CLIMATE-SMART AGRICULTURE: EMPHASIS ON PRINCIPLES AND PRACTICES OF SOIL MANAGEMENT

Abstract

Climate change is an alarming issue of today's world. Besides, world population is also growing fast. So, agriculture practices need to be modified to 'climate-smart' strategies to overcome dual challenges of climate change as well as food security. The concept of climate smart agriculture (CSA) is based on three pillars: (1) ensuring agronomic and economic productivity, (2) building resilience to combat climate change, (3) mitigating climate change i.e., reducing and/or removing carbon emissions. Climate-smart agriculture is an amalgamation of weather, water, soil, crop, nutrient, carbon-energy and institute-knowledge smart technologies. This article aims to discuss principles and practices of soil management segment of CSA which is based on principles like erosion control, sustainable management of land, carbon management etc. Among different soil management practices Integrated nutrient management (INM), organic farming, conservation agriculture, precise application of fertilizer, smart fertilizers, biochar application, agro forestry etc. are promising. However, in CSA, soil management necessitates both innovative concepts and long-term planning and policies to attain a win-win situation.

Keywords: Climate smart agriculture, pillars of CSA, principles, soil management

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I. INTRODUCTION

According to Inger Andersen, Executive Director of UN’s Environment Programme, the issue of climate change is now a reality and has become an immediate threat. Moreover, the global population is rising day by day. The world population is expected to grow by more than a third (or 2.3 billion people) between 2009 and 2050. If present income and consumption patterns continue, the Food and Agriculture Organization (FAO) anticipates that by 2050, agricultural production must increase by 60% to meet the predicted demand for food and feed [1]. By 2050, the demand for cereals is expected to increase from its current level of around 2.1 billion tonnes to almost 3 billion tonnes for both food and animal feed [2]. So, a paradigm shift in agriculture is much needed which would sustain food production and would be able to feed the entire global population as well as would have some adaptation and mitigation strategies to combat climate change. Climate-smart agriculture is one such strategy that takes into account all these aspects and could be a win-win approach for sustainable food production, and mitigation of adverse consequences of climate change.[3]. For sustained productivity and ecological services to occur, healthy soil is a prerequisite. Among different management strategies, soil management in CSA plays a crucial role in carbon sequestration, greenhouse gas emission, and sustainable development. So, this chapter aims to highlight the principles and practices of soil management in the purview of climate-smart-agriculture.

II. CLIMATE-SMART AGRICULTURE (CSA)- DEFINITION AND CONCEPT

An integrated strategy for creating the necessary technical, policy, and financial conditions to enable sustainable agricultural development for food security under climate change is known as climate-smart agriculture [2].

FAO has developed the concept of climate-smart agriculture (CSA) as a strategy to ensure food security in a changing environmental conditions. Through the adoption of appropriate practices, the development of policies, and the mobilisation of necessary funds, the CSA strives to increase food security, assist communities in adapting to climate change, and contribute to climate change mitigation.[2]. It is a strong idea that emphasises the relationship between agriculture and climate change while allowing for location-specific flexibility. With no regrets, trade-offs, or losers, the CSA is a triple win for investors, farmers/producers, and consumers.

In 2009, the phrase "climate-smart agriculture" (CSA) was first used. The idea of CSA was subsequently introduced at the first international conference on "Food Security, Agriculture, and Climate Change" in Hague in 2010. The sourcebook for CSA endorsed the idea in 2012 at the 2nd global conference in Hanoi, Vietnam, to particularly help small and marginal farmers and vulnerable people in poor nations. The work and conversation regarding the CSA alliance were started in the very next year, in 2013, at the third global summit in Johannesburg, South Africa. Finally, the global alliance for the CSA action plan was presented in 2014 at the Climate Summit in New York.

III. PILLARS OF CSA

Three pillars support the idea of CSA: (1) sustainably and economically increasing agricultural productivity (agronomic and economic productivity); (2) adjusting to and enhancing resistance to climate change; and (3) climate change mitigation, or lowering and/or eliminating carbon emissions.

