo-Gangetic plains, especially in the adoption of no-till wheat within the rice-wheat cropping system. Advocates of conservation agriculture understand the trade-offs but recognize that the benefits outweigh the drawbacks. These methods offer potential advantages including reduced production costs, improved water and nutrient conservation, increased crop diversity and yields, and more efficient resource utilization.

Keywords: Conservation agriculture; traditional agriculture; zero-tillage; resource use efficiency.

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1. INTRODUCTION

The Food and Agriculture Organization (FAO) describes Conservation Agriculture (CA) as a system for managing agro-ecosystems that aims to ensure food security, enhance profitability and protect environmental resources. According to the United Nations' Committee on World Food Security, food security means that everyone, at all times has physical, social and economic access to sufficient, safe and nutritious food that fulfills their dietary preferences and needs for an active and healthy life. Currently, nearly 800 million people lack adequate food, over 2 billion suffer from deficiencies in essential micronutrients and about 60% of individuals in developing countries face food insecurity [1]. Additionally, anticipated population growth, climate change and environmental impacts are likely to worsen these issues in the coming decades. Given the scale of the challenge, food security is interconnected with all the Sustainable Development Goals (SDGs) established by the United Nations.

Conservation agriculture is a management approach for agroecosystems that stands out as a key method for achieving agricultural sustainability, aiming to enhance productivity while safeguarding the environment [2]. Originating in the 1930s in the USA to address soil degradation caused by water and wind erosion. Conservation Agriculture (CA) is defined by the use of three interconnected principles, which are applied through locally adapted practices and complemented by other agricultural methods [3]. These three core principles are:

- (1) Continuous minimum mechanical soil disturbance;
- (2) Permanent soil organic cover with crop residues and/or cover crops;
- (3) Species diversification through varied crop rotations, sequences, and associations.

The main challenges facing the majority of Asian countries are ensuring food security for a growing population, reducing poverty, and maintaining agricultural systems under recent scenarios of diminishing natural resources, adverse effects of climatic variability, spiraling input costs, and unstable food prices. In addition to these difficulties, soil erosion, a decrease in soil organic matter, and salinization are the main signs indicating non-sustainable agricultural practices. These are mostly brought on by (i) reduced soil organic matter content, rate of water infiltration, wind and water erosion as a result of extensive tillage; (ii) the inadequate return of

organic material; (iii) mono cropping. Consequently, for future productivity and to maintain the sustainability of natural resources, a paradigm change in agricultural techniques is required to remove a few aspects of conventional agriculture such as tillage or ploughing of soil, monoculture, and removing soil organic matter. Concerns about the sustainability of agriculture throughout the world led to the development of the idea of conservation agriculture (CA), which has grown gradually to occupy almost 8 percent of the total arable land (124.8 million hectares) in the world [4]. Conservation agriculture is a resource-saving system of crop production to achieve high yields and production intensification and enhance the base of natural resources [5]. According to Wolff and Stein [6], traditional agriculture, which relies heavily on mechanization and tillage, has been blamed for issues such as surface and subsurface water contamination, soil erosion, and increased water consumption. Additionally, it is linked with low energy efficiency, the depletion of biodiversity and wildlife, the degradation of land resources and the issues associated with climate change [7]. Therefore, conservation agriculture is considered as a method of growing both annual and perennial crops that relies on managing crop waste and cover crops, as well as zero and conservation tillage, which offers an enduring soil cover and an spontaneous rise in the amount of organic materials in surface horizons. The primary environmental effects of this technique have been studied globally to provide the farming and scientific communities with an overview of the research and documentation that are now accessible. In contrast to traditional agriculture, it emphasizes the extremely positive effects of a conservative way of farming on the global environment (biodiversity, air, water, and soil) [8]. It additionally reveals the actual gaps or concerns regarding the opinions of the scientists on these environmental issues.

