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A Review on Conservation Agriculture: Challenges, Opportunities and Pathways to Sustainable Farming

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This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A cutting-edge kind of sustainable agriculture, conservation agriculture (CA) involves reducing tillage, maintaining constant soil cover, using a variety of cropping techniques, and effectively utilizing the resources at hand. For instance, CA in India has made impressive strides in the past 20 years, particularly in the Indo-Gangetic plain's rice-wheat rotation. There are many disadvantages that limit the use of CA, despite its many benefits, which include cost savings, improved crop production, water and nutrient conservation, and environmental advantages. Numerous issues include the lack of appropriate seeders for small and medium-sized farmers, agricultural leftovers that compete with livestock feed for CA, burning of these residues, which destroys soil organic matter, a lack of labor, and a general bias in favor of traditional tillage. Therefore, in order to effectively promote CA, we advise immediate policy development and planning. CA reduces soil erosion, preserves SOM, suppresses weeds, conserves soil moisture, avoids compaction, promotes good soil structure, and improves biological processes and biodiversity both above- and below-ground. This article looks at the new problems that are coming from traditional farming practices, as well as the constraints, opportunities, regulations, and areas that need more study in order to expand conservation agriculture in India. This emphasizes that for conservation agriculture to be successfully implemented, governments, researchers, farmers, and other groups must collaborate. Therefore, we have the ability to get past these obstacles and reap the rewards of this kind of farming.

Keywords: Conservation agriculture (CA); minimum tillage; climate change; Climate Smart Agriculture (CSA) and Climate Resilient Agriculture (CRA).

1. INTRODUCTION

Concern over the productivity of soils and the broader environmental effects of traditional agricultural methods, particularly the tilling of soils with a plow, disk, or hoe, is developing in many parts of the world. Conservation Agriculture (CA) is a farming system that can prevent losses of arable land while regenerating degraded lands. It promotes maintenance of a permanent soil cover, minimum soil disturbance, and diversification of plant species. Governments and farmers are now investigating alternate agricultural techniques that preserve soil structure and productivity as a result of this. The use of cover crops, long crop rotations, and straw mulch are all clear and growing alternatives to conservation tillage, whether it be minimum- or no-till. The Food and Agriculture Organization of the United Nations (FAO), the European Conservation Agriculture Federation (ECAF), and others have recently packaged and marketed these well-known methods under the umbrella of "conservation agriculture." Agriculture is at a pivotal point in a time marked by problems such as climate change, depleting natural resources, and a fast-growing global population. It is now more important than ever to produce enough food to support a populous planet while simultaneously preserving the fragile balance of our planet's ecosystems. Conservation agriculture emerges as a source of hope in this story. a strategy that offers a path to using resilient farming methods. The main objective of conservation agriculture, according to its proponents, is to maximize the use of agricultural resources (compared to conventional agriculture) by managing available soil, water, and biological resources in an integrated manner that minimizes the need for outside inputs (FAO, 2001). Conservation agriculture, which combines rotations with permanent soil cover (mulch) and minimal soil disturbance (no-till, NT), is a new agricultural management approach that is becoming more and more well-liked worldwide. Conservation agriculture, or CA, is a major change in how we perceive and engage with the agricultural landscape rather than a farming method. It represents a set of values that uphold equilibrium, enhance soil health, and guarantee long-term food security without endangering the environment (Sangar & Abrol, 2005). According to this strategy, farming methods that damage the environment and consume excessive amounts of resources must be abandoned. Rather, it promotes a regenerative strategy. The concepts, foundation, and success of conservation agriculture, as well as its worldwide influence and potential to revolutionize the agricultural sector toward a more sustainable future, will all be thoroughly examined in this chapter. We ask you to join us as we explore the field of conservation agriculture, where innovation and age-old wisdom combine to create a path that balances environmental health with human needs. Soil carbon is regarded as the "black gold" of crop production. According to reports, up to 78 billion metric tons of carbon dioxide were lost as a result of automation. (Lal, 2004). CA systems are widely adaptable in different ecologies (Jat et al*.,* 2014).

