Review Article

Conservation Agriculture as a Climate Change Mitigation Strategy: A Review

Abstract

To deepen our knowledge of agriculture's role in mitigating climate change, it is imperative to precisely measure its carbon sequestration potential. This entails accounting for various factors, including regional climate patterns, crop selections, soil management practices, and soil types. Climate change presents a substantial threat to food and nutritional security on regional, national, and global scales. The heightened concentrations of greenhouse gases, encompassing carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), pose immediate challenges.Vulnerable populations, especially those living in impoverished conditions, face an elevated risk of food insecurity due to the impacts of climate change. Additionally, the conversion of non-agricultural land, such as forests, into agricultural use, and the anthropogenic emissions of greenhouse gases resulting from agricultural activities, make significant contributions to climate change.

The rising concentration of greenhouse gases (GHGs), particularly CO_2, in the atmosphere is contributing to global warming. Over the past century (1906–2005), the global mean surface temperature has increased by approximately 0.60 to 0.90 degrees Celsius, with the most rapid rate of temperature rise occurring in recent decades. The global average temperature continues to steadily increase, and it is projected to rise by 2 degrees Celsius by the year 2100, a change that could result in substantial economic losses at the global level.

The concentration of CO_2, a significant component of greenhouse gases (GHGs), is increasing at an alarming rate. This rise has led to improved plant growth and productivity due to heightened photosynthesis. However, the benefits of increased photosynthesis are counterbalanced by higher temperatures, resulting in increased crop respiration rates, greater evapotranspiration, higher pest infestations, a shift in weed species, and reduced crop durations. Moreover, climate change has a pronounced impact on soil microbial populations and their enzymatic activities.

This paper reviews the information collected through the literature regarding the issue of climate change, its potential causes, its impact on the agriculture sector, as well as its influence on the physiological and metabolic activities of plants. It also examines the potential and reported implications for plant growth, productivity, and mitigation strategies.In recent years, there has been a growing recommendation for the adoption of conservation agriculture as a more

sustainable alternative to conventional farming practices. Conservation agriculture not only sustains soil health but also enhances agricultural productivity, making it a crucial tool for mitigating the impacts of climate change.

Keywords: Conservation agriculture; greenhouse gases, carbon dioxide (CO_2) emissions; climate change mitigation

1.0 Introduction

Climate change has evolved into a concern of regional, national, and global significance, as substantiated by numerous physical and biological transformations occurring across the globe, hence more precisely referred to as global climate change.The reasons for global climate change are both global warming, which mainly results from enhanced greenhouse effects owing to access to emissions of greenhouse gases in the atmosphere, and global dimming due to increasing levels of gaseous pollutants and aerosols in the air, mainly through anthropogenic activities.The most imminent of these is an increased concentration of greenhouse gases (GHGs), namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in the atmosphere [1, 2]. The current atmospheric concentration of CO_2 is 417.15 ppm, CH_4 is 1907.80 ppb, and N_2O is 335.48 ppb [3]. However, only CH_4 and N_2O are emitted from agriculture.On the other hand, CO_2 is not considered to be emitted from agriculture as it is taken up by plants. The global warming potential of CH_4 and N_2O is 25 and 310 times higher, respectively, than that of CO_2[4]. Over the past decade, there has been a notable stability in the N_2O budget within the atmosphere, with no alarming increase [5]. This can be attributed to a harmonized input of inorganic N fertilizers, the implementation of nitrification inhibitors, and the adoption of integrated fertilizer management strategies. Conversely, the concentration of atmospheric CH_4 has exhibited a dramatic and concerning increase [6,7]. For instance, in the early 2000s, CH_4 levels were rising at a rate of approximately 0.5 ppb (parts per billion) per year. However, in recent years, the concentration of CH4 has surged, increasing at a staggering rate of 9–12 ppb per year [8].

