Prospects and Way Forward in Conservation Agriculture

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The global population is projected to experience a notable increase, moving from its current 8 billion in 2022 to an estimated 9.7 billion by the year 2050, as indicated by the United Nations in 2022. This surge in human numbers presents a dual challenge on a global scale, particularly in the South Asian region (Falcon *et al.,* 2022). The challenge entails the necessity to enhance production to meet the escalating demands for food due to the growing populace while concurrently reducing the ecological impact. This complex situation is compounded by the ongoing depletion of natural resources, exemplified by the diminishing per capita availability of both land and water resources. Furthermore, the confluence of factors such as climate change and water scarcity has rendered agricultural production systems acutely vulnerable, significantly affecting the livelihoods of millions in this geographical area. Notably, the agricultural sector stands responsible for approximately 30% of the overall greenhouse gas emissions, encompassing CO2, N2O, and CH4. Coincidentally, this sector finds itself in the crosshairs of the repercussions stemming from a changing climate. Historically, conventional intensive agricultural practices have succeeded in attaining production targets. However, their success has come at a steep cost, leading to the degradation of natural resources and thereby imperiling the future potential of agricultural productivity. This mode of agriculture has been implicated in the decline of soil organic matter, deterioration of soil structure, diminished rates of water infiltration, erosion-related predicaments, inefficient utilization of water resources, and a contribution to the global warming predicament (Wassie *et al.,* 2020).

The cumulative impact of these multifaceted challenges underscores the imperative need to expeditiously explore and implement strategies that can effectively counteract the threats posed to the agricultural sectors of West Africa and India. In 2008, the Food and Agriculture Organization (FAO) introduced the concept of Conservation Agriculture (CA) as a means of establishing a resource-efficient framework for crop production. This innovative approach is designed to tackle the contemporary challenges encountered by agriculture.

Conservation Agriculture is envisaged as a means to reverse the degradation of natural resources, thereby steering agricultural practices toward sustainable trajectories. The central focus on sustainability assumes paramount importance in the contemporary agricultural landscape, and in this context, CA emerges as a robust and viable path forward. The shift from conventional practices to CA methodologies holds considerable promise in fostering the vitality of soil ecosystems, chiefly through the enhancement of soil organic carbon (SOC), bolstering soil aggregation, augmenting water infiltration capacities, and curbing soil erosion (Hajer *et al.,* 2016).

The merits of Conservation Agriculture extend beyond these ecological aspects. The approach embodies a potential strategy for both mitigating and adapting to climate change, effectively functioning as an adaptive mechanism in the face of the ever-evolving climate patterns. Moreover, CA is particularly poised to benefit African agriculture by bolstering crop productivity, a region grappling with challenges ranging from low yields and soil health issues to capital constraints and labor shortages. Its adaptability across diverse agricultural production systems and farm types positions CA as an inclusive approach.

Over the course of the past three decades, Conservation Agriculture has emerged as a cornerstone for transitioning toward the sustainability of intensive agricultural systems on a global scale.

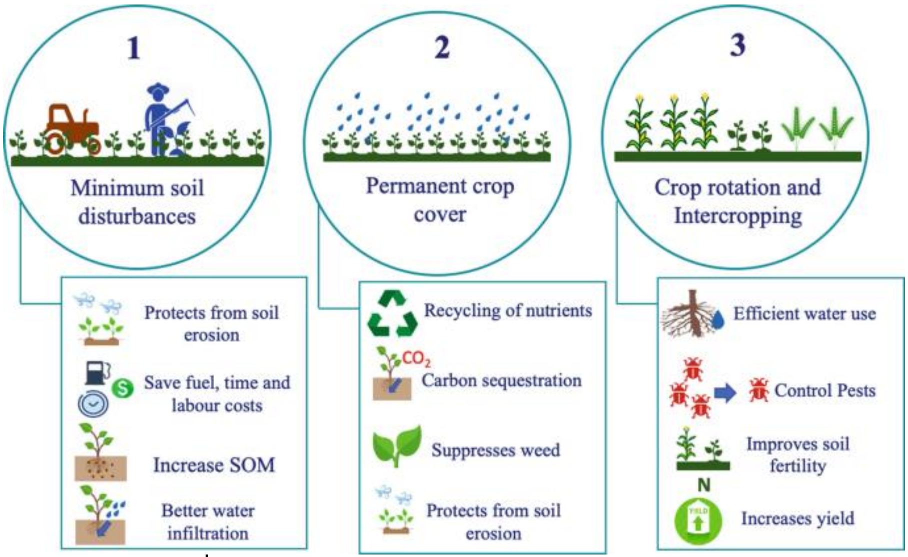

Figure: 1 Three principles of conservation agriculture (Naorem, 2021)

Conservation agriculture conserves natural, biodiversity and labor. It increases available soil water, reduces weeds, reduces heat and drought stress, and builds up soil health in the longer term.

Conservation agriculture, as defined by the United Nations' Food and Agriculture organisation (FAO), is "**a farming system that promotes maintenance of a permanent soil cover, minimum soil disturbance, and diversification of plant species**.