2. PRINCIPLES OF CONSERVATION AGRICULTURE (CA)

CA has been seen as a paradigm shift in the direction of sustainable farming. It is based on the idea that many traditional farm management practices have harmed biodiversity, ruined soils, and increased CO_2 emissions, putting farming's long-term viability in jeopardy. However, the main goal of conservation agriculture, which is based on a number of principles, is to preserve and replenish the natural resources that are essential to the success of any farming endeavour. But it also seeks to provide a sufficient crop production (Jat *et.al.,* 2011).

The basic principles of Conservation Agriculture as follows:

Minimal Soil Disturbance: On the other hand, the CA causes little or no disruption. These include reducing practices like ploughing that shift structures and release carbon, which leads to soil erosion. Because CA preserves the organic matter and soil structure, water and nutrients are better retained and made available. Examples of soil erosion and land deterioration can be found throughout the US's westward Euro-American settlement (Dabney et al*.* ,2012). Minimal soil disturbance is a key principle of conservation agriculture (CA) that involves reducing or avoiding tillage practices. This can be achieved through direct seeding, also known as no-till or zero tillage farming.

Fig. 1. Agricultural soil

Here are some benefits of minimum soil disturbance:

- **Soil health**: Improves soil structure, organic matter, and fertility. It also reduces soil compaction and erosion.
- **Biodiversity**: Improves food supplies for birds, insects, and small mammals. It also promotes higher biodiversity below and above the soil surface.
- **Energy use**: Reduces the amount of energy used by agricultural machinery.
- **Water**: Improves water infiltration and drainage.
- **Pests and diseases**: Controls the build-up of pests and diseases through the simultaneous build-up of natural antagonists. This can reduce the need for pest control measures.

Permanent Soil Cover: Maintaining the soil throughout the year with crop residues, cover plants, or manure cover is a key component of CA. While keeping weeds under control, this acts as a canopy to guard against soil erosion and moisture loss. It does this to draw in healthy soil organisms and improve the soil's organic matter (Tanner, 2012). Permanent soil cover is a farming practice that involves keeping the soil covered with cover crops or residue year-round. It's a key principle of conservation agriculture, which aims to improve soil health and sustainability. Cover crops can be planted between main crops, or interceded. They can be legumes, cereals, or other crops. The type of crop and how it's managed determines how much residue is produced, how long the cover remains, and the soil cover generated. For example, grain species decompose more slowly than legumes.

Fig. 2. Productivity

Benefits of permanent soil cover include:

- **Soil protection**: Protects soil from the damaging effects of rain, sun, wind, and extreme weather events

- **Improved soil quality**: Improves soil fertility, structure, and biological activity
- **Reduced erosion**: Helps manage soil erosion and reduce sediment runoff
- **Increased biodiversity**: Increases biodiversity in the agro-ecosystem and provides a habitat for wildlife
- **Carbon sequestration**: Turns agricultural land into a carbon sink
- **Reduced GHG levels**: Helps reduce greenhouse gas levels

Crop Diversity and Rotation: Crop rotation and diversification are essential components of conservation agriculture. Growing different crops at different periods also disrupts the cycles of pests and diseases, restores depleted soil nutrients, and improves the soil's general health. This type of diversification also brings biodiversity to life by creating room for different organisms both inside and outside the farm (Sangar & Abrol, 2005). Crop diversity and rotation are important strategies in conservation agriculture that can improve soil health, reduce the risk of pests and diseases, and increase the efficiency of farming systems. Diversified crop rotation (DCR) improves the efficiency of farming systems all over the world. It has the potentiality to improve soil condition and boost system productivity. Improved soil attributes such as increased soil water uptake and storage, and a greater number of beneficial soil organisms, may improve yield tolerance to drought and other hard growing conditions in a variety of crop rotations. Crop rotations with a variety of crops benefit the farmers, reduce production risk and uncertainty, and enhance soil and ecological sustainability. Farmers may be able to diversify their sources of income by adopting diversified crop rotations. Furthermore, because of the distinct structure, function, and relationship of plant community with soil in DCR, it contributes to the long-term development of soil health by decreasing insect, weed, and disease incidence and increasing the physical and chemical structure of the soil. DCR is becoming more popular approach for maintaining sustainable crop production.

