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Review Article

Scrutinizing Agricultural Sectors to Uncover the Existing Challenges for the Goal of Climate Change Mitigation Targets

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Abstract

Agriculture acts as a crucial facilitator while currently being the primary victim of climate change. This review paper examines the agricultural sectors role in achieving climate change mitigation targets, focusing on critical challenges and proposing on actionable solutions. The review also highlights the need for system-based approach that integrates technological innovation, sustainable land management, and policy interventions. It underscores the importance of cross-sector collaboration, economic incentives and robust monitoring frameworks to overcome barriers and accelerates the sector's transition towards sustainability. Climate change (CC) is one of the most pressing challenges confronting the global community at present and constitutes a significant jeopardy to the existence, nutritional stability, and economic progression of numerous nations. This climate fluctuation exerts an impact on all nations regardless of their developmental status; it constitutes unbounded global challenge. It is important that land use regulation alongside soil and water conservation methodologies be augmented to mitigate the ramification of climate change, specifically in the management of floods, erosion and landslides. Different approaches are followed to mitigate current challenging climate changes; such as irrigation management strategy, recycling bio-wastes, incorporation of crop residue into soil, and soil and water conservation as well as, managing soil moisture are crucial strategies.

Keywords

Climate Change, Mitigation, Greenhouse Gas, Irrigation, Agriculture, Fertilizer, Food

1. Introduction

World population is escalating rendering access to sustenance, increasingly challenging on daily basis. The agricultural production is necessary to meet the surging demand for food mostly hinges on climatic conditions, soil quality, and water availability. Scholarly assessments pertaining to climate, soil and water are exceptionally noteworthy. [42] revealed, agriculture constitutes; the fundamental basis for existence, in food production, and exhibits pronounced susceptibility to climate change and its advancement practices are inextricably linked to the degradation of the environment, prominently in emission of greenhouse gases (GHGs) and it encompasses 10-12% [42, 44]. As stated by [59]; 12% of GHG emissions, nearly 7.1 billion tones CO_2 equivalent (Gt $CO_{2\text{-eq}}$) of the total anthropogenic greenhouse gas emissions produced worldwide.

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Various scholars dictated; agriculture functions as both a significant contributor to and a primary victim of the climate change [87]; nearly, 30% of this detrimental greenhouse gases are emanated from agricultural sector, predominantly due to over application of chemical fertilizers, pesticides, and mis-management of animal wastes, bio-wastes, and food leftover [12].

The proportion of gas emissions attributed to agriculture from the overall emissions framework is projected to escalate in the future because of (a) reduction from other sectors in emission of GHGs; (b) an anticipated increase in food production; and (c) the challenge of mitigating gas emissions from agricultural practices, which is complicated by the heterogeneity of its sub-sectors and the intricate biophysical processes that underpin their operations [77, 7].

Food and Agricultural Organization asserts that greenhouse gas emissions attributable to agriculture, forestry, and other land uses (AFOLU) are approximately 10.6 Gt of $CO_{2\ equ}$ [10]. Across various regions, the magnitude and origins of GHG emissions from agriculture, forestry, and other land use sectors exhibit considerable variability. In terms of the contributors to gas emission from the agricultural sector, resulting from the intestinal fermentation of ruminants, 40%; which is primary source of methane emission, manures pastures remains, 16%; followed by artificial fertilizers, 12%; and ultimately, rice cultivation, 10% [10]. In the regional scale, the significance of alternative sources of emission from agriculture also varies; in East and Southeast Asia, rice cultivation emerges as the second largest greenhouse gas source, in Australia, 59% of gas emissions are from cultivation of organic soil. In Sub-Saharan Africa, North Africa, and West Asia, alongside Latin America and the Caribbean regions, the second source of emission is manure on pasture, while in developed nations (North America and Europe), the consumption of artificial fertilizers is the dominant contributor of these gases as it was revealed by [10].

Schoalrs found that, climate change highly influences agricultural productivity and it is expected that an expanding and increasingly affluent global population will escalate worldwide demand for agricultural products by 50% by the mid of 21^{st} century [9, 49], leading to greenhouse gas emissions exceeding international climate targets [33]. As a result, it is imperative that agriculture be incorporated into any comprehensive climate change mitigation framework aimed at achieving net-zero GHG emissions [17].

Globally, agriculture represents the predominant consumer of freshwater resources and thus places food security in a position reliant on the availability of freshwater supplies [13], which necessitates focusing on the phenomena of global agricultural water scarcity within the framework of humanity's capacity to fulfill forthcoming food requirement. According to [66, 41] findings, agricultural Green Water Scarcity (GWS), transpires when the volume of precipitation fails to satisfy the Crop Water requirement (CWR), potentially resulting in water stressed crop development. In such scenarios, supplementary blue water is utilized through irrigation practices to guarantee sufficient crop development to feed the nations and mitigate water stress [51].

Ethiopia ranks among the most vulnerable nations in East Africa to the fluctuations associated with climate change, primarily attributable to its populace's dependence on rain-fed agricultural practices [20, 73]. As described by researchers, in Ethiopia, the agricultural sector is particularly susceptible owing to profound reliance on climate variables which exerts huge impact on food security by diminishing agricultural productivity [25, 76, 50]. It is arduous to mitigate the influences of climate change through cultural trends and actions, given that the majority of Ethiopian farmers rely on rain-fed agriculture, which is inherently sensitive to climate conditions [18, 85].