What are the principles of conservation agriculture?

CA relies on the simultaneous application of three core principles (also called as three pillars) which are linked to each other in a mutually reinforcing manner:

1. Minimum soil disturbance or no tillage

2. Permanent organic soil cover through crop residues or other cover crops

3. Diversification of crop species through the use of crop rotation or/ and intercropping (Naorem, 2021)

Challenges in agriculture and their solution

Conventional agriculture relies on intensive tillage to achieve several objectives, including soil loosening, weed control, enhanced nutrient release for crops, and alteration of soil water movement and aeration patterns. However, this method has been identified as a contributing factor to the gradual reduction of soil organic carbon (SOC), primarily due to accelerated oxidation and erosion resulting from the excessive breakdown of soil aggregates. Notably, the widespread adoption of conventional tillage (CT) practices has resulted in significant soil loss through erosion, particularly exacerbated by wind and water actions, leading to desertification in numerous developing countries, including various parts of Africa.

Furthermore, conventional agriculture practices often involve the removal or burning of crop residues, which introduces pollution through greenhouse gas (GHG) emissions and the loss of valuable plant nutrients. Inadequate crop rotation strategies have also worsened the situation in multiple countries. The extensive use of heavy machinery in conventional tillage further contributes to GHG emissions and soil compaction. Within the context of smallholder agriculture in West Africa, CT among farmers with access to draft animals involves employing animal-drawn plows for primary tillage, followed by harrowing and cultivation during the cropping season for weed control. On the other hand, for smallholders lacking draft animal power, CT continues to rely on manual hoe cultivation in sub-Saharan Africa.

However, conventional agricultural practices are struggling to keep up with the growing demands imposed by expanding human and livestock populations. Unlike conventional systems where soil tillage is a necessary step, Conservation Agriculture (CA) excludes tillage from its strategy. Instead, CA emphasizes retaining crop residues on the soil surface combined with no tillage (NT), initiating processes that promote improved soil quality and overall resource enhancement. A gradual shift occurred globally over the course of several decades, moving away from the traditional belief that extensive plowing was the sole means of enhancing farm productivity. The recognition that significantly reduced or zero tillage (ZT) was more advantageous marked a pivotal change in perspective.

To ensure both food security and environmental sustainability, there is an urgent imperative to embrace and implement CA-based best practices across various agricultural aspects. CA functions as a sustainable management system applicable to both irrigated and rainfed regions. It does not enforce rigid rules, but rather offers adaptable guidelines for cultivating crops in a more sustainable manner, allowing farmers to tailor CA practices to local conditions such as soil type, rainfall patterns, and financial capacities.

Adopting CA practices involves retaining crop residues on the soil surface alongside ZT, catalyzing processes that lead to enhanced soil quality and overall resource enrichment. However, transitioning to CA necessitates a comprehensive paradigm shift from conventional agriculture. This shift encompasses the management of crops, soil, water, nutrients, weeds, and farm machinery. CA introduces a profound alteration in the management of soil systems and cropping system design, subsequently triggering significant changes in required field operations and mechanization approaches.

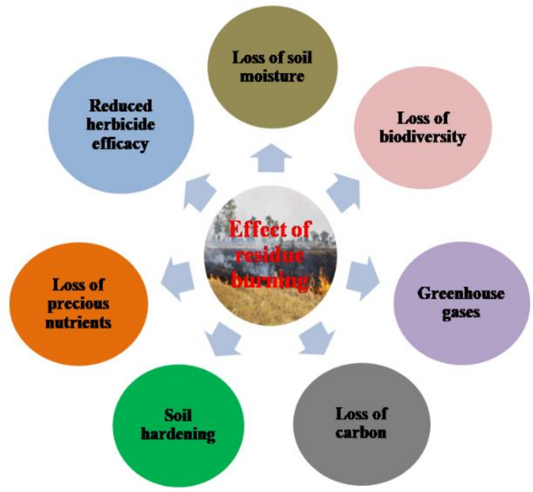

Figure: 2 Negative impacts of residue burning on soil health and environment (Kumar *et al.*, 2023)

Goal of conservation agriculture

- Conservation agriculture aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs.
- It contributes to environmental conservation as well as to enhance and sustain agricultural production.
- It can also be referred to as resource efficient or resource effective agriculture.
- It can also maintain many sustainability issues, such as declining water resources, degrading soil health, and environmental degradation which further responsible for low land productivity (Pokharel *et al*, 2018).

Machinery in conservation agriculture:

Machinery and agriculture tool that supports conservation agriculture usually with minimum or zero tillage and management of crop residue. Agricultural machinery or tools, which support CA generally, refer to the cultivation with minimum or zero tillage and management of crop residues. Minimum tillage is aimed at reducing tillage to the minimum necessary that would facilitate favorable seedbed condition for satisfactory establishment of crop.