Fig. 3. Crop diversity and rotation

Conservation of Natural Resources: CA emphasizes resource optimization and is very resource-driven. Along with reducing the use of synthetic chemicals and selecting crops that are appropriate for a certain temperature zone, efficient water management is also required. By doing this, CA highlights how important cost-cutting and environmental preservation are to long-term economic viability (Duncan and Burns, 2012). In general, conservation agriculture aims to create an agricultural system that is affordable, sustainable, and ecologically benign. Furthermore, it stabilizes the soil, increasing crop yields and decreasing susceptibility to weather patterns. Additionally, it can help mitigate climate change by reducing greenhouse gas emissions from typical farming practices and sequestering carbon in the soil. Conservation agriculture (CA) is a sustainable farming system that helps conserve natural resources and the environment in a number of ways. Other methods of conserving natural resources include: Reforestation, Rainwater harvesting, and treating industrial effluents.

3. HISTORY AND ADAPTATION OF CONSERVATION AGRICULTURE

CA is a farming technique that has evolved throughout time to address certain issues related to agricultural operations. It is founded on three main pillars: (A) reduced soil tillage, (B) permanent soil cover and (C) mixed cropping (Derpsch, 2004).

Here is a brief overview of the history and adaptation of Conservation Agriculture: -

1. **Historical Background:** Preservation Indigenous knowledge and a variety of sustainable traditional farming methods form the foundation of agriculture. However, the 20th century saw it take on its current name and form. This is a chronology of historical events:

1940s - 1950s: During this time, crop leftovers and less tillage gained popularity. Researchers like Harry Young Jr. (USA) advocated for these approaches.

1960s - 1970s: In addition to encouraging intense tillage techniques, the green revolution expanded the use of high-yielding crop types to increase food production. As a result, incidents of soil erosion and deterioration started to raise concerns. Degradation is mostly caused by inadequate land management (Paroda, 2009).

1980s - 1990s: The current CA concepts began to take shape. Among other groups, CIMMYT and FAO advocated for crop rotation, mulching, and minimum tillage.

2. Adaptation and Development: Certain areas, cropping methods, and environmental requirements have made conservation agriculture appropriate (Gardner et al*.,* 2012).

Important modifications consist

- **Minimum Tillage:** CA encourages no-till or minimal tillage farming, which reduces soil loss and causes little disturbance of the soil. The method has been modified to fit various farming styles, such as large-scale mechanized farming in wealthy nations and smallholder agriculture in developing nations. Minimum tillage is a soil conservation system like strip-till with the goal of minimum soil manipulation necessary for a successful crop production. It is a tillage method that does not turn the soil over, in contrast to intensive tillage, which changes the soil structure using ploughs. In minimum tillage, primary tillage is completely avoided and only secondary tillage is practiced to a small extent. Minimum tillage includes practices like minimum furrowing, use of organic fertilizer, use of biological methods to control pests, and minimum use of chemicals.
- **Mulch and Cover Crops:** In many climates and cropping systems, crop leftovers and cover crops have been used for generations to prevent soil erosion and promote soil health. Mulching and cover crops are both soil conservation practices that can help with erosion, water infiltration, and weed control in conservation agriculture. Mulching protects soil from raindrops, reduces evaporation, and checks weeds. Mulch can also help loosen heavy clay soils, making it easier for plants to grow. Slow down rainfall, provide a cover for base crops, and help control weeds. Cover crops can also improve soil porosity, organic matter, and biodiversity
- **Conservation Agriculture Machinery:** CA is made easier with the use of specialized tools like seed drills and no-till planters. Conservation agriculture is a farming system that aims to maintain soil cover, minimize soil disturbance, and diversify plant species. Farm machinery can include a wide range of equipment, from basic hand tools to large-scale automated machines. The purpose of these machines is to increase efficiency, productivity, and profitability in agricultural operations
- **Interplanting and Agro forestry:** CA is being used in some places to implement agroforestry and intercropping systems that improve sustainability and biodiversity. Combining multiple trees and crops in the same space, usually with no distinct arrangement. The practices of intercropping and agroforestry are widespread in many areas of world, with visibility of these multiple cropping systems increasing at the national and international levels.
- **Customization for Smallholders:** CA has been modified for smallholder farmers using locally accessible mulch materials and a hand-powered seed drill. Conservation agriculture is a farming system that aims to maintain a permanent soil cover, minimize soil disturbance, and diversify plant species