These scholars disclosed that, in order to sustainably mitigate the adverse of climate-related shocks on agricultural outputs, the adoption of climate smart agriculture (CSA) practice is gaining prominence in Ethiopia as both an adaptive and mitigative strategy [3, 4]. CSA represents a comprehensive methodology aimed at enhancing the productivity, adaptive capacity, and resilience of agricultural systems against the detrimental effects of climate change, while concurrently addressing the adverse contribution of agriculture to climate change [45, 48]. Understanding the adaptive drivers is crucial for delineating the adaptation and mitigation strategies pertinent to smallholder farmers, thereby providing enhanced awareness and information that is essential for policymakers [1, 48].

There has been a trend in recent years toward lowering GHG production in the food production sector, but extensive efforts should be made in this direction to uphold global climatic assurances. The global warming potential (GWP) of methane is 25 times more than that of CO_2 over a period of 100 years. The conversion of microbial nitrogen (N) in soil and manure, as well as the dung and urine left behind by grazing animals, is the main source of nitrous oxide. Over a 100-year timeline, nitrous oxide has greater GWP (298 times) than CO_2. Agricultural sub-sectors can contribute to mitigating the consequences of climate change, if the increasing of food production will not affect the increasing of gases in the atmosphere. Agriculture has mastered a unique carbon sequestration process; at the current level of development of technologies, one of the main instruments for sequestering carbon dioxide from the atmosphere is forest complexes and restoration of degraded land.

1.1. Significance of the Review

Scrutinizing agricultural practices is imperative for addressing climate change, in which agricultural sector is both the contributor and victim of climate change. As agriculture plays great role in the emission of greenhouse gases through various activities including livestock husbandry, rice cultivation, inappropriate disposal of bio-wastes and over application of chemical fertilizers, all of which emits significant quantities of methane, nitrous oxide and carbon dioxide. Through meticulous analysis of these practices, it is possible to pinpoint and rectify the most emission-intensive components, with the ultimate goal of minimizing their ecological footprint. Advancement in soil management mechanisms, curtailing deforestation, optimizing crop rotation, and implementing agroforestry practices can collectively enhance carbon sequestrations and diminish emission as well as incorporation of sustainable practices such as precision agriculture; leads to reduction of wastes and energy consumption, which concurrently supports the climate objectives of resilience and adaptation. In similar way, critical evaluation, modernizing and modifying agricultural technologies in line with climate change mitigation, can transform the sector into a crucial ally in promoting climate stability which in turn ensures food security in the current challenging climate change conditions.

Sustainable Development Goals (SDGs) adopted as United Nations (UN) agenda for 2030 consists of 17 goals and 169 targets setting a blueprint for sustainable future in the coming generations. Addressing the global challenges for sustainability, SDGs aim at minimizing global poverty, inequality and hunger, managing climate change and environmental degradations, and reducing risk management under extreme weather conditions. All the 17 goals are interconnected and any action taken towards one target affects the progress of others [5].

This scholarly review holds significant importance in elucidating the innovative methodologies and straightforward yet impactful initiatives associated with Ethiopia's Green Legacy program, which embodies essential components and a systematic frameworks designed to fulfill the established sustainable development objectives and strategies for addressing climate change; furthermore, this undertaking underscores the necessity of extensive afforestation initiatives aimed at restoring ecosystems, enhancing biodiversity, and promoting sequestration, thereby contributing to the realization of the Sustainable Development Goals (SDGs), delineated by the United Nations by the year 2030. Integrating indigenous knowledge with modern agricultural practices can significantly enhance climate adaptation efforts in Ethiopia by leveraging local expertise and traditional methods alongside scientific advancements. This synergy can lead to more effective and culturally relevant strategies for resilience against climate change.

By assessing current practices, scholars needs to uncover effective mitigation strategies and improve carbon sequestration that can foster informed policy frameworks and the implementation of sustainable practices that are congruent with climate objectives and sustainable development goals.

1.2. Effects of Methane Gas, CH_4

Methane; CH_4 is influential greenhouse gas (GHG), exacerbating global warming; and it is imperative to examine its fluxes within the global carbon cycle, especially given that its concentration escalated to 1.5 times the levels recorded during pre-industrial epochs [74]. Its emission exerts considerable impacts on agricultural practices, particularly in the domains of rice cultivation and livestock production; which contributes to the phenomena of global warming and climate change.

Many scholar found crop residues, which are frequently employed to improve soil fertility and enhance soil health can function as both source and sink for atmospheric CO_2 and CH_4 [83, 2]. The incorporation of crop residue supplies carbon substrates and essential nutrients that facilitates methanogenesis, and this elevates the production and consumption of CH_4 [34]. The integration of residues can establish anaerobic microsites, enhancing soil moisture levels and promoting methanogenesis and CH_4 emissions; in the reverse, enhanced aeration resulting from residue incorporation stimulates methane oxidation by fostering the activity of methanotrophic microorganisms [47, 86].