CA promotes reverse degradation processes, improves resource quality, reduces production costs and helps achieve sustained high productivity. Global area under CA was about 180Mha, corresponding to about 12.5% of the total global crop land in 2015/16 [9]. CA is considered as a sustainable practice, which increases natural biological processes, both below and above the soil. This technology is an eco-friendly, more efficient technology, which restores soil fertility along with increasing crop productivity and improving moisture conservation, which directly acts as a source of

climate change mitigation and reduces total cost of cultivation and helps in timely operations [10]. Conservation agriculture encourages most soils with richer biodiversity and bioactivity, improved soil structure, cohesion and higher levels of natural physical protection from wind, rain, and wet or dry spells. This results in decreased soil erosion and bio degradation of pesticides along with slightly reduced transport of agronomic inputs in soil. Conservation agriculture is a productive substitute for conventional agriculture that minimizes its drawbacks.

2. CONSERVATION AGRICULTURE

According to Hobbs [11], conservation agriculture can be defined as the widely adapted group of management practices that can guarantee more sustainable agricultural output. Conservation agriculture improves and enhances the efficient utilization of natural resources through the integrated management of easily accessible natural resources such as water, soil, and biological resources along with external inputs. It supports socially, environmentally, and economically viable agricultural production in addition to environmental protection [12]. According to FAO [12], it is also known as resource-effective or resource-efficient agriculture. This more environmentally friendly farming method has been referred to as "conservation agriculture" to set it apart from the more restrictive conservation tillage [13]. Conservation agriculture can be defined as a kind of farming that preserves the soil cover by retaining agricultural wastes on the surface and reducing or eliminating tillage. The management of crops, weeds, nutrients soil, water, and farm equipment in traditional agriculture requires a paradigm shift to implement conservation agriculture methods. Conservation tillage techniques like zero tillage are one way toward the transition from traditional tillage to conservation tillage. Here it can be said that conservation agriculture addresses a comprehensive idea of the entire agricultural system.

3. BASIC PRINCIPLES

Many regions of the world employ conservation agricultural techniques, which are based on ecological principles and increase the sustainability of land usage [14,15]. Conservation agriculture must be used to increase agricultural yield and resource use efficiency (RUE). Essentially, the three basic principles of conservation agriculture, are interconnected with each other for proper planning, design and

implementation procedures. These three principles are:

3.1 Minimal Disturbance of Soil Enabled through Reduced Tillage or No-Till

The soil biological activity creates highly stable soil aggregates and a range of pore diameters that permit air and water penetration. This method is incompatible with mechanical tillage and is referred to as "biological tillage." The organic activities that structure the soil will be eliminated by mechanical disturbance of the soil. According to Kassam and Friedrich [16], minimum soil disturbance balances the ideal amounts of gases required for root respiration in the rooting zone, moderates the rate of oxidation of soil organic matter, offers porosity for transportation of water retention, and release of water, and restricts the exposure of weed seeds and their germination.

3.2 Maximum Residues or Permanent Cover of Soil

A permanent cover in the soil is necessary to protect the soil from the damaging effects of sunlight and rain, to provide a steady supply of food for the micro and macro organisms living there, and to modify the microclimate in the soil to promote the best possible growth and development of microbes and plant roots. Maximum residue retention in soil enhances soil aggregation, soil biological activity, carbon sequestration and soil biodiversity [17].

3.3 Diversified Crop Sequences or Rotations (Temporal or Spatial Crop Sequencing)

Crop rotation is essential for providing a diversified diet to the microorganisms living in soil as well as for exploring various soil levels in search of nutrients that have seeped to deeper layers and may be recycled by the crops in rotation. Additionally, a diversity of soil fauna and flora are found by rotating a variety of crops. Legume crop rotations and crop sequencing disturb the life cycle of pathogens, biological fixation of nitrogen, increase biodiversity, and reduce off-site pollution [18], [16].