Climate change is likely to heighten the risk of food insecurity, particularly for vulnerable groups, such as those living in poverty. Agriculture plays a significant role in contributing to climate change through both anthropogenic emissions of greenhouse gases (GHGs) and the conversion of non-agricultural land, like forests, into agricultural use. The predominant contributors to the observed increase in GHGs over the past 250 years have been fossil fuels, changes in land use, and agricultural practices. Concentrations of CO_2, CH4, and N_2O have markedly risen by 40%, 150%, and 20%, respectively, since 1750, as a consequence of human activities, particularly since the onset of the industrial revolution [9].The escalation in greenhouse gas (GHG) concentrations, with a particular emphasis on CO_2, in the atmosphere is a driving force behind global warming. The global mean surface temperature has consistently risen over the past century, with the rate of increase being most pronounced in recent decades. Notably, fourteen out of the last seventeen years (1995–2011) have been classified as the warmest years since 1850. According to the projections by the Intergovernmental Panel on Climate Change (IPCC) [10], it is likely that by the end of the 21st century, the temperature will increase within the range of 2 to 4.5 °C.The temperature rise is likely to be higher in the winter season than in the rainy season. For the South Asia region, including India, a rise in temperature of 0.88 °C to 3.16 °C by 2050 and 1.5 °C to 5.44 °C by 2080 has been projected by the IPCC [11].Carbon sequestration in soil can be significantly improved through various methods, such as no-till farming, residue mulching, cover cropping, and crop rotation, all of which find more extensive application in organic farming compared to conventional farming.

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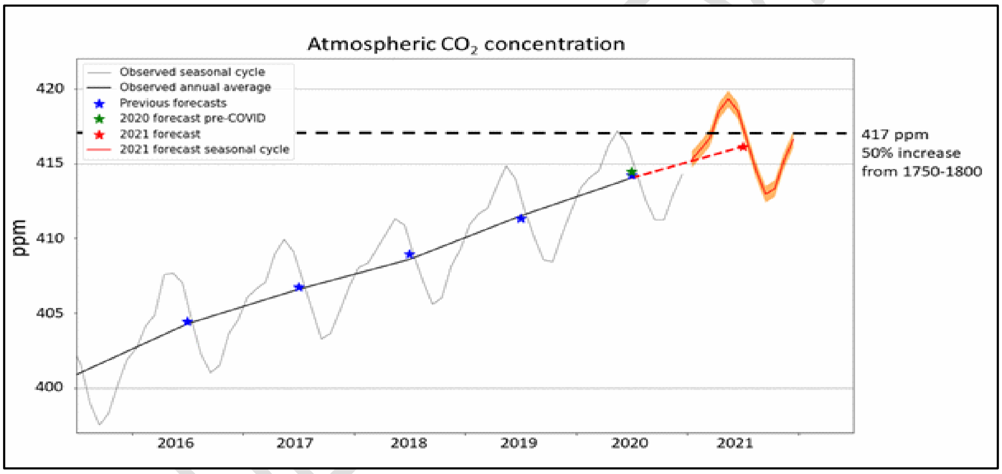

Fig. 1. The rise in atmospheric carbon dioxide concentration (source: [3])

2.1 Soil as a Source and Sink of Greenhouse Gases

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The IPCC has concluded that agriculture contributes approximately 13.5% of global greenhouse gas (GHG) emissions worldwide [12]. Among the significant contributors to GHG emissions, agricultural soil management plays a prominent role. Soil serves as both a source and sink for GHGs, accounting for roughly 20% of total CO_2 emissions through soil respiration and root respiration, 12% of CH_4 emissions, and a substantial 60% of anthropogenic N_2O emissions [13].The conversion of forests and grasslands to agricultural use has substantially increased the atmospheric CO_2 concentration in past centuries.Global deforestation during 1850–1985 contributed approximately 120 Gt to the atmosphere [14]; the majority of the soil C losses occurred within the first few years, particularly in the tropics [15,16]. The application of higher doses of nitrogen fertilisers and microbial processes like nitrification and denitrification in the soil increase the emission of N_2O [13]. Production and emission of N_2O from the soil to the atmosphere account for about 70% of both anthropogenic and naturalsources [17]. Soil production of CH_4 is linked to various sources, including wetlands, flooded rice production, termites, landfills, and areas of oil and natural gas production. Approximately 40% of the roughly 500 Tg of CH_4 generated each year originates from soil sources. Notably, natural wetlands, spanning approximately 500–600 million hectares, contribute significantly by emitting around 100 Tg of CH_4 annually [18]. Flooded rice fields occupy about 148 Mha and emit about 50 Tg of CH_4 annually [14]. The consumption of atmospheric CO_2 occurs mainly through carbon sequestration; improved crop production increases residue return, and better nutrient management increases C input in soil [14]. In the case of CH_4, methane-oxidising bacteria in the soil consume and convert it into CO_2, which further accelerates global climate change. Soil CH_4 consumption is influenced by agricultural practices and the intensification of land use in both temperate [19, 20]; and tropical soils [21].