Soil moisture content plays decisive contribution in modulating CH_4 emissions by affecting the availability of soil water and oxygen for microbial processes, as well as influencing carbon and nitrogen mineralization, along with CO_2 respiration [88, 40]. Reduced soil moisture levels promotes CH_4 uptake in semi-arid environments due to enhanced oxygen diffusivity, and this condition facilitates the oxidation of soil CH_4 oxidation. [63], indicated excessive soil moisture resulting from flood irrigation combined with straw incorporation produced the highest mean CH_4 fluxes, culminating in a total CH_4 emission of -0.94 kg ha^{-1}. As bacterial activity increased under anaerobic conditions facilitated by irrigation practices, a concomitant increase in methane (CH_4) emission was observed, signifying that various irrigation practices can exert a huge influence on greenhouse gas emissions. Moreover, fluctuations in soil moisture levels play a critical role in determining the redox potential of the soil, which in turn, significantly affects the rates of soil derived GHG emissions [84, 5].

1.3. Effects of Nitrous Oxide, N_2O

Among the non-CO_2 greenhouse gases, nitrous oxide is significant long-lived, with agriculture identified as its predominant source on a global scale. [55], showed that, N_2O serves as a substantial catalyst for climate change and is recognized as an exceedingly reactive gas, as well as potent ozone-depleting agent in the atmosphere. It incurs negative ramifications for agricultural output and public health [11]. The release of N_2O can result in an indirect health consequence, specifically the degradation of stratospheric ozone layer; which facilitates promoted levels of ultraviolet (UV) radiation penetrating the Earth's surface, consequently elevating the prevalence of skin cancer cases [82]. In addition, areas characterized by heightened N_2O concentration suffers from air pollution attributable to its contributions. N_2O interacting with other pollutants, and generates ground-level ozone and fine particulate matter, which damage respiratory conditions, among individuals predisposed to asthma and chronic obstructive pulmonary diseases. The escalating temperature of the earth attributed to rising N_2O concentrations can also yield harmful effects on precipitation patterns and engender more extreme thermal conditions, which negatively impact plant development and productivity. Various mechanisms in the nitrogen cycle including nitrification, de-nitrification, and nitrifier de-nitrification, are acknowledged as the primary contributors to N_2O emissions. Scholars, like [75] found that agriculture is the major anthropogenic sources of N_2O emission, globally contributing nearly, 3.8 Tg N yr^{-1} or 22% to the atmospheric N_2O budget.

Many scholars explicitly explained that over application of synthetic fertilizer, utilization of manure and agricultural farm land expansion are among the primary contributors to N_2O emission emanating from soil [91, 92]. When the root systems of the plant are unable to assimilate all the applied fertilizer because of different factors, some portion of the nutrient is subjected to runoff or leaching, while the residual amount is utilized by soil microorganisms, which converts ammonia into nitrate. Nitrous oxide is released as a secondary by-product during biochemical processes that transform ammonia/ammonium into nitrate and subsequently convert nitrate into nitrogen gas (N_2) via microbial nitrification and de-nitrification respectively [27]. Global agricultural food system is heavily reliant on the utilization of synthetic fertilizers in order to enhance crop yields; the excessive application of these fertilizers is inherently unsustainable due to the resultant emissions of N_2O from soil, as well as the contamination of aquatic ecosystems through nitrate leaching.

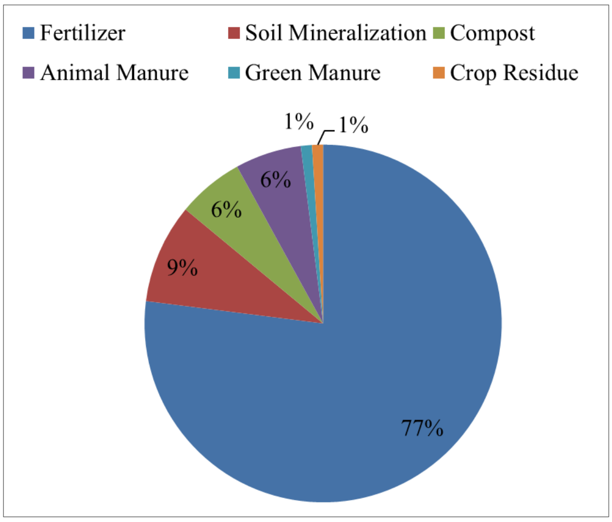

Figure 1. *Contribution of different sources to N_2O emission from soil; [27].*

1.4. Effects of Carbon Dioxide, CO_2

The effect of carbon dioxide emissions on the agricultural sector are complex, influencing both crop productivity and soil vitality. Increased level of CO_2 can impact the process of photosynthesis, particularly in C3 crops; these crops dominate the agricultural landscape accounting over 85% of plant species; wheat, rice, barley, rye, evergreens, water hyacinth, and soybean are among some of their lists; ultimately resulting in enhanced growth and increased productivity. Elevated CO_2 (eCO_2) can elevate photosynthetic rates, enhances yields from 20-35% for C3 crops, like wheat and rice, while the increase for C4 crops is notably 10-15%; are distinctive crops in photosynthetic mechanisms, offer specific advantages over C3 crops, regarding efficiency and resilient to environmental stressors [67]. The phenomenon of global warming and climate change presents many threats to agricultural productivity as the pace of carbon dioxide emissions continues to escalate dramatically. It is noteworthy that agriculture ranks as the second largest source of CO_2 emissions worldwide, with livestock production significantly contributing to greenhouse gas emissions and global warming [43].