3. Global Spread and Adoption: Because conservation agriculture suggests solutions for issues like soil erosion, water scarcity, and climate change, its application has expanded globally. Several regions of the world, including Europe, Asia, Africa, and the North and South America, have used the system. Government policies, non-governmental groups, and international organizations have advanced CA through a variety of means, including research, capacity building, and financial incentives (Hagen (2004).

The determinants of Conservation Agriculture adoption: A new farming technique called conservation agriculture (CA) aims to boost food production while conserving land, water, and other environmental resources (Miner et al*.,* 2013). Conservation agriculture, therefore, aims to improve the use of agricultural resources through the combined management of soil, water, and biological resources. The adaptability of conservation agriculture is influenced by a number of factors:

1. **Soil Health Improvement:** In order to maintain the fertility and structure of the soil, CA recommends little ploughing. The apparent increases in soil health, which

result in higher yields with declining input costs, encourage farmers to embrace conservation farming (CA). Healthy soil is the foundation of productive, sustainable agriculture. Managing for soil health allows producers to work with the land- not against-to reduce erosion, maximize water infiltration, improve nutrient cycling, save money on inputs, and ultimately improve the resiliency of their working land.

2. **Water Conservation:** CA techniques help to conserve soil moisture and prevent water runoff by reducing tillage and crop residue cover. This is particularly crucial in areas with erratic rainfall or water scarcity (Sivakumar & Stefanski, 2011).
3. **Cost Savings:** Farmers can save money by using these strategies, which include reducing tillage, using less synthetic fertilizer and pesticides, and keeping crop residues. The majority of farmers that are considering ways to cut farming expenses will find that using CA techniques ensures that they will have lower input costs (Unger et al*.,* 2012).
4. **Enhanced Crop Yields:** In recent years, CA has been shown to boost crop yields, particularly in regions with poor soils. A primary motivation for many farmers to adopt CA is to guarantee higher yields, which can provide food security and revenue.
5. **Environmental Benefits:** In recent years, CA has been shown to boost crop yields, particularly in regions with poor soils. A primary motivation for many farmers to adopt CA is to guarantee higher yields, which can provide food security and revenue.
6. **Climate Resilience:** Some farmers are choosing more reliable practices, like drought and flood-resistant crops, as a result of climate change. (Sharma and others, 2015) One method for adjusting to climate change is CA, which deals with soil health and moisture conservation (Sidhu et al*.,* 2019). Climate resilience is the ability to prepare for, respond to, and anticipate the effects of climate change. These effects include rising sea levels, extreme temperatures, and more intense storms. Climate change is caused by long-term shifts in weather patterns and temperatures, which are mainly driven by human activities like burning fossil fuels.
7. **Government Support:** In order to encourage the implementation of CA, government policies and incentives like as subsidies, extension services, and trainings are essential. Some farms may find it more affordable to adopt CA techniques thanks to these policies (Cook, 2003). Environmental, social, and economic factors all have a significant impact on how well conservation agriculture is received. More farmers are probably going to use this sustainable farming practice as their awareness of its advantages grows.

