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CONSERVATION AGRICULTURE: PROTECTING SOIL FOR FUTURE GENERATIONS

Sudha Yadav*, Shruti Setia, Harjeet Singh, Sanjeev Kumar

Agronomy Section, ICAR- National Dairy Research Institute, Karnal, Haryana

**Corresponding author email*: sudhamehtaa@gmail.com

ABSTRACT

In 2024, India's population reached 1.44 billion, growing at 0.92%, placing immense pressure on agriculture to meet food demands amid resource constraints inherited from the Green Revolution. Climate change further threatens food security by intensifying stress on land under intensive cultivation. Conservation agriculture (CA) offers a sustainable pathway by improving soil health and productivity through minimal soil disturbance, permanent soil cover, and diversified crop rotations. However, CA is knowledge-, machinery-, and herbicide-intensive, requiring strong institutional support. Widespread adoption demands coordinated efforts from farmers, researchers, and policymakers, particularly in arid regions, to achieve long-term agricultural sustainability.

KEYWORDS: Crop residue, greenhouse gases, soil health, sustainable agriculture, zero tillage

INTRODUCTION

The Green Revolution of the 1960s resulted in enhanced agricultural output and the eradication of significant foodgrain shortages in India. Green revolution primarily involved growing of improved varieties of rice and wheat, use of high doses of chemical fertilizers and other agrochemicals, and intensive irrigation facilities. This was also accompanied by the other cultivation methods, which are maximum tillage, clean cultivation with removal of crop residues and residue burning, crop rotations mostly involving cereals, and the elimination of fertility-restoring leguminous plants and oilseed crops in the highly productive Indo Gangetic plain zone of the country. However, the transformation of 'traditional animal-based subsistence farming' to 'intensive chemical- and tractor-based modern agriculture' has led to a raised issues questioning sustainability of system. The implementation of these technologies has resulted in diminished resource use efficiency, deteriorating soil health, eutrophication of ponds, lakes and other water sources, increasing cost of production, air pollution and reduced profitability.

Major concern nowadays primarily in Indo-Gangetic Plains (IGP) is ignition of fossil fuels and residue burning and puddling for the rice cultivation leading to increased emission of greenhouse gases (GHGs), leading to climate change and global warming. Conservation agriculture (CA) is a new model in resource management for mitigating the problems associated with these modern cultivation practices. It is a comprehensive strategy for enhancing soil health and productivity. In order to prevent biological disruption, CA is known to optimize the use of external inputs (agrochemicals), decrease tillage, and improve biological and natural processes both above and below ground. All system components work better in CA systems, and plants are stronger, efficient, and resilient.

PRINCIPLES OF CONSERVATION AGRICULTURE

1. Minimum soil disturbance through no-tillage or reduced tillage: though zero-till is ideal, CA can involve controlled tillage where no more than 20-25 percent of the soil is disturbed.
2. Permanent maintenance of soil mulch by retaining crop residues or cover crops on the field: A minimum of 30 percent permanent organic soil cover is maintained as per CA definitions.
3. Diversification of cropping systems through proper crop rotation: crop rotation and intercropping using legumes are recommended.

Conservation agriculture is an integrated approach, requiring high knowledge and site-specific adaptation. The CA technologies are essentially herbicide-intensive, machine-intensive, and knowledge-intensive. It, therefore, requires expertise and resources for wide adoption. Policy makers, researchers, and farmers. must adopt a different perspective in order for adoption to be more widespread. Tremendous efforts will be needed to convince farmers to adopt Conservation Agriculture, specifically in dry regions. It is particularly encouraging that the CA Global Community at the 8th World Congress on Conservation Agriculture set a notional goal of transforming 50% of the global cropland area into CA by 2050.

KEY PRINCIPLES OF CONSERVATION AGRICULTURE

Core practices of conservation agriculture (CA) activate a range of interlinked physical, chemical, biological, and hydrological processes that help revive and sustain the health and functionality of soil systems (Anderson, 2015). CA along with complementary agricultural strategies- like integrated management of crops, soils, nutrients, water, pests, energy, labour, and farm machinery to enhanced productivity, improved ecosystem services, and higher efficiency and sustainability across various land-based agricultural systems.

The following ecological improvements are made possible by key principles of conservation agriculture: they are regenerative, increase the potential for land productivity, and allow any modern or modified traditional genotype to operate at its best phenotypically.