1.5. Conventional Farming System and Greenhouse Gas Emission

In the global context, approximately 1.2 million tons of nitrous oxide is released annually from synthetic fertilizers, considering the implications for greenhouse effect, possess a potency that is 260 times greater than that of carbon dioxide, and overutilization of chemical fertilizers incurs substantial financial costs [56]. In response to these challenges, different stakeholders are increasingly adopting sustainable farming practices aimed at enhancing productivity and simultaneously mitigating nitrous oxide emission associated with synthetic fertilizers application. In combating this, farmers cultivate legumes like purple or velvet beans, soybean, fababean, which harbor root-associated bacteria capable of converting atmospheric nitrogen into useable form, thereby enriching the soil with organic nutrients essential for plant growth. This agronomic strategy aids farmers in reducing their expenses for the chemical fertilizers which meets with the goals to be achieved by 2030- a notable reduction in greenhouse gas emission, in comparison to the emission levels recorded in 2005 [22]. Since 2000, rapid expansion of croplands has augmented the global agricultural area by 9%, primarily driven by agricultural development in Africa and South America [53]. Large yield disparities; defined as gap between actual farm yields and the potential yields achievable through optimal management practices that minimizes yield losses that persist as a formidable challenges in developing nations [16].

The major source of greenhouse gas (GHG) emissions from the agricultural sector is methane; constituting 54% of total emissions, followed by nitrous oxide at; 28%, and carbon dioxide at 18%. Methane and nitrous oxide are recognized as highly potent GHGs, possessing global warming potentials nearly 256 and 28 times greater than carbon dioxide when evaluated over a century- long timescale respectively [32, 17]. Therefore, achieving net-zero emissions in the agricultural domain necessitates the attainment of net-zero emissions not only for carbon dioxide (CO_2), but also net-zero methane (CH_4) and nitrous (N_2O) emissions.

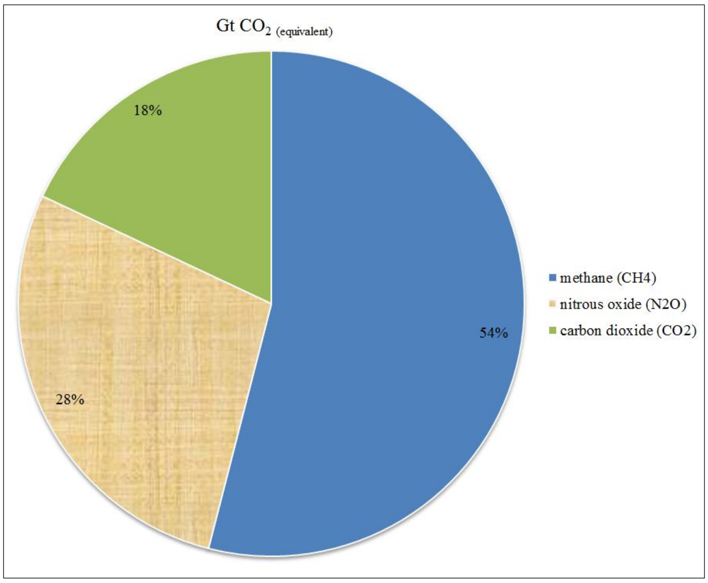

Figure 2. *GHG Emission from agricultural system, 2020, [59].*

1.6. Food System as a Major Contributor to Greenhouse Gas Emissions

Greenhouse gases emitted from the food system represent substantial factors in the phenomenon of global climate change, comprising roughly one third of human induced emissions. These emissions emerge from multiple phases, including agricultural production, processing, transportation, and waste management practices. Comprehending the origins and potential mitigations approaches is imperative for effective addressing this pressing concern.

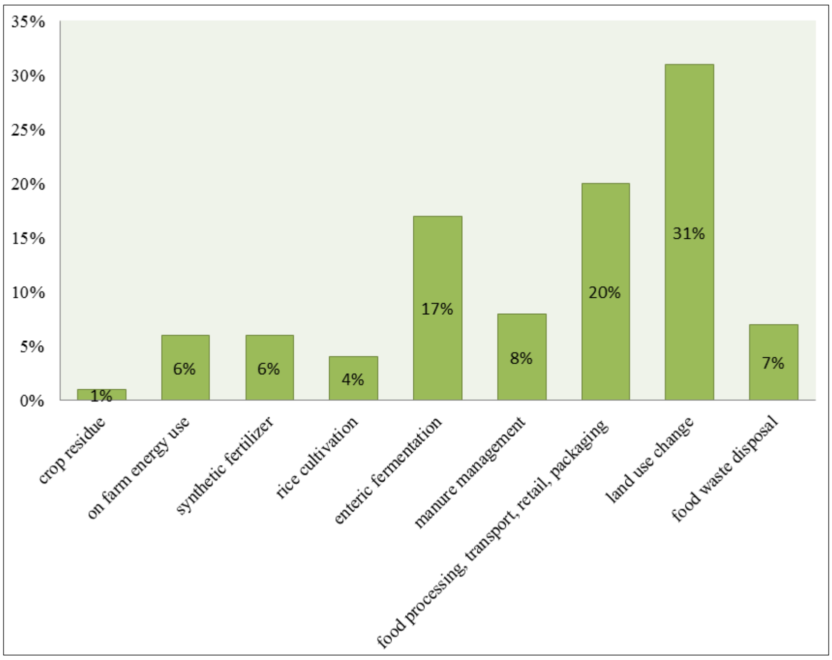

Figure 3. *Global emission of GHG from food system, 2020 [59].*

In 2020, energy consumption on farms derived from fossil fuels emitted 1.03 Gt $CO_{2\text{-eq}}$, representing 2% of the total greenhouse gas emissions; emitted for diverse applications including for the operation of machinery and equipment, pumping of irrigation water, and the provision of electricity for lighting, heating and cooling purposes. Roughly, 50% of the emission is associated with on-farm energy consumption originated from electricity usage (0.46 Gt $CO_{2\text{-eq}}$ annually), and the remaining 50% results from the combustion of fuels utilized in agricultural operations (0.53 Gt $CO_{2\text{-eq}}$ annually), encompassing diesel oil, gasoline, coal, and natural gas [23]. Figure 3