4. CONSERVATION AGRICULTURE (CA) PRACTICES

CA is a farming method that supports soils, preserves the environment, and produces effective crop yields. This encompasses a variety of methods and tools designed to reduce soil disturbance, keep crop wastes in the fields, and support biological diversity. Bennett noted that "one man cannot stop the soil from blowing, but one man can start it (Egan, 2006). The following are some important technologies and practices based on conservation agriculture:

1. **No-Till Farming:** Soil disturbance-free sowing is known as "no-till" farming. Because of this, soil loss is reduced, soil structure is enhanced, carbon is retained, and soil health and water-holding capacity are improved (Barrett et al*.,* 1998).
2. **Crop Rotation:** Crop rotation is the practice of growing various crops in a particular order on the same patch. This enhances soil fertility, increases nutrient cycling, and reduces pest-disease cycles. Crop rotation is the practice of growing a series of different types of crops in the same area across a sequence of growing seasons. This practice reduces the reliance of crops on one set of nutrients, pest and weed pressure, along with the probability of developing resistant pests and weeds
3. **Mulching:** Applying mulch, such as agricultural waste or organic materials, to the soil's surface retains moisture, prevents weed growth, and adjusts soil temperature.
4. **Precision Agriculture:** In order to maximize resource application, minimize input waste, and enhance crop output, precision farming uses advanced technologies including remote sensing, unmanned aerial vehicles, and GPS. The

four principles of precision agriculture (PA) are the 4 R's: Right source, Right rate, Right time, and Right place. The 4R of Precision Agriculture - GeoPard Agriculture. PA is a farming management technique that uses information technology (IT) to ensure that crops and soil receive the exact amount of what they need to be healthy and productive. It can help to increase profitability, sustainability, and environmental protection

5. **Agro forestry:** Growing trees alongside crops can improve soil quality, help store carbon, and provide a variety of income streams, among other benefits.
6. **Conservation Tillage:** Conservation tillage minimizes soil exposure, hence conserving soil structure, and decreasing the amount of carbon released. Conservation tillage (CT) is a farming method that aims to reduce soil erosion and runoff by minimizing tillage and covering the soil with crop residue. CT is a widely adopted soil conservation method that can provide a number of environmental and economic benefits. While CT can provide many benefits, there are some potential disadvantages, including: Higher herbicide costs, More difficulty controlling certain weeds, and Slower warming of soils in the spring.
7. **Integrated Pest Management (IPM):** Holistic approach towards the reduction in use of chemicals pesticides in the environment by using techniques such as biological control and monitoring the pests.
8. **Drip Irrigation:** The drip irrigation system delivers water at the plant’s base hence reducing water losses, increasing water use efficiency, and lowering soil erosion.
9. **Terracing and Contour Farming:** These practices assist in achieving flat/semi-flat planting surface, thus slowing the water flow from sloping territories.
10. **Crop Residue Management:** Crop residues left in the farm after harvest are able to shield the soil against erosion.
11. **Alley Cropping:** It is a type of agriculture plantation known as alley cropping where trees are arranged in rows at intervals and allow crops to be cultivated on spaces therein. Forests help in providing timber and agricultural goods which improves the richness of the soil and also increases diverse revenue streams.
12. **Soil Conservation Structures:** Structures such as terraces check dams, or silt fences help control soil erosion and channel water in the field. For sustainable agriculture to be supported and production to be sustained for many years, nature-based conservation is essential

5. CROP YIELD AND PROFITABILITY IN CONSERVATION AGRICULTURE

By using ecologically friendly production techniques, conservation agriculture increases crop productivity and farmer returns. Here are several ways that CA affects crop profitability and productivity:

1. **Improved Soil Health:** These include techniques like cover crops and no-tillage farming, which enhance soil health by lowering erosion and increasing organic carbon and moisture-holding capacity. It is important to remember that crops grow more productively in good soils because they provide comparatively consistent and nourishing circumstances.
2. **Increased Water Use Efficiency:** These assist in helping to retain the soil moisture of California through practices like mulching, reduced tillage, and crop residue cover. Thus, such crops can survive dry spells leading up to greater and constant product supply.
3. **Enhanced Nutrient Management:** Soil testing will inform conservation agriculture which is geared toward precision fertilizer application. Fertilizers make crops grow bigger. The best part is that it helps save on the cost of the fertilizers by ensuring they have enough nutrients for optimal yield.
4. **Reduction in Production Costs:** CA processes such as less usage of machines, less intake of water, fuels, and chemicals lead to reduced production costs. It could have a big influence on how much of a profit is generated for a farmer and improve the cost benefits ratio. (Gathala et al*.,* 2013).
5. **Long-Term Sustainability:** Conservation Agriculture saves on the costs associated with soil restoration and erosion control. This protects the productivity of the farmland for a longer period and contributes to continuous profits.
6. **Reduced Pest and Disease Pressure**: Through crop rotation, yet another CA method of action, pests and disease cycles

are broken, significantly decreasing the need for chemical controls.