4. CURRENT SCENARIO OF CONSERVATION AGRICULTURE IN INDIA

Around 125 million hectares of land are under conservation agriculture globally. Adoption of conservation agriculture is still in its initial phases

in India. Adoption of conservation agriculture and zero tillage has increased over the last three years, covering over 1.5 million hectares. Conservation agricultural methods have been promoted in India for about a decade, but farmers have just begun to accept them in the last eight to ten years [19]. Some of the State Agricultural Universities, institutes under ICAR, and the Rice-Wheat Consortium for the Indo-Gangetic plains have joined forces to develop and promote conservation agriculture. In the irrigated areas of the Indo-Gangetic plains region, where rice-wheat cropping systems are predominant, the expansion of the setotechnologies can be seen. Other important agro-eco regions such as the rainfed semi-arid tropics and the dry parts of the mountain agro-ecosystems have not yet promoted or tested conservation agriculture techniques.

Developing and marketing zero-till seed-cum fertilizer drills for wheat planting in rice-wheat cropping systems has been the main focus for the development of conservation technology. Raised bed planting, residue management techniques, land leveling assisted by laser technology, and substitutes for the rice-wheat system etc. are important interventions. As per the reports of Sangar et al. [20] the area of wheat, planted with the zero-till drill has been rising quickly. Currently, 25 percent to 30 percent of wheat grown in Indo-Gangetic plains as a part of rice-wheat cropping systems is zero-tilled [19]. The farmers in the north-western region of India are also adopting raised-bed planting and laser field leveling at an increasing rate.

5. PROSPECTS

The way India as well as other countries in Asia choose to fulfil the energy and food demands in the upcoming decades will have a significant influence on energy security, natural resource base, and climate change. These challenges emphasize the necessity and urgency of finding solutions to address the risks to the agricultural sector caused by the depletion of natural resources, rising production costs, and climate change. A potential approach to address these issues is switching to no-till conservation agriculture. Farmers and researchers will always require assistance in reorienting their agricultural techniques to produce more at a lower cost of production by adopting more secure options and routes. Therefore, it appears that continuing with conventional agriculture would not result in sustainable food grain production. Instead, in the

majority of ecological and socio-economic situations of Indian agriculture, conservation agriculture-based crop management practices adapted to meet local needs are likely to be essential. The promotion of conservation agriculture in the Indian environment results in the following prospects:

5.1 Limiting Production Cost

This is one of the major elements driving the fast adoption of zero-till technologies. Research conducted by Malik et al., [21] revealed that the cost of production of wheat might decrease by between ₹2,000 and ₹3,000 per ha. A decrease in the cost of production contributes to reduction in diesel, man power and input expenses especially those of herbicides.

5.1.1 Reduced weed incidence

The majority of research shows that when zero-tillage is used, *Phalaris minor* infestation in wheat fields, tends to decrease, which in turn reduces the need for herbicides.

5.2 Yield Increase

Yields were constantly higher in well-managed zero-till planted wheat compared to conventionally prepared fields for similar sowing dates. Due to the effects such as improving soil moisture regime, improving soil fertility, preventing soil degradation and crop rotational benefits, conservation agriculture has been reported to enhance crop yield levels. In the Indo-Gangetic plains, zero-till wheat has shown better yield improvements of 200–500 kg ha⁻¹ as compared to the wheat grown conventionally in a rice-wheat cropping system [22]. African Conservation Tillage Network [23] declares that conservation agriculture leads to greater and more consistent crop yields, while there are also many cases of no yield advantages and even cases of declining yield particularly in the initial years of implementation of conservation agriculture.

5.3 Conserving Soil Nutrients and Moisture

Zero-till planting can result in significant savings in soil nutrients and water (up to 20%–30%), especially for crops that are bed-planted and laser-leveled [19]. A lower rate of evaporation over the preceding period can be indicated by a

higher soil moisture content under zero tillage than under traditional tillage [24]. Additionally, it was revealed that under zero tillage, the soil moisture content was almost 20 percent higher as compared to traditional tillage throughout the course of growing seasons.