Synthetic fertilizers are decisive input in modern agriculture, but they also contribute about 1.01 Gt CO_2-eq per year, or 2% of global total GHG emissions. One third of GHG emissions come from direct CO_2 emissions due to energy inputs for ammonia production [61], while two thirds are from nitrous oxide produced during soil microbial conversion of excess nitrogen-based fertilizers [24, 46]. Figure 3

Enteric fermentation is a biochemical process that transpires in the digestive system of ruminant animals, including cattle, sheep, and goats. Ruminants possess a unique ability to ingest forage and graze on lands that are deemed unsuitable for conventional crop cultivation. 2%-12% of the gross energy consumed is transformed into enteric methane during ruminal digestion process [8], accounting 40% or 2.85 Gt CO_2-$_{eq}$ annually, of worldwide agricultural GHG emissions, or 5% of total global GHG emissions. Enteric fermentation also generates biogenic CO2, which is considered as carbon-neutral and it does not contribute to GHG emissions from a climatic standpoint. Figure 3

Manure management is an essential practice in modern agriculture; but it also contributes 1.34 Gt $CO_{2\text{-eq}}$ annually, or around 2% of the total global GHG emissions. Annually, manures generate methane; 0.28 Gt $CO_{2\text{-eq}}$, and 1.06 Gt $CO_{2\text{-eq}}$, due to the decomposition of organic matter present in the manure. Methane emitted during the anaerobic decomposition of organic materials, whereas, nitrous oxide is released throughout the storage and processing stages of manures. Figure 3.

Annually, crop residues, including straw, stover, and foliage, are responsible and contributes nearly, 0.23 Gt $CO_{2\text{-eq}}$, which represents 0.4% of the overall global greenhouse gas emissions. The decomposition of crop residues in agricultural fields, as well as their incineration, can lead to the emission of methane; 0.03 Gt $CO_{2\ eq}$, and nitrous oxide; 0.20 Gt $CO_{2\text{-eq}}$. During the combustion and decomposition process, crop residue also emits biogenic CO_2; carbon-neutral from a climatological perspective and consequently, it is not included in the calculations of greenhouse gas emissions [80]. Figure 3

1.7. Contribution of Organic Farming in Mitigating Climate Change

An investigation conducted by [70], the ramification of organic agriculture on greenhouse gas emission in the United States from 1997 to 2010, were meticulously examined. The research revealed that the influence of organic agriculture was both negative and statistically significant. The finding indicated that 1% increase in the average is dedicated to organic farming results in a reduction of greenhouse gas emission ranging from 0.015% to 0.095%. Conversely, the outcome of the study robustly and unequivocally demonstrates the beneficial impact of agricultural practices; both conventional and organic on emissions. Specifically, 1% expansion in agricultural farm land correlates with an increase in emissions between 0.103% and 0.131%. As studied by [52] agro-ecology integrates ecological concepts and principles into agricultural frameworks. By emphasizing on the interaction among flora, fauna, human populations, and the surrounding environment, the organic or agro-ecological methodology in agriculture fosters the sustainable development of agricultural households, thereby contributing to food security and sequestering carbon in the soil system.

2. Approaches to Mitigations

With new insightful, novel and empirical observations, different stakeholders in agricultural sector are able to discern the origins of greenhouse gas emissions and devise different strategies to mitigate the release of these harmful gases. The methodology employing the stable carbon-13 isotope facilitates the evaluation of soil quality and identification of carbon sources derived from soil. This, in turn, provides opportunities to understand how diverse configurations of crop rotation, land cultivation practices, and land cover can enhance agricultural productivity and optimize utilization of scarce natural resources, including water and various chemical inputs [28]. Contemporary technological advancement aimed at curtailing greenhouse gas emissions; promote the generation of biomass, implementation of cost effective methods for regulating plant growth and application of bio-fertilizers, utilization of bio-chars, nitrogen fixation by leguminous crops, and minimization of pesticide application, and the adoption of crop rotation and integrated livestock production techniques, among others [19]. Plants sequester CO_2 from the atmosphere, employing it in the process of photosynthesis. Carbon dioxide and nitrous oxide concentration increase in the soil correlates with heightened reproductive activity of microorganisms present therein [37]. Nitric oxide, which is generated from the soil and subsequently emitted, constitutes essential component of numerous synthetic fertilizers. Through the application of modern technologies, it becomes feasible to ascertain the quantity of nitrogen that plants assimilate from the soil.

Depending on quantified data, it is possible to supply the plant with precise amount of chemical fertilizer requisite for its growth; concurrently minimizing greenhouse gas emissions released into the atmosphere [64]. The emission of nitrous oxide are anticipated to escalate in the forthcoming decades as a result of the predicted rise in food demand driven by expanding global population, increased agricultural land utilization, and higher application rates. Nevertheless, the proactive management of agro-ecosystems through the regulations of soil and plant dynamics presents a viable and sustainable strategy for the mitigation of N_2O emissions, while simultaneously safeguarding crop growth and food production [80].