7. **Diversification through Agro forestry and Crop Rotation:** The use of agro forestry in CA enables farmers to diversify their sources of income because it entails growing both trees and food crops together. While crop rotation enhances the soil quality, it also enables varieties of marketable crop types that reduce single-crop risks. To sum up, conservation agricultural production techniques increase crop yields and profitability while also protecting the environment and conserving land. CA offers a path to more economical and effective sustainability agriculture by improving soil health, lowering production costs, and boosting resilience.

6. CONSERVATION AGRICULTURE AND SOIL HEALTH

CA is crucial for maintaining and enhancing soil health. The goal of sustainable conservation agriculture (CA) techniques is to preserve and extend the life of soil. CA supports soil health in the following ways:

1. **Minimal Soil Disturbance:** Cultivation practices such as zero tillage and reduced tillage minimizes disruption to the soil structure. Thus, it avoids soil compaction, conserves soil aggregations, and provides a habitat for useful microorganisms, earthworms as well as other soil inhabitants.
2. **Enhanced Organic Matter:** Crop residue retention for CA is advocated. They break down and increase organic matter concentration of the soil. Soil with higher levels of organic matter has better structural integrity, holds more water, and retains nutrients better.
3. **Reduced Soil Erosion:** They greatly lessen soil erosion by utilizing methods like cover crops and preserving crop remnants on the land. It keeps the soil from deteriorating and guarantees that nutrients are kept in the topsoil.
4. **Water Management:** A frequent CA practice that increases the soil's capacity to hold onto water for a longer period of time when rainfall has stopped in a given location is mulching and minimal tillage. Additionally, it implies that the crops will receive enough moisture from the soil during droughts, improving their resilience and reducing water stress.
5. **Nutrient Cycling:** One prevalent practice in California is crop rotation, which also promotes appropriate nutrient cycling. For crop systems that are healthier and more productive, nutrient outflow is decreased and plant nutrient availability is increased.
6. **Carbon Sequestration:** CA practices sequester more carbon into the soils, leading to less CO_2 in the atmosphere. Apart from combating global warming, this facilitates soil health in forming a steady and rich habitat.
7. **Reduction in Soil Compaction:** Less soil compaction is affected through reduced machinery traffic on CA. This makes it easy for the roots to penetrate and therefore allows quick intake of water and nutrient.
8. **Balanced Soil Microbial Communities:** Because there are fewer disruptions and organic material from CA activities, soil microorganisms can flourish, improving carbon sequestration. This involves a diverse microbial community that suppresses illnesses and helps with nutrition cycling.
9. **Increased Soil Biodiversity:** CA contributes to soil biodiversity, especially when combined with cover crops or agroforestry. Healthy soils and resilient ecosystems have been linked to the dynamic soil ecosystem that is produced by such variety.
10. **Minimized Chemical Dependency:** CA reduces the usage of artificial fertilizers and agrochemicals. The detrimental effects of excessive chemical use on soil quality can be mitigated by reducing the likelihood of contamination.
11. **Long-Term Sustainability:** Additionally, the CA's integrated management strategy promotes healthy soils, guaranteeing both sustainable land use and ongoing agricultural yield. In conclusion, soil health and conservation agriculture are inextricably linked. By reducing soil disturbance, boosting organic matter, reducing erosion, and promoting nutrient cycling, the CA method improves the environment for both farmers and the ecosystem. The aforementioned actions are essential to maintaining the agricultural soils' economic viability.