1. **Sustainably increasing agricultural productivity:** The first pillar, "productivity," aims to raise agricultural output in a sustainable way to ensure food security and promote economic growth while minimizing environmental damage [3, 4]. In this regard, [5] reported an alternate way of growing rice in Tanzania (System of Rice Intensification-SRI) that uses less water and so flooding is not required, resulting in lower emission of methane. The authors proposed that more institutional action is needed to ensure profitability for smallholder farmers.

2. **Adapting and building resilience to climate change:** Adoption of resilient strategies to cope-up with climate change is considered to be the second pillar of CSA. The editorial of [6] primarily emphasized the “Adoption” measures to combat climate change. However, they also mentioned the benefits of combining the three pillars of CSA. The necessity for financial incentives to promote the adaptation of CSA technologies by small farmers has been noted by authors.[7].

3. **Mitigation strategies to reduce carbon emission:** It is the reduction or elimination of greenhouse emissions where practicable, by avoiding deforestation and utilizing agricultural methods that reduce greenhouse gases emission. The emission reduction is achieved through low emissions technology (LED) that is based on the difference in emissions between those utilizing traditional agricultural practices and those employing innovative CSA methods. “Since LED prioritizes human needs such as food over mitigation, it initially identifies agricultural development goals before moving on to the various mitigation strategies that can be used to achieve those goals.” [8]. There are still disagreements regarding the implementation of international agreements like the Global Alliance for Climate-Smart Agriculture (GACSA), which was introduced at the United Nations Secretary General's Climate Summit in September 2014 with the aim of assisting 500 million smallholder farmers to practice CSA.

IV. COMPONENTS/DIMENSION OF CSA

1. **Weather-Smart CSA:** Small and marginal farmers are especially susceptible to the effects of climate change. Due to heat and cold stress, their livestock and crops are frequently in danger. However, a crucial and frequently overlooked part of "weather-smart" CSA is weather prediction-based livestock protection from harsh weather occurrences. Real-time weather monitoring and reporting, weather-based crop agro-advisory services, real-time weather-fluctuation-based crop insurance (CI), climate awareness, and climate-smart housing for animals are the components of the "weather-smart" dimension.

2. **Water-Smart CSA:** Rainwater harvesting, in-situ moisture conservation, aquifer recharge, efficient irrigation application systems, drainage management, and integrated farming systems are the main elements of "water-smart" CSA.