2.1. Incorporating Crop Residues into Soil for Mitigation Strategies

The incorporation of crop residues into the soil has garnered huge scholarly attention as a viable approach for the mitigation of greenhouse gas emissions. Crop residues including straw, stover, and other vegetative remnants remaining post harvests which are rich in organic carbon that, when reintroduced into the soil, can facilitate carbon sequestration, diminish greenhouse gas emissions, and enhance soil health [68]. The process of crop residue decomposition in the soil results in a portion of the carbon within the plant material being converted into stable organic carbon, by improving the levels of soil organic carbon (SOC); contributing to the enhancement of soil fertility and promoting long-term crop productivity [15].

Adoption of no-till or minimum agricultural tillage system practices can further minimize soil carbon losses and emission of by reducing the extent of soil disturbance [15]. Crop residue provides nourishment to soil microorganisms, which are integral to the processes of carbon and nitrogen cycling which influence GHG emissions. The presence of robust microbial community can result in a more efficient cycling of carbon and nitrogen, mainly leading to improved GHG balance over time scales [80]. Agricultural residue incorporation can lower nitrogen based fertilizer requirements as the residue releases nitrogen during the process of decomposition. Reduction of fertilizer application can lead to decrease in nitrous emission, a highly detrimental greenhouse gas originating from the soil. An overabundance incorporation practice of residues can aggravate N_2O emissions, specifically if the soil condition is conducive for anaerobic reaction in compacted soils, leading to de-nitrification; underscoring the necessity for meticulous management [91].

2.2. Recycling Bio-Wastes for Enhancing Crop Production

One-third of the food that was originally designated for human consumption is either lost or wasted on annual basis throughout the production and supply chain, culminating in an estimated global total of nearly 1.3 billion tons. The considerable volume of food that is wasted and lost indicates systematic inefficiencies within the food system; impacting food security, environmental sustainability, producer profitability, consumer pricing, and the progression of climate change [54]. Recycling of biological wastes emerged as an advantageous strategy for not only improving agricultural productivity, but also facilitating the mitigation of climate change [6]. The conversion of organic refuse into essential fertilizers enhances soil health and reduces reliance on synthetic agricultural inputs; which influence the climate and environment. Despite the existence of various types of biological wastes, three predominant and readily accessible categories; agricultural waste, animal waste and sewage sludge are available for utilization as substrate for bio-fertilizer [79]. Microbial fermentation represents an innovative approach wherein microorganisms convert the by-products of consumables plants into oils and fats [81]. This approach not only reinforces sustainable agricultural methodologies but also aids in the abatement of greenhouse gas (GHG) emissions through processes of carbon sequestration and reductions of linked to fertilizer production.

Microbial fermentation represents an innovative approach wherein microorganisms convert the by-products of consumable plants into oils and fats [81]. These microorganisms encompass yeasts, bacteria, and fungi [81]. This approach not only reinforces sustainable agricultural methodologies but also aids in the abatement of greenhouse gas (GHG) emissions through processes of carbon sequestration and the reduction of emissions linked to fertilizer production.

2.3. Management of Irrigation System

Irrigation management system constitutes essential component of agronomic practices, which guarantees the wise utilization of water resources in a secure manner. Irrigation represents a staggering 90% of the global freshwater consumption, occupies 22% of the cultivated land, and facilitates the production of 40% of global food [57]; furthermore, in the impending years, the scope of irrigation is expected to expand across agricultural lands as a strategic adaptation to climate change. Adequate governance of these systems enables the maximization of crop yield while concurrently minimizing wastage, which contributes to greenhouse gas emissions. Systematic water distribution methodologies, thorough strategic frameworks, and incorporation of cutting-edge technologies can significantly improve the management of irrigation, enhancing sustainability and productivity within agricultural practices. In the developing countries; India, Pakistan, Bangladesh, and considerable parts of Africa, flood irrigation (FI) methodologies emerge as a predominant irrigation paradigm [51].

The substantial volumes of water supplied to crop through FI lead to the dilution of fertilizer, fostering conditions that promote anaerobic environment; these conditions are conducive to the generation of N_2O and nitrate leaching [65]. In order to alleviate these challenges, the adoption of a meticulous water management strategy holds the promise of conserving water resources while simultaneously curtailing N_2O emissions. In a similar way, intermittent irrigation, characterized by altering cycles of watering and draining the field, demonstrate significant potential to mitigate N_2O emissions from soil, as this irrigation technique enhances soil oxidative conditions by promoting root activity, increasing soil bearing capacity, and ultimately reducing water inputs that foster anaerobic environment; which facilitates the infiltration of oxygen into paddy soils; contributing to reduction in N_2O emissions. Another alternative irrigation approach is the sprinkler-irrigated field (SI), in which the surface layer exhibits a comparative looser structure than that of flooded irrigation (FI). Consequently in such soil conditions, the leaching of NO_3-N and NH_4-N is diminished, resulting in a greater concentration of these nutrients in the root zone, thus rendering them more readily absorbable by plant roots and consequently decreasing the like likelihood of their conversion to N_2O [71].