5.4 Opportunities for Crop Diversification

Crop diversity may be achieved through the conservation of agriculture. Agroforestry system and cropping sequences or rotations, when implemented in suitable temporal and spatial patterns, can augment ecological processes. Studies suggest that a number of crops, including sugarcane, pigeon pea, mustard, and chickpea, may be well suited to this new system of crop production.

5.5 Environmental Benefits

Zero-tillage and crop residue retention on the surface in conservation agriculture present a better opportunity to prevent crop residue burning, which is a major source of greenhouse gases including CO₂, N₂O, and CH₄. Crop residue burning contributes significantly to nutrient loss, which can be recycled through proper management. Large-scale burning of crop residue poses a serious threat to public health.

5.6 Enhancement of Resources Uses

In combination with surface crop residue management, no-tillage initiates the processes leading to a gradual breakdown of surface residues, improving soil structure and increasing recycling and plant nutrient availability. Mulch-like surface residues lower soil temperatures, enhance biological activity and decrease evaporation.

6. ISSUES FACED WHILE ADOPTING CONSERVATION AGRICULTURE IN INDIA

Farmers, extensionists, technicians and researchers must adopt a different perspective to transition from conventional tillage to sustainable no-tillage farming [25]. Persuading farmers that tillage is not necessary for successful farming is the largest obstacle [26]. Many farmers might not notice additional advantages of conservation agriculture as they are primarily concerned with the financial savings from less tillage. Sustaining conservation agriculture as a pathway to sustainable agriculture will need continuous

scientific investigation and advancement. The following are some significant obstacles that prevent conservation agriculture from being widely adopted:

- Many marginal and small farmers are not well equipped with the necessary seeders. Additional research is required despite considerable attempts to develop and commercialize machinery for sowing wheat in zero-tillage system. Development, standardization, and promotion of high-quality machinery appropriate for arrangement of crops and cropping sequences are necessary for successful adoption. Management of crop residue involves developing permanent bed and furrow planting methods and enhancing harvesting techniques for managing crop residues.
- Farmers frequently use crop residues for fuel and animal feed in rainfed areas. Nevertheless, there aren't enough crop residues to cover all demands due to restricted biomass production. This creates conflict between using residues for cattle feed and for conservation agriculture practices. Hence, promoting conservation agriculture in such regions is significantly hampered.
- In the case of the rice-wheat cropping system of North India, due to a lack of machinery for seed sowing under conservation agriculture, farmers frequently burn crop remnants to facilitate timely seeding of the next crop. Although this approach helps with timely planting, it causes serious ecological concerns in the region.
- Farmers and extension agents lack awareness of the advantages of conservation agriculture. Consequently, all conservation agricultural practices including sowing, harvesting, nutrient and water management, and disease-pest control are to be developed, evaluated, and adapted to meet the needs of modern crop production systems.
- Management of conservation agricultural system needs experts. Scientists must collaborate closely with farmers and other stakeholders and approach issues from a systems view point. Improved methods for exchanging information and knowledge are also required.
- Over the past few decades, conservation agriculture techniques have been adjusted

to various socio-economic, agro-ecological and farming systems. For these techniques to spread and assist more farmers, though, more backing from regional, national and local stake holders including legislators is essential. Even though there has been a lot of study done on conservation agriculture in India, especially at the Indian Agricultural Research Institute (IARI), farmers have not yet fully embraced it. The previous perception or mindset of the farmers towards traditional tillage can be considered as a major cause of the limited adoption of the conservation agriculture concept [26]. Hence, Un favourable legislative contexts and farmers' customary inclination for tillage are major obstacles. Participatory on-farm research to evaluate and improve CA technology is crucial to overcoming these obstacles. Large-scale demonstration can then aid in the promotion of these techniques. To promote its wider use, India is now starting a network research initiative centre don the on-farm assessment and demonstration of conservation technology.