3.0 Major greenhouse Gases

Agriculture is widely known as a source of greenhouse gases (GHGs). Regrettably, the rice-wheat system, commonly practiced in the Indo-Gangetic Plains, plays an active role in GHG emissions. These emissions are detailed below:

3.1. Carbon Dioxide

Tillage operations contribute to CO_2 emissions by accelerating the rapid decomposition of organic matter due to increased oxygen supply, which results in a larger surface area. Experiments conducted in Mexico have revealed that tillage almost doubles the rate of decline in soil organic carbon levels within the top 20 cm of soil. Additionally, each liter of diesel fuel consumed by tillage machinery and irrigation pumps contributes 2.6 kg of CO_2 to the atmosphere [22]. As a result, nearly 400 kg of CO_2 would be generated per hectare, assuming an annual use of 150 liters of diesel in the conventional rice-wheat system. Moreover, the presence of nitrogen (N) enhances microbial decomposition and the release of CO_2 during the production of N fertilizers. Specifically, every kilogram of nitrogen fixed in fertilizer production produces 1.8 kg of CO_2. It is presumed that any CO_2 generated by burning crop residues will be absorbed by the subsequent crop [23].

3.2 Methane

Methane is generated through fermentation, which involves the anaerobic decomposition of organic matter, transforming CO_2 into CH_4. The continuous flooding of rice fields leads to CH_4 production owing to the anoxic conditions created, and rice plants act as pathways for its release into the atmosphere. Multi-location experiments conducted in five countries have examined CH4 emission rates, demonstrating seasonal variations. Notably, rainfed rice fields exhibit emissions that are less than half of those observed in irrigated fields. To effectively reduce the CH_4 emission rate, periodic aeration of fields can be employed as an alternative to continuous flooding.

In the expansive 12 million hectares of rice-wheat cultivation in the Indo-Gangetic Plains, approximately 0.7 million metric tons (Mt) of CH4 are produced annually through rice cultivation. This substantial production is primarily attributable to the low organic carbon levels in this region [24]. Additionally, the burning of crop residues contributes around 0.14 Mt of CH4, assuming that half of the crop residues, produced at a rate of 10 tons per hectare (for rice and wheat) in the 12 million hectares, are incinerated. This represents roughly 20% of the total CH_4 emissions from paddy fields in the same area [25].

3.3 Nitrous Oxide

This gas is released even from soils to which no nitrogen-containing fertilizer has been applied. Destruction of the ozone layer due to N_2O is an important consideration beyond the concern for nitrogen losses from applied fertilizers and manures. Experiments have shown that both the processes of nitrification and denitrification contribute to the release of N_2O from the soils into the atmosphere[26]. N_2O production is significantly influenced by soil water content, as water creates anaerobic conditions by reducing the oxygen diffusion rate by ten thousand times. Typically, increased denitrification and potential N_2O losses are observed following irrigation or rain in aerobic or partially aerobic soils. Rice paddies are not considered a significant atmospheric source of N_2O since it is further reduced to N_2 under strong anaerobic conditions caused by standing water. However, N_2O flux experiences a sharp increase when the fields are drained at the mid-tillering stage.

Burning crop residue results in the release of 40 g N_2O per ton. Assuming that half of the 10 t/ha of crop residue produced on 12 million ha is burnt, approximately 2000 tons of N_2O (equivalent to about 0.2 MMTCE/annum) are released into the atmosphere. Notably, this represents nearly a quarter of the emissions associated with CH_4 from the same process [27].

4.0 The Contribution of Indian Agriculture to Global Warming

Indian agriculture is input-based and greatly challenged. India feeds 17% of the global population in only 2.3% of its land area, supported by 4% of its fresh water resources. The cosmic rate of population increase may demand more from these limited resources in the future, and we may have to adopt highly intensive agriculture, which demands higher doses of fertilizers. It may further exploit the soil and land resources by depleting organic carbon, secondary nutrients, and micronutrients, and also enhance greenhouse gas emissions and groundwater contamination. So, these conditions may lead agriculture largely becoming a non-point source of environmental pollution. CO_2, CH_4, and N_2O are responsible for contributing 75%, 15%, and 5% of GHGs, respectively [4].

Agriculture and allied sectors produce about 35%, 50%, and 70%, respectively, of the total anthropogenic emissions of these gases. In India, out of total GHG emissions from anthropogenic activity, the agriculture sector contributes 28%. The emissions are mainly due to the clearing of forests for agricultural use, which increases the emission of CO_2, methane emission from rice fields (23%), enteric fermentation in ruminant animals (59%), and N_2O from the application of manures and fertilisers (Fig. 2A and 2B) [28,29].As per [30], a recent estimate for the base year 1994-95 indicates that CH_4 and N_2O emissions from Indian agricultural fields amounted to 2.9 Tg (equivalent to 61 Tg of CO_2) and 0.08 Tg (equivalent to 39 Tg of CO_2), respectively.

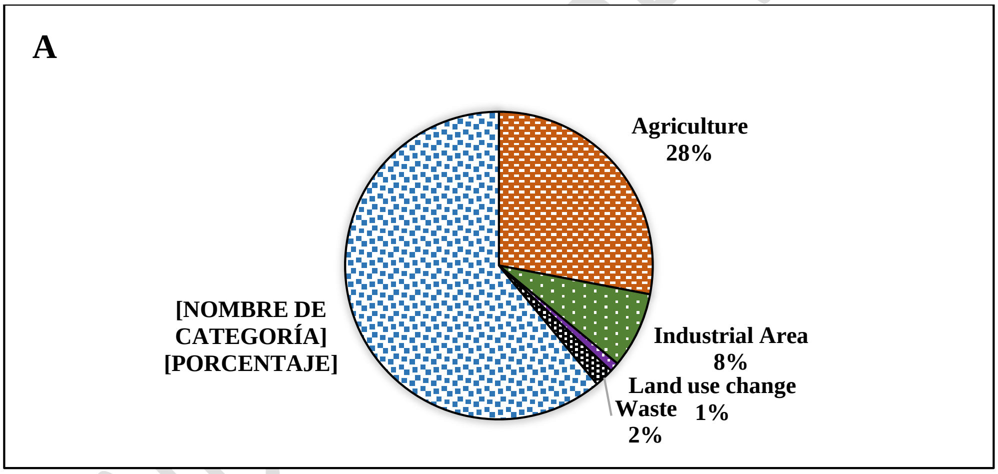

Fig. 2A.The Contribution of Major Sectors to Greenhouse Gas Emissions in India

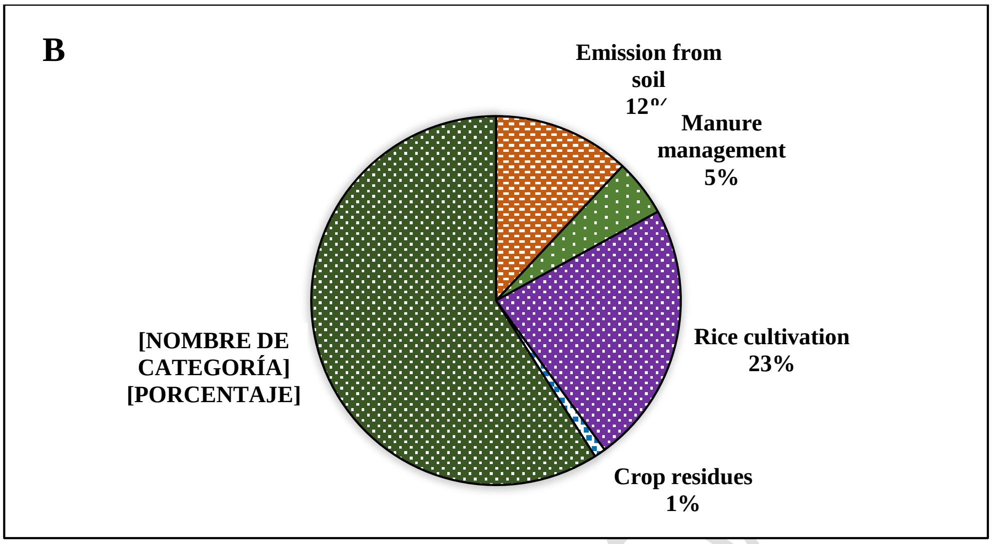

Fig. 2B. Evaluating the Relative Contributions of Agricultural Sub-sectors to Emissions in India

4.1 The Impact of Greenhouse Gases on Agriculture

Climate change and agriculture are intricately linked global phenomena. Climate change exerts various impacts on agriculture, encompassing shifts in average temperatures, alterations in rainfall patterns, and the emergence of climate extremes such as heatwaves. Furthermore, agriculture is affected by changes in pest and disease patterns, variations in atmospheric concentrations of carbon dioxide and ground-level ozone, fluctuations in the nutritional composition of certain crops, and shifts in sea levels.

4.2 Impacts of Climate Change on Soil

Soils, crucial for plant growth, undergo several significant impacts. Elevated temperatures may accelerate the decomposition of soil organic matter. The CO_2 fertilization effect results in increased litter production with a higher C/N ratio, leading to a greater amount of organic matter available for incorporation into the soil as humus. However, slow decomposition of high C/N litter can potentially create a negative feedback loop affecting nutrient availability. Enhanced plant growth due to increased CO_2 levels may result in shortages of other essential nutrients like N and P. Nevertheless, the rise in CO_2 stimulates mycorrhizal activity, making soil phosphorus more accessible, and enhances biological nitrogen fixation, whether symbiotic or not. Moreover, increased root growth can lead to enhanced weathering of the substrate, providing a fresh supply of potassium and micronutrients.

5.0 Conservation Agriculture: Its Role in Greenhouse Gas Mitigation

Adapting agriculture to climate change is a practice as old as agriculture itself. For over ten thousand years, people have continually adapted to changing conditions. Whether facing challenges like heat, cold, drought, severe weather, climate change, natural disasters, disease, land conflicts, war, persecution, or migration, individuals have consistently sought new ways to produce food, sustain their livelihoods, and care for their ecosystems [31].

Some major mitigation strategies to address current climate change include:

(a) Implementing methods that significantly enhance carbon sequestration in soil, such as no-till farming and residue management.

(b) Improving forecasting and early warning systems to better prepare for and respond to climate-related challenges.

- Implementing hazard and vulnerability mapping.
- Increasing public awareness.
- Developing community-based forest management and afforestation projects.
- Promoting practices like mulching, cover cropping, and crop rotation, which are more commonly employed in organic farming as opposed to conventional farming.

In recent years, conservation agriculture (CA) has been increasingly recommended over conventional farming methods for its ability to sustain soil health, enhance agricultural practices, and contribute to climate change mitigation [32, 29]. Globally, CA is practiced on approximately 180 million hectares of land [33]. Some of the major CA practicing countries include the USA (26.5 million hectares), Argentina (25.5 million hectares), Canada (13.5 million hectares), and Australia (17.0 million hectares) [34]. In India, CA adoption is not as widespread, with zero tillage and CA practices covering approximately 1.5 million hectares [35].

Conservation agriculture (CA) comprises practices that minimize soil disturbance, maintain permanent soil cover, and involve diversified crop rotations [36]. Currently, CA is being adopted on over 5 million hectares in the Indo-Gangetic plains of South Asia, with the area dedicated to CA continuing to expand [37]. This shift in land use practices is expected to bring about changes in soil properties, including enhanced water infiltration, reduced erosion, decreased compaction, increased surface soil organic matter and carbon content, and improved soil aggregate structure [38, 39, 40, 32]. Among various tillage practices, no tillage demonstrates a promising impact on enhancing soil health [41, 42], resulting in a significant increase in soil carbon content compared to tilled soils [43]. Additionally, microbial biomass carbon tends to increase more in no-tillage systems compared to tilled soil [44].Greater CO_2 emissions and higher respiratory quotients have been reported in tilled soils in comparison to zero-tilled soils [45]. Furthermore, various microbial enzyme activities have been documented to be more pronounced in zero-tilled soils [46].As per [47], conservation agriculture (CA) encompasses a system of agronomic practices that involve reduced tillage (RT) or no-till (NT), maintaining permanent organic soil cover by retaining crop residues, and incorporating crop rotations that include cover crops. The potential contribution of Conservation Agriculture (CA) to climate regulation and its role as a strategy for mitigating global warming depends on the direction and magnitude of changes in soil carbon, nitrous oxide (N_2O), and methane (CH_4) emissions associated with its implementation compared to conventional practices. The assessment of the global warming potential of these farming practices is contingent on soil conditions, climate, and management factors [48, 49].The impact of tillage practices on the rate of CH_4 consumption is generally contingent on changes in soil gas diffusion characteristics [50, 51]. A study reported in [52, 46] on cultivation practices and CO_2 emissions indicates that activities like ploughing, soil aggregate disruption, and soil organic carbon exposure to microbial activity enhance the rate of decomposition and CO_2 emissions into the atmosphere.

The implications of Conservation Agriculture (CA) on greenhouse gas (GHG) emissions have been investigated, revealing that, on average, 29.3 Mg ha^{-1} of GHGs are emitted over a 20-year period in conventional rice-wheat systems across the Indo-Gangetic plains. This figure decreased only by 3% with the widespread adoption of CA.As noted in [11], methane (CH_4) consumption in the rhizosphere of a soybean-wheat cropping system under different fertilizer management practices in a tropical Vertisol was reported. It highlighted that organic farming can significantly reduce the global atmospheric CH_4 budget while also improving soil physical and biological properties. Similarly, another study reported [53] that alterations in drainage regimes and the incorporation of crop residues in rice production systems can reduce CH_4 emissions. Crop management practices that enhance soil organic carbon in semi-arid regions also lead to reduced CH_4 emissions.However, the wetting and drying of soils may also enhance N_2O emissions and soil C mineralization, potentially reducing the net greenhouse gas (GHG) mitigation potential. A study examining the relationship between conservation tillage and greenhouse gas emissions found that tillage plays a significant role in the flux of CO_2 and CH_4 [54]. Specifically, no-tillage significantly reduced CH_4 emissions during rice growing seasons compared to conventional tillage. Methane (CH_4) consumption in agricultural soils is essential for mitigating global climate change, and recently, no-tillage has been recommended as an effective strategy for sustainable agriculture, showing promising effects on soil health improvement [41].However, there is limited literature concerning methane monooxygenase activity in response to tillage and cropping systems. Conservation agriculture aims to reverse the degradation associated with conventional agricultural practices such as intensive agriculture and the burning or removal of crop residues. Its goal is to conserve, enhance, and optimize the use of natural resources through the integrated management of available soil, water, and biological resources, along with the judicious use of external inputs. This approach can also be described as resource-efficient or resource-effective agriculture.

5.1 Managing Crop Residues for Climate Change Mitigation

The primary threats to soil resources include soil erosion, the loss of organic matter, soil compaction, and soil sealing, among others. It is widely recognized globally that conserving crop residues through conservation agriculture can help reverse soil degradation. With the ever-increasing demand for food driven by population growth, rising fertilizer costs, and the depletion of native mineral sources, there is a growing imperative to rethink and make effective use of crop residues left in the field.In many parts of the country, the dominant cropping system consists of rice, wheat, and soybeans. However, the residue left on the field during harvesting poses significant challenges for the next crop and creates recycling difficulties for farmers. The most straightforward and immediate method to deal with this residue is by burning it. Consequently, residue burning remains a common practice in many regions of the country. In general, crop residue is applied to the soil in several ways, including using it as mulch on the soil surface, incorporating raw residue into the soil, or mixing in burnt ashes.

- Microbial and root activities are primarily influenced by soil moisture and temperature. Environmental variations in temperature and moisture are, in turn, impacted by residue management practices like burning and tillage.
- For instance, burning removes residue, and the absence of the insulating effect of residue cover on the soil surface can lead to temperature increases, potentially stimulating microbial activity and soil respiration while intensifying fluctuations in soil moisture and temperature.
- The management of crop residues through burning also eliminates the evaporation barrier that the residue typically provides, causing the soil to dry out more rapidly. This, in turn, affects microbial activity and soil respiration.
- Agricultural soils have the potential to function as a significant carbon sink, at least until they reach their maximum capacity for carbon storage, provided improved residue management and reduced tillage systems are adopted.
- Therefore, it is essential to develop alternative residue management strategies to minimize or eliminate the conventional practice of residue burning and thereby reduce soil respiration.

5.2 Tillage, Crop Rotation, and Carbon Sequestration

The Intergovernmental Panel on Climate Change (IPCC) determined that agriculture is directly responsible for approximately 20% of annual anthropogenic greenhouse gas emissions [17]. Nevertheless, agricultural soils have the potential to act as significant carbon sinks rather than carbon sources, at least until their maximum carbon storage capacity is reached, provided that improved residue management and reduced tillage systems are adopted [52]. Hence, it is imperative to develop alternative residue management strategies to reduce or eliminate the conventional practice of residue burning and subsequently decrease soil respiration.

Conventional agriculture traditionally relies on soil tillage, often accomplished through ploughing. Tillage practices, in the past, have been associated with improved fertility by enhancing the mineralization process, albeit at the long-term cost of organic matter loss in the soil. Tillage effectively mixes and loosens the soil, stimulating microbial activity, organic matter oxidation, and soil respiration. However, it has been recognized that frequent soil disturbances have detrimental effects. Furthermore, tillage is becoming increasingly expensive for farmers, accounting for 20% or more of total crop production costs, depending on the crop and soil type. In order to maintain farming as a profitable enterprise, farmers must find ways to reduce production costs and enhance productivity.

6.0 Current Initiatives for Adaptation and Mitigation in India

Adaptation, within the context of climate change, involves taking measures to minimize the adverse impacts of climate change. For example, this might entail relocating communities residing in close proximity to the seashore to contend with rising sea levels or transitioning to crops that can withstand higher temperatures. On the other hand, mitigation encompasses actions aimed at reducing the emissions of greenhouse gases responsible for climate change in the first place. This may involve shifting to renewable energy sources such as solar, wind, or nuclear energy instead of relying on the combustion of fossil fuels in thermal power stations [55, 56].

Currently, government expenditure in India on adaptation to climate variability exceeds 2.6% of the GDP, with specific areas of concern including agriculture, water resources, health and sanitation, forests, coastal zone infrastructure, and programs addressing extreme weather events.

6.1 Crop Improvement: These programs encompass various measures, including the development of arid-land crops, pest management, and the capacity building of extension workers and non-governmental organizations (NGOs). These efforts are designed to support the adoption of better vulnerability-reducing practices.

6.2 Drought Proofing: The current programs are geared towards mitigating the adverse effects of drought on crop and livestock production, as well as on land, water, and human resource productivity. The ultimate goal is to make the affected areas more resilient to drought. Additionally, these programs aim to foster overall economic development and enhance the socio-economic conditions of the impoverished and disadvantaged populations.

6.3 Forestry: India has established a robust and rapidly expanding afforestation program. This initiative gained significant momentum with the implementation of the Forest Conservation Act of 1980, which sought to halt the clearing and degradation of forests by introducing stringent, centralized control over the use of forestland and mandating compensatory afforestation in case of any diversion of forestland for non-forestry purposes. Additionally, an ambitious afforestation and sustainable forest management program led to the annual reforestation of 1.78 million hectares from 1985 to 1997, and this rate currently stands at 1.1 million hectares annually. As a result of these efforts, carbon stocks in Indian forests have increased over the last 20 years, reaching 9–10 gigatons of carbon (GtC) from 1986 to 2005.

6.4 Water: The National Water Policy (2002) emphasizes the adoption of non-conventional methods for water utilization, which includes practices such as inter-basin transfers, artificial groundwater recharge, desalination of brackish or seawater, and traditional water conservation techniques like rainwater harvesting, including roof-top rainwater harvesting. These measures are encouraged to enhance the availability of usable water resources. In response, many states have introduced mandatory water harvesting programs in several cities.

6.5 Disaster Management: The National Disaster Management Programme plays a crucial role by offering grants-in-aid to victims of weather-related disasters and coordinating disaster relief operations. Furthermore, India actively backs disaster prevention initiatives, which include the distribution of information and the training of disaster management personnel. India has also put in place a robust policy, regulatory, and legislative framework relevant to greenhouse gas (GHG) mitigation, with the adoption of the Integrated Energy Policy in 2006. Key provisions include:

a. Promoting energy efficiency across all sectors.
b. Prioritizing mass transportation solutions.
c. Encouraging the use of renewable energy sources, including the development of biofuel plantations.
d. Advancing the development of nuclear and hydropower as sources of clean energy.
e. Concentrating on research and development (R&D) in various clean energy-related technologies.

The experience gained thus far empowers India to adopt an even more proactive stance through the National Action Plan on Climate Change (NAPCC). The NAPCC identifies measures that align with our development objectives while also delivering co-benefits for effectively addressing climate change. It outlines a series of steps to concurrently progress

India's development and achieve climate change-related goals in adaptation and mitigation [57, 58, 59]. The National Action Plan revolves around eight key national missions, forming the cornerstone of this integrated, long-term approach to accomplishing pivotal objectives within the climate change context:

I. National Solar Mission
II. National Mission for Enhanced Energy Efficiency
III. National Mission on Sustainable Habitat
IV. National Water Mission
V. National Mission for a Green India
VI. National Mission for Sustainable Agriculture
VII. The National Mission on Strategic Knowledge for Climate Change plays a crucial role in advancing our understanding and strategies for addressing climate change.

Farmer coping options

i. Climate Change Awareness: Farmers need to have a thorough understanding of climate variability, climate change, its potential impact on crop production, and the strategies available for coping with these changes.
ii. Agromet Advisories: Agromet advisories are publicly shared with the farming community. These bulletins are developed by taking into account the current weather conditions, crop and soil conditions, and future forecasts. They provide guidance on measures, practices, and recommendations to be implemented based on the weather forecast, with the aim of minimizing losses and optimizing agricultural inputs (such as land preparation, crop selection, sowing and harvesting timings, irrigation scheduling, pesticide and fertilizer application, and preparation for extreme weather events).
iii. The agro-advisory bulletin is structured into three sections:(i) The first part covers weather events from the previous week and forecasts for the upcoming five days. This includes climate data such as cloud cover, rainfall, average wind speed, wind direction, relative humidity, and both the highest and lowest temperatures. (ii) The second part provides precise information regarding the state and growth stage of crops, ongoing farming activities, and occurrences of diseases and insect pests.(iii) The third section offers valuable guidance on recommended farm tasks based on the weather conditions.
iv. The extension system should prioritize the development of income-generating opportunities, adapt suitable cropping patterns to local climate changes, promote the cultivation of drought-tolerant crops, encourage a greater involvement in non-agricultural activities and agro-forestry practices, identify and promote traditional coping strategies,

and emphasize on-farm soil and water conservationrequiring mixed cropping patterns, and providing access to an assortment of resources[60].

7.0 CONCLUSION

Climate change poses an imminent threat to global, national, and regional food and nutritional security. In contrast to the traditional paradigm of agricultural research and development, which primarily focuses on achieving specific food grain production targets in India, conservation agriculture presents an innovative strategy. The study also provides insights into CA's potential to reduce CO_2 emissions. According to the findings, soil organic matter is depleting due to tillage and surface residue, which may impact crop yields, evaporation, and respiration. Climate change leads to reduced precipitation in tropical and semi-arid regions, and CA may assist in minimizing and adapting to this challenge.

To mitigate the adverse effects of climate change on agricultural sustainability, several mitigation and adaptation strategies have been developed. These technologies encompass crop diversification, raised-bed planting, direct-seeded rice, rainwater harvesting, micro-irrigation, precision nutrient application, crop residue management, stress-tolerant varieties, ICT-based agrometeorological services, zero-tillage, legumes, crop residue management, and knowledge-enhancing activities (such as agricultural extensions to enhance capacity). These technologies significantly mitigate the negative impacts of climate change on crops and enhance their resilience to changing climatic conditions.

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