7. CONSERVATION AGRICULTURE AND GREENHOUSE GASES

Conservation agriculture (CA) is an efficient approach for GHG emission reduction and combating global warming. Here's how CA practices influence greenhouse gases:

1. **Carbon Sequestration:** CA promotes practices that prevent locked-in soil carbon from being released into the atmosphere, such as limited soil disturbance and no-till farming. In order to reduce the amount of CO_2 in the atmosphere, carbon is sequestered as organic matter that stays in the soil for a long period. Carbon sequestration is the process of capturing and storing carbon compounds from the environment to reduce the greenhouse effect and mitigate climate change.

There are several types of carbon sequestration, including:

Biological carbon sequestration:

Stores carbon dioxide in vegetation, soils, oceans, and other bodies of water. This is also known as "indirect" or "passive" sequestration. For example, plants use carbon dioxide during photosynthesis to create components they need to live and grow.

Geological carbon sequestration: Stores carbon dioxide in underground geologic formations, or rocks. Carbon dioxide is captured from industrial or energy-related sources, pressurized until it becomes a liquid, and then injected into porous rock formations.

Ocean sequestration: Involves compressing and liquefying carbon dioxide, transporting it to specific sea areas, and injecting it into the deep sea. Oceans are considered to be a large reservoir of carbon sinks. Other methods of carbon sequestration include direct binding at the source and advanced techniques such as mineral carbonation.

2. **Reduced Carbon Emissions:** Carbon deposited in the soils is released into the atmosphere as CO2 when traditional agriculture entails heavy soil disturbance and plowing. By minimizing soil disturbance, conservation-tillage (CA) techniques help reduce the CO2 emissions linked to these farming operations.
3. **Methane Emissions Reduction:** Encouraging CA techniques that improve soil structure and preserve water will reduce water logging, which causes methane emissions to emerge from flooded fields. By making sure that soils are properly drained and structured, CA helps to lower methane emissions.
4. **Nitrous Oxide Emissions Reduction:** Since nitrous oxide is a potent greenhouse gas, its emissions are kept to a minimum by managing nutrients well and using less fertilizer, which makes up CA. One of the main causes of N_2O emissions is the overuse of nitrogen fertilizers and nitrogen losses via erosion and washing.
5. **Reduction of Energy-Intensive Practices:** Conservation agriculture aims to reduce the frequency of large-scale field operations that consume fossil fuels, such as harrowing and ploughing. This further lowers CO_2 emissions linked to energy.
6. **Climate-Resilient Agriculture (CRA):** In the agricultural environment, CA technologies guarantee increased farming sustainability in the face of climate change. By enhancing soil health and water-use efficiency, CA makes agriculture more climate-resilient and less susceptible to extreme weather events that may cause soil disturbance and the release of several greenhouse gases.
7. **Long-Term Carbon Storage:** CA methods better improve the integrity of permanent soil carbon storage. Reducing greenhouse gasses like CO2 and the overall impact of agriculture on the atmosphere are critical. In summary, conservation agriculture increases carbon sequestration within the agricultural sector and improves net emissions of greenhouse gases. In addition to providing agronomic and environmental advantages, CA practices that contribute to the mitigation of global warming include sustainable soil health, water conservation, and effective nutrient usage.

8. CONCLUSION

Lastly, conservation agriculture is a method that has a lot of potential to address the most important sustainability issues in agriculture. However, there are obstacles to implementation, like initial resistance to adoption, ongoing capacity building, mentorship, and support. As research advances, technology advances, and more farmers become involved, conservation agriculture can become a part of the future of globally sustainable agriculture and environmental management. As a result, it is time for people to embrace conservation agriculture as one way to address the most important issues in modern farming. It offers practices that will improve soil health for better crop performance and lessen negative environmental impacts. Additionally, it needs to be flexible enough to accommodate different regional circumstances and settings. This does not, however, bode well for conservation agriculture's success. Enhancing resilience to climate change, improving soil health, and reducing adverse environmental impacts are significant positive viewpoints. There is hope that, with the right promotion, conservation agriculture may maintain food security for growing people around the world without causing environmental damage.

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 writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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