Irrigation exerts considerable environmental effects regarding carbon emissions attributable to fossil fuel-driven water pumping [62, 69]; it is estimated that approximately 80% of global energy consumption associated with groundwater extraction results in CO_2 emissions stemming from irrigation practices, by rendering the mitigation of groundwater-dependent irrigation critical [89]; this activity contributes 0.22 Gt of CO_2 emissions from irrigation, approximately representing 15% of the global greenhouse gas emissions and energy utilization in agricultural operations [59] on global scale, nearly half of irrigation practices are executed using electric pumping systems, while the other half relies on diesel-powered mechanisms [60, 14]. the implementation of electric pumping and irrigation technologies powered by low-carbon electricity, such as solar energy-assisted drip irrigation; which have the potential to decrease energy consumption and carbon emissions by 95% [60].

Different researchers determined that emission of carbon dioxide (CO_2), nitrous oxide (N_2O), and nitric (N)) oxide can be reduced by 62% through the implementation of surface drip irrigation techniques [30]. The concomitant application of nitrogen fertilization with precise precipitation forecasting or scheduled irrigation practices can facilitate a further reduction in greenhouse gas emissions. Drip irrigation system is more effective in lowering GHG emissions than a flood irrigation system, while simultaneously enhances crop water productivity through the adoption of optimal irrigation schedule. [31], reported that by tailoring irrigation method, duration, and volume to specific agricultural requirements, GHG emissions can be further significantly mitigated. Advanced irrigation technologies, including soil moisture sensors and automated controllers, have the potential to enhance irrigation efficiency, curtail non-productive water utilization, and minimizes energy consumption as revealed [26]. Other scholars, [29], also indicated, no-till farming, minimum tillage, mulching, and the implementation of agrivoltaics can facilitate greater water retention within the soil by minimizing soil evaporation, thereby reducing the demand for irrigation water. Deficit irrigation, characterized by the cultivation of crops under mild water-stress conditions, has the capacity to decrease water and energy consumption, as well as CO_2 emissions [58]. An irrigation exercise also contributes to nitrous oxide emissions and methane from the soil.

Research conduted showed comparative studies at field scale indicated that nitrous oxide emissions can escalate by 50% to 140% in irrigated cropping systems compared to non-irrigated lands; however drip irrigation is projected to induce 32% to 46%, less nitrous oxide emissions relative to furrow or sprinkler irrigation methods [38, 78]. Further irrigation is vitally important in order to quantify the benefit and to promote the widespread adoption of water management practices among agricultural producers.

2.4. Soil and Water Conservations

The mitigation of climate change through the conservation of soil and water resources is progressively acknowledge as an essential approach in mitigating the impact of climate change, especially in the agricultural sector. The proficient management of soil moisture and water resource has the potential to markedly diminish the detrimental consequences of climate variability, bolster food security and foster sustainable agricultural strategies. Limited soil moisture is one of the most critical environmental factors affecting crop production and food security in the semi-arid zones of East and Southern Africa (ESA) [21]. Soil moisture serves as an essential function in the mitigation of climate change by affecting both carbon sequestration process and the resilience of the ecosystem. The preservation of soil moisture levels can clearly reduce land warming and postpone vital temperature thresholds, while concurrently improving agricultural productivity and enhancing preparedness for disasters.

In various angles, writers revealed that insufficient or increasingly unpredictable precipitation is exacerbated by substantial runoff originating from agricultural fields, which is estimated to be between 25% and 30% of precipitation received under conventional tillage practices [72],. The elevated runoff can be attributed, in part, to inappropriate tillage practices, employed by small holder farmers, as well as in absence of vegetative cover on the soil surface. As a result, numerous soils are rendered degraded and unproductive as an outcome of nutrient leaching; erosion caused by water and wind and the incessant practice of cropping, leaving farmers unable to achieve an optimal yield potentials.

Researchers found that preserving existing soil moisture content can mitigate 32.9% terrestrial warming in the context of low emission scenario, thereby deferring significant warming benchmarks by a minimum of ten years [90].

Table 1. *Benefits of forage for soil and water conservation.*

Forage arrangement (only KK2 considered against baseline)	**Annual rainfall (mm)**	**Increase in maize yield (%)**	**Increase in biomass (%)**	**Reduction in erosion (%)**	**Increase in soil moisture storage (%)**	**Increase in income (%)**
Sustainable intensification domain		productivity		Environment		Economic
Control (baseline)		n/a[2]	n/a	n/a	n/a	n/a
Napier on contour(sole)		15	10	25	31	10
Napier + desmodium on contour	Long 1100	22	15	45	57	15
Napier + lablab on contour control		n/a	n/a	n/a	n/a	n/a
Napier on contour		13	15	35	42	14
Napier desmodium on contour	Seloto 850	20	25	40	47	20
Napier + lablab on contour		28	20	55	65	30

Both farm labor and on farm inputs were considered in the calculation of net income. Net income includes yield income less the costs of seeds, labor for planting, and management, n/a= not applicable (Source; [36]).

The utilization of perennial forage significantly mitigated soil erosion by reducing runoff and at the time enhanced productivity, biomass accumulation, soil moisture retention, and net economic returns. In the validation trials indicated in the table, the management approach for Napier sole exhibited minor variations as integration of Napier with desmodium and Napier with lablab consistently achieved complete ground coverage; which effectively suppressed weed growth. Moreover, the synergetic combination of Napier with lablab appeared to yield the most advantageous co-benefits [36].