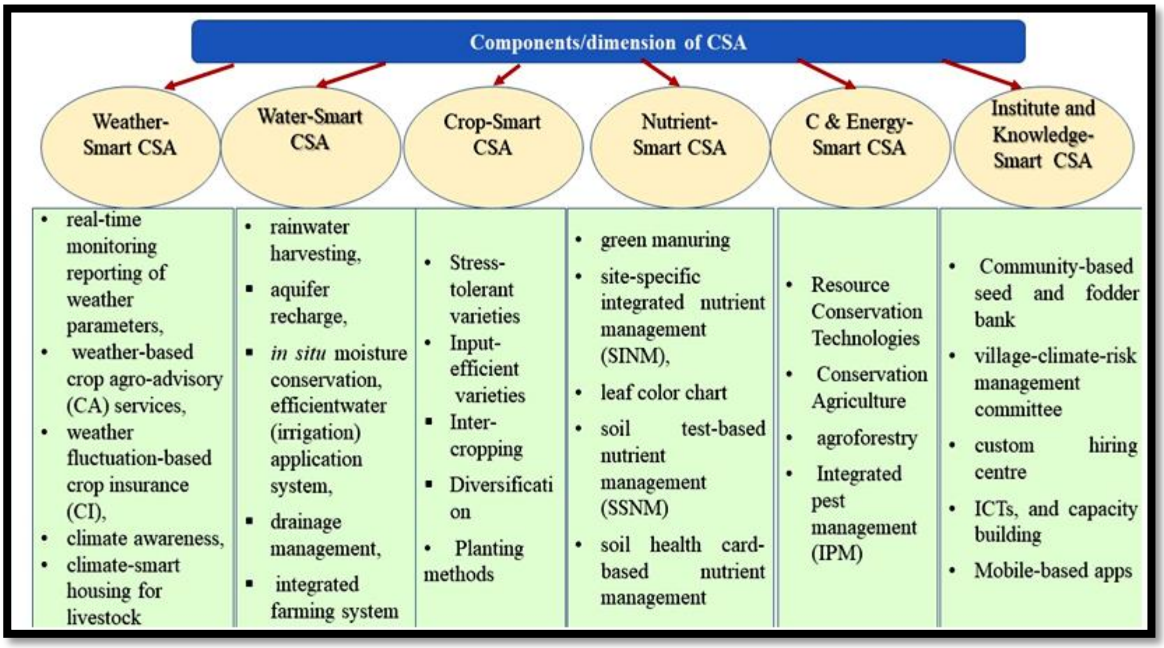
3. **Crop-Smart CSA:** Climate change poses a severe threat to food security, agriculture, and livelihood for a large number of people in vulnerable areas around the world [9]. Extreme weather events like the melting of glaciers, global warming, sea level rising, changing rainfall distribution, frequent droughts, and floods, all have harmed crop productivity. [10, 11, 12]. Furthermore, the enormous loss of crop biodiversity, low input use efficiency, and abrupt pest outbreaks as a result of climate change are all likely causes of yield losses [13]. Different studies reported that because of expected effect of climate change, yield of rice, wheat, maize, sorghum,barley would reduce by 35, 20, 60, 50, 13% [14]. Therefore, to meet such problems and assure the security of food, livelihood, and environment, "crop-smart" adaptation solutions are needed. Some viable strategies for crop smart CSA are introduction of cultivars resistant to abiotic stress, development and adaption of varieties with improved input use efficiency, mixed cropping, intercropping, inclusion of legume-based crops in cropping systems etc. For example, raised-bed planting of maize/sugarcane, direct seeding or rice as compared to transplanting, coir-bed plantation of vegetables, pit plantation for fruits, and are few crop-smart technologies of CSA [4].

4. **Nutrient-Smart CSA:** The smart management of nutrients is the key strategy of CSA. Proper nutrient management could be win-win strategy for ensuring higher production, GHG mitigation, maintaining resilience of system. Improved soil quality is achieved by the introduction of legumes, in cropping system, precise nutrient management, and integrated nutrient management.[4].

5. **Carbon and Energy-Smart CSA:** The main objectives of carbon- and energy-smart technologies main objectives are to cut GHG emissions and reduce climate change. Some "carbon/energy-smart" agricultural approaches include integrated pest management (IPM), conservation agriculture (CA), resource conservation technologies (RCTs), and agroforestry [15]. These techniques assist in carbon sequestration and reduce CO_2, CH_4, and N_2O emissions by 15 to 25%, depending on the location and crops/livestock used. Residue management and zero tillage are examples of "carbon- and energy-smart" agriculture under CA, with many advantages including carbon buildup, soil compaction, increased infiltration, ideal soil porosity, microbial health protections, and improved soil aggregation. [4].

6. **Institute and Knowledge-Smart CSA:** To make agriculture “knowledge smart,” institutionalisation of technology delivery and maintenance systems, as well as a robust knowledge base (a mix of traditional and current scientific knowledge) are required. Moreover, CSA needs to institutionalize the technology innovation cum delivery mechanism. Knowledge smart CSA includes gender equality, ICTs, and capacity building of farmers through an awareness campaign and onsite training. Mobile-based apps for nutrient, pest, and disease management with a smart advisory in the local language nowadays were very popular [4].

Figure 1: Components/Dimension of CSA