- **Continuous no or minimum mechanical soil disturbance**. Sowing of plants directly into untilled soil and zero-till weeding using herbicides preserves soil organic matter; promotes soil biological processes; improves soil structure and porosity and overall soil health; and enhance productivity, system efficiency, resilience, and ecosystem services.

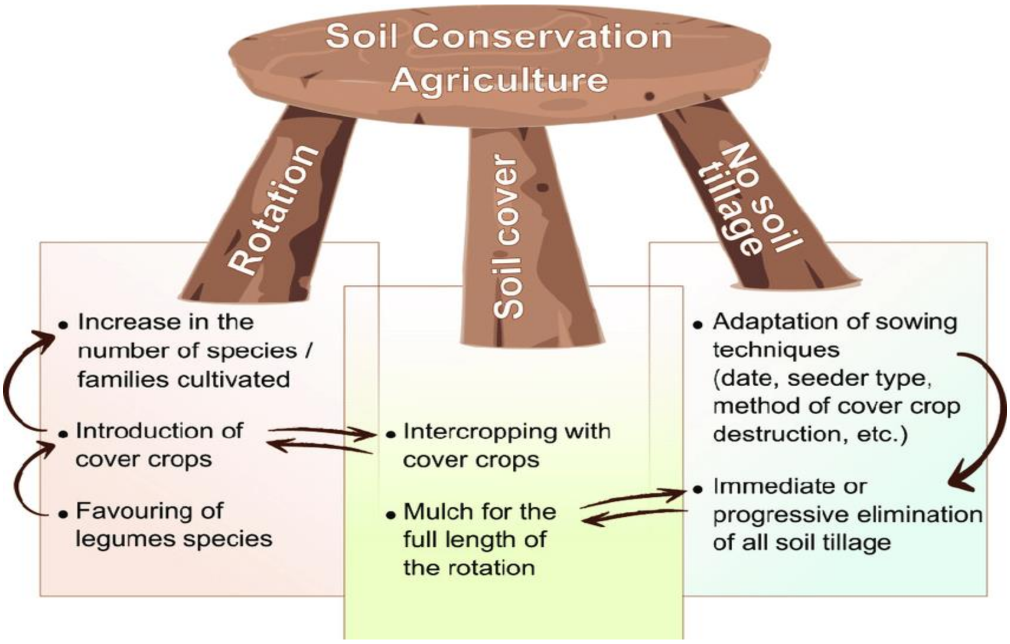

Fig: Components of Conservation Agriculture (Chabert, A. (2018).

- **Permanent maintenance of biomass mulch soil cover.** Crop residues, such as stubble, and cover crops are retained on the soil surface for soil conservation; increasing soils ability to store water and nutrients; incorporation of organic matter and carbon into the soil improving soil's microbial activity and enhanced soil health, enhances soil structure; help in integrated weed, pest, and nutrient management; and boost ecosystem services, productivity, system efficiency, and resilience (Farooq *et al*., 2022).
- **Diversification of crop species**. Crop diversification like crop rotations, associations, and sequential cropping with maintains soil's fertility and nutrient balance is adopted. This helps in soil organic matter buildup and increasing system productivity, efficiency and sustainability. Crops may be annuals, perennials like trees, nitrogen-fixing legumes, and pasture, as appropriate, including cover crops. Scientific and empirical evidence from around the world supports the earlier contribution.

BENEFITS OF CONSERVATION AGRICULTURE

AGRONOMIC BENEFITS

Adoption of conservation agriculture (CA) significantly improves soil productivity and crop performance. The retention and incorporation of crop residues increase soil organic matter content, initially in the surface layers and gradually in deeper soil horizons. Enhanced organic matter improves fertilizer-use efficiency, soil water-holding capacity, aggregation, and cation exchange capacity, thereby strengthening the physical, chemical, and biological health of soils. Conservation agriculture also improves soil structure through greater aggregate stability and promotes effective soil and water conservation.

ENVIRONMENTAL AND SOIL HEALTH BENEFITS

Conservation agriculture enhances soil microbial activity and biodiversity by increasing organic inputs. Surface residues protect the soil from the impact of raindrops, reducing crust formation, runoff, and erosion while increasing water infiltration. Residue cover also acts as a barrier to wind and water flow, slowing evaporation and conserving soil moisture. Additionally, CA improves air and water quality by minimizing nutrient losses and contributes to climate change mitigation through carbon sequestration (Teng et al., 2024).