- Considering that conservation agricultural systems are intricate and hence effective management processes necessitate a thorough comprehension of basic processes and component interactions. Farmer collaborations for system approach are critical since farmers have the most in-depth knowledge of their farming systems. For the development and promotion of new technologies, cooperation between farmers, scientists, extension agents, policymakers and stakeholders in the private sector is essential. The FAO [27] states that advisors ought to collaborate with farmers to identify and address issues rather than relying solely on farmers to carry out outside initiatives. A participatory system is required in place of a top-down strategy, where farmers are given the tools and instruction to test conservation technology and assess its efficacy while making the required modifications for their land.
- It is essential to offer farmers financial assistance at fair interest rates so they can purchase machinery, inputs, and equipment for the successful implementation of conservation agriculture. Furthermore, these purchases have to be subsidized by the government.

- Adaptation of conservation agriculture concepts in local contexts becomes important for small farmers and resource-poor farmers and requires collaborative adaptive research involving community stake holders. To do this, conservation agricultural methods must suit the specific needs of the area. This includes choosing suitable crop species, managing crops and cover crops effectively, maintaining soil cover, and resolving issues with the cost-effectiveness of key inputs like seeds, machinery, and herbicides. To promote the wide spread implementation of conservation agriculture techniques and improve agricultural sustainability and resilience in local ecosystems, policy frameworks that make these inputs more affordable and available must be advocated.

7. CHALLENGES OF CONSERVATION AGRICULTURE IN INDIA

As an innovative model for crop production, conservation agriculture will need an innovative system viewpoint to address the flexible, diverse, and context-specific requirements of technologies along with their management. The effort to conduct research and development in conservation agriculture will thus need to incorporate several novel elements to meet the challenge.

7.1 Better Understanding of the System

Conservation agriculture is even more complicated than traditional agriculture. It will be extremely difficult to manage such complex systems effectively without a better understanding of component interactions and the fundamental practices, which may impact system performance as a whole. According to Gupta and Jat [28] crop residues kept on the soil surface function as mulching material, preventing soil moisture loss from evaporation and maintaining a moderate range of soil temperature. Crop residues, thus, can act as a readily decomposable source of soil organic matter and at the same time, they may contain undesired pest populations. The zero-tillage system affects the depth of root penetration and their distribution in soil layers, which in turn affects the intake of water and nutrients as well as the cycling of minerals. Moreover, no-tillage and maintaining surface crop residues improve resources gradually, with benefits emerging overtime.

Often, increases in yield are not seen in the early years of adopting conservation agriculture. It is essential to understand the dynamics and interactions of biological, chemical, and physical processes. Therefore, it is important to know about conservation agriculture as a system and design strategies for its management, and research in conservation agriculture requires a long-term perspective.

7.2 Technological Challenges

The implementation of conservation agricultural techniques in different farming conditions is a significant barrier. These challenges are related to the development, adoption, and standardization of farm machinery for crops owing to crop harvesting that causes the least amount of soil disturbance.

7.3 Site Specificity

The primary barrier to the widespread adoption of conservation agriculture is the site-specific information [25]. Strategies for conservation farming systems will need to be extremely site-specific. Knowledge gained across the sites will help to understand why some technologies or practices work well in a few circumstances but not in others. The entire learning process will boost the establishment of the base of foundational knowledge for sustainable resource management.

8. CONCLUSION

Conservation agriculture emphasizes sustainable crop production, conservation of resources, and soil health, and it is a necessary deviation from traditional agricultural practices. This strategy demands better scientific ability, strong farmer alliances, and efficient knowledge-sharing systems. By integrating such components conservation agriculture, especially in rainfed areas, can reverse environmental degradation, lower the cost of cultivation, and improve agricultural productivity and sustainability. Thus, the primary objective in ensuring long-term agricultural sustainability and production is to embrace and promote conservation agriculture. India can ensure more competitive, sustainable and efficient farming practices that benefit both the present and future generations by prioritizing the concept of conservation agriculture.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during the writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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