Success story of conservation agriculture:-

1. Diversified Cropping Systems: The introduction of conservation agriculture led to a shift from the traditional rice-wheat cropping pattern to diversified cropping systems that include pulses, oilseeds, vegetables, and fruits. This diversification enhances soil health and reduces the risk of pest and disease outbreaks.
2. No-Till Farming: No-till or reduced tillage practices were promoted to minimize soil disturbance and maintain soil cover. This helps in reducing erosion, improving water retention, and enhancing overall soil structure.
3. Residue Management: Farmers were encouraged to retain crop residues on the field after harvest. These residues act as natural mulch, protecting the soil from erosion, conserving moisture, and promoting soil microbial activity.
4. Water Management: Conservation agriculture practices promote efficient water use through improved soil structure and reduced evaporation. This is particularly significant in a region facing water scarcity challenges.
5. Yield Increases: Over time, farmers who adopted conservation agriculture reported significant increases in crop yields. This was attributed to improved soil health, better water management, and diversified cropping systems.
6. Cost Reduction: By reducing the need for plowing and decreasing chemical inputs, farmers practicing conservation agriculture have been able to reduce their production costs.
7. Environmental Benefits: The adoption of conservation agriculture practices has led to reduced chemical runoff and pesticide use, contributing to a healthier environment.

The success of conservation agriculture in Punjab has sparked interest in other parts of India facing similar challenges. Farmer field schools, extension services, and collaborations between agricultural universities, NGOs, and government agencies have played a crucial role in disseminating knowledge and encouraging adoption.

It's important to acknowledge that the transition to conservation agriculture may face challenges related to farmer knowledge, equipment availability, and initial costs. However, the case of Punjab demonstrates that with proper training, support, and long-term commitment, conservation agriculture can lead to sustainable farming systems that benefit both farmers and the environment.

Conclusion

The impending global population increase presents a critical challenge for agriculture, particularly in regions like South Asia. Conservation Agriculture (CA) emerges as a sustainable solution, with its core principles of minimum soil disturbance, permanent organic soil cover, and crop diversification. CA addresses the detrimental impacts of conventional practices, fostering improved soil health, water management, and climate resilience. The success story in Punjab exemplifies how CA can enhance yields, reduce costs, and promote environmental well-being. While challenges persist, the transformative potential of CA, supported by education and collaboration, offers a promising path forward for ensuring food security and ecological sustainability in the face of evolving global dynamics.

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Table. 1 Difference between conservation agriculture and conventional agriculture

Sr No.	Conservation Agriculture	Conventional Agriculture
1	No compaction in the field because Controlled traffic in CA	Poor root growth and poor yields and lower earnings due to free-wheeling of farm machinery, increased soil compaction in crop area.
2	Crop diversification and more effective crop rotation	Mono cropping/culture, less efficient rotations
3	Infiltration rate of water is high because less compaction of field found in CA	Runoff and soil erosion are most common due to low water infiltration and inefficient use of fertilizers leading to pollution.
4	Permanently soil covered with surface retention of residues	Bare soil surface due to residue burning or removal
5	Minimum tillage or zero tillage reduce the tillage operation in field	Heavy soil erosion due to intense mechanical tillage operations
6	Conserve the natural resource with minimum soil disturbance	Degrade the natural resource by cultivating land, using science and technology

Table 2. Machinery used for retaining the crop residue on soil surface along with their advantages and limitations.

Machinery	Description	Advantage	Limitations
Zero-till Drill	It is a passive type seeding machine with/without a fertilizer drilling mechanism. It is usually fitted with inverted T-type furrow openers.	Used for seeding the crops in an untilled field with/without anchored residue.	Clogging of furrow openers with loose residue • Poor traction of seed metering drive wheel due to the presence of loose straw • Non-uniform depth of seed placement due to frequent lifting of the implement under heavy residue conditions • Higher infestation of dicots weeds
Mulcher	It is an active type residue chopping machine, which cuts the residue into small pieces.	After mulching operation, chopped stubbles can be incorporated into soil using rotavator or disc harrow followed by crop sowing with zero-till drill.	Requires additional field operation
Straw management system (SMS)	It is an optional attachment, which can be integrated with a combine harvester. It chops the crop straw into small pieces and distributes it on the soil surface.	In SMS operated field, chopped residue can either be retained on the surface or mixed with soil easily. Chopping crop straw into small pieces reduces the clogging of blades/furrow openers of seeder or planter.	Not suitable for small land holding. Increased fuel consumption of about 2.5–3 l h-1 during combine operation
Happy Seeder	It is an active type seeding machine having flails at the front and seeding attachment at rear.	It can be used for seeding the crops in untilled field with anchored and loose residue.	Does not work efficiently under moist residue condition • Low operation window of the machine • Low field capacity compared with conventional seed drills
Rotary Disc Drill	It is an active type seeding machine having Soil Razor discs at the front and seeding attachment at rear.	It can be used for seeding the crops in untilled field with anchored and loose residue in rice-wheat and sugarcane-wheat cropping systems. Works on wet residue	Seed covering issue under dry soil condition

(Kumar *et al.*, 2023)

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