CHALLENGES OF CONSERVATION AGRICULTURE

Conservation agriculture is a holistic approach for growing crops which requires an innovative system perspective to deal with diversified, flexible and context specific needs of technology and their management. So, more Research and Development will require for various distinctive features to address the challenge. Among them are:

(a) **Understanding The System** Conservation agricultural is more complicated as compared with conventional system. The primary barrier to the CA system's widespread adoption has been site-specific knowledge. It will be extremely difficult to manage these systems effectively in terms of understanding the fundamental procedures and component interactions that drive the overall system performance. For example, surface-maintained crop residues act as mulch and so reduce soil water losses through evaporation and maintain a moderate soil temperature. However, at the same time crop leftovers represent an easily decomposable supply of organic matter and could harbour undesired pest populations or affect the system ecology in some other way. No-tillage systems will affect the root system's distribution and penetration depth, which will affect the uptake of nutrients and water as well as the cycling of minerals.

Therefore, it is necessary to acknowledge conservation agriculture as a system and create management plans (Bhan & Behera, 2014).

(B**) Building A System and Farming System Perspective**– A system viewpoint is established working in conjunction with farmers. A core group of scientists, farmers, extension workers and other stakeholders working in partnership mode will therefore be important in developing and promoting innovative technologies. This differs slightly from traditional agricultural R&D in that resources are allocated and research goals are determined within a framework, with minimal focus on establishing connections and forming alliances with partners in related disciplines.

(C) **Technological Challenges**– Although the fundamental ideas of conservation agriculture, such as surface managed crop wastes and no tillage, are widely known, the main obstacle is implementing these techniques in different farming contexts. These issues include the creation, standardization, and uptake of agricultural equipment for minimally disturbing the soil during planting, as well as the advancement of crop harvesting and management systems.

(D) **Site Specificity**– Although conservation agriculture system adaptation will be very site specific, learning from different sites will be a valuable approach to understand why some technologies or practices work well in one set of circumstances but not in others. Building a knowledge base for sustainable resource management will be accelerated by this learning approach.

SUSTAINABLE SOLUTIONS

In order to support and sustain the spread and widest benefit sharing from the application of all rainfed and irrigated CA systems, the science that supports the CA paradigm must be established as a regular part of the concern for managing a dynamic and innovative knowledge system that can help to generate new knowledge, new technologies, and new enabling social and institutional arrangements. This must involve the immediate restructuring of both public and private research, education, and development organizations toward the acceptance and dissemination CA.

- It is important to recognize the harm that both traditional and modern tillage-based agriculture have produced around the planet. It is necessary to stop and reverse the rate of land deterioration and abandonment in order to restore them using the CA's principles.
- The agriculture industry as a whole has tremendous prospects to use CA-based agricultural land and landscape management to provide its entire spectrum of ecosystem services, including providing, regulating, supporting, and cultural. It is the duty and responsibility of farmers, land managers, the

food and agricultural service sectors, policymakers, and supporting institutions to minimize or prevent the degradation of agro-ecosystems and ecosystem services and to restore them to their ecologically desirable state.

- Subsidy-based agricultural development tactics must be discontinued in favour of incentive-based agricultural growth. Farmers should receive recognition and incentives for implementing CA systems and practices that benefit society through ecosystem services.
- The creation of national CA associations must be encouraged in order to support and create farmer-driven procedures for CA adoption and dissemination, as well as to get and draw in the institutional support needed to sustain an innovative and competitive CA-based food and agriculture industry.
- In order to monitor CA adoption, its impact on agriculture and rural development, and to encourage the mainstreaming of CA on farms and in all auxiliary public, private, and civil sectors, multi-stakeholder national platforms for CA development and dissemination in the Asia-Pacific region must be established.

CONCLUSION

Conservation agriculture (CA) represents a key pathway toward sustainable agricultural development by promoting efficient resource use and long-term ecosystem health. Its benefits operate across multiple scales: at the nano- and field level, CA improves soil structure, organic matter, and biological activity; at the micro-level, it reduces input use, lowers production costs, and enhances farm profitability; and at the macro-level, it contributes to poverty reduction, food security, and climate change mitigation. Realizing these benefits at scale requires coordinated global action involving international institutions such as the World Bank and the Food and Agriculture Organization of the United Nations. The establishment of supportive legislation at national and regional levels is essential, followed by integration into a global CA platform. Additionally, increased international funding is needed to strengthen research, extension, and awareness, particularly among smallholder farmers in tropical regions. By reducing resource degradation, lowering cultivation costs, and improving efficiency, conservation agriculture can drive productive, competitive, and environmentally sustainable farming systems. “Conserving resources while enhancing productivity” should therefore guide future agricultural policy and practice.

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