The research undertaken, regarding the impact of forage grass-legume intercropping on a 10% gradient revealed that runoff volumes were decreased by an annual range of 60-120 mm. the findings indicated significant enhancement in soil moisture retention estimated approximately, 25 mm of water over a 50 cm depth, representing a 30% increase in comparison to the control regions devoid of forage legumes (Figure 4).

According to [39], incorporation of organic constituents derived from agricultural residues and livestock excrement enhances the physicochemical characteristics of soil, including bulk density, and porosity, thereby promoting superior retention of water and accumulation of organic matter. Conservation agriculture promotes equilibrium between microbial necromass and plant detritus, resulting in sustainable soil organic carbon (SOC), reservoir. Researchers, [35] indicated that, the accumulation of microbial residue was markedly enhanced with the incremental incorporation of plant residues over time.

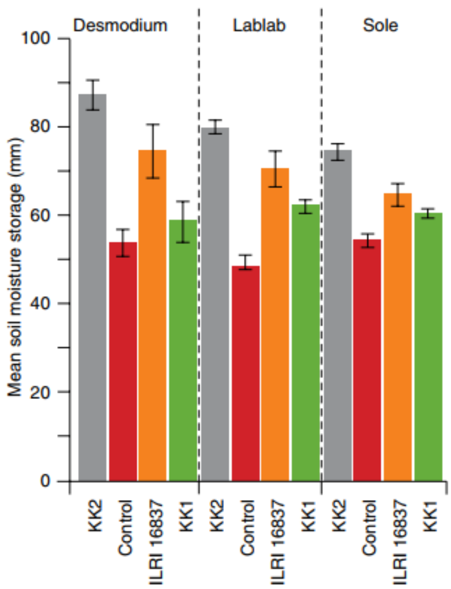

Figure 4. *Mean soil moisture storage for forage grass and legume combinations along contour strips with a 10% slope in a maize farm (2014–2015). Horizontal axis: KK1 represents Kakamega 1, KK2 is Kakamega 2; these and ILRI 16837 are Napier grass accessions from the International Livestock Research Institute. Source: [36].*

Table 2. Effect of tillage and organic materials management on bulk density.

Treatment	Bulk density (Mgcm^3)		
	2013 major season	2013 minor season	2014 major season
Tillage			
No-tillage	1.48 [a]	1.46[a]	1.53[a]
Hoe tillage	1.43 [a]	1.38 [a]	1.55 [a]
Amendment			
Control	1.50 [a]	1.52 [a]	1.52 [a]
Cattle manure	1.45 [a]	1.37 [b]	1.55 [a]
Cowpea	1.42 [a]	1.34 [b]	1.49 [a]
Elephant grass	1.46 [a]	1.37 [b]	1.51 [a]
Maize	1.43 [a]	1.38 [b]	1.51 [a]
Lsd (0.05)			
Tillage	NS	NS	NS
Amendment	NS	0.1	NS
CV (%)			
Tillage	2.50	2.50	0.90
Amendment	4.30	3.30	1.30

NS- not significant at 5%, a,b- with the same alphabet, within the column is not statistically different (Source:, [35])

3. Conclusions

Agriculture is a cornerstone of human survival and growth, supplying food, fiber and resources that supports livelihood of worldwide. With the global population projected to exceed 9 billion by 2050, agriculture faces mounting challenges to sustainably feed everyone. Climate change significantly impacts agriculture, requiring effective mitigation and adaptation strategies to ensure food security and sustainability. These strategies includes enclose a range of practices targeted at reducing greenhouse gas emissions; through adoption of precision agriculture, agroforestry, and conservation agriculture, and enhancing resilience to climate related challenges. Utilization of solar, wind and biomass energy sources in agricultural operations can lower carbon footprints; in addition, minimizing food wastes, implementing efficient irrigation system and water saving techniques can help farmers to cope with altered precipitation patterns. Balancing instant agricultural demands with enduring sustainability goals remains complex challenges for policymakers and farmers alike.

4. The Way Forward

Climate change mitigation involves a comprehensive approach which integrates technological advancement, regulatory frameworks, and ecological stewardship. Robust strategies must incorporate carbon reduction initiatives, adaptive measures, and the facilitation of sustainable practices across diverse sectors. The application of carbon sequestration technologies encompassing both geological and biological approaches is crucial for the effective capture of atmospheric CO_2. Sustainable forest management practices can improve carbon storage capacities while simultaneously supplying materials that serve as substitute for energy-intensive commodities. The mitigation of short-lived climate forcers, such as methane and black carbon is of paramount importance, given their significantly greater warming potential relative to CO_2. Various designed initiatives; Global Methane Pledge are substantial to curtail methane emissions, thereby facilitating the achievement of climate goals with greater efficacy. This strategy offers holistic responses to challenges of climate change mitigation; however, obstacles persist in their implementation, specifically in developing nations where resources and technological capabilities may be constrained. Addressing these inequities is essential for fostering global advancement.

Abbreviations

GHG Greenhouse Gas

FI	Flood Irrigation
SI	Sprinkler Irrigation
GWP	Global Warming Potential
UN	United Nation
SDG	Sustainable Development Goal

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Adugna Bayata: Conceptualization , Investigation,Methodology , Resources, Supervision, Writing – original draft, Writing – review & editing

Getachew Mulatu: Supervision , Validation ,iting – original draft, Writing – review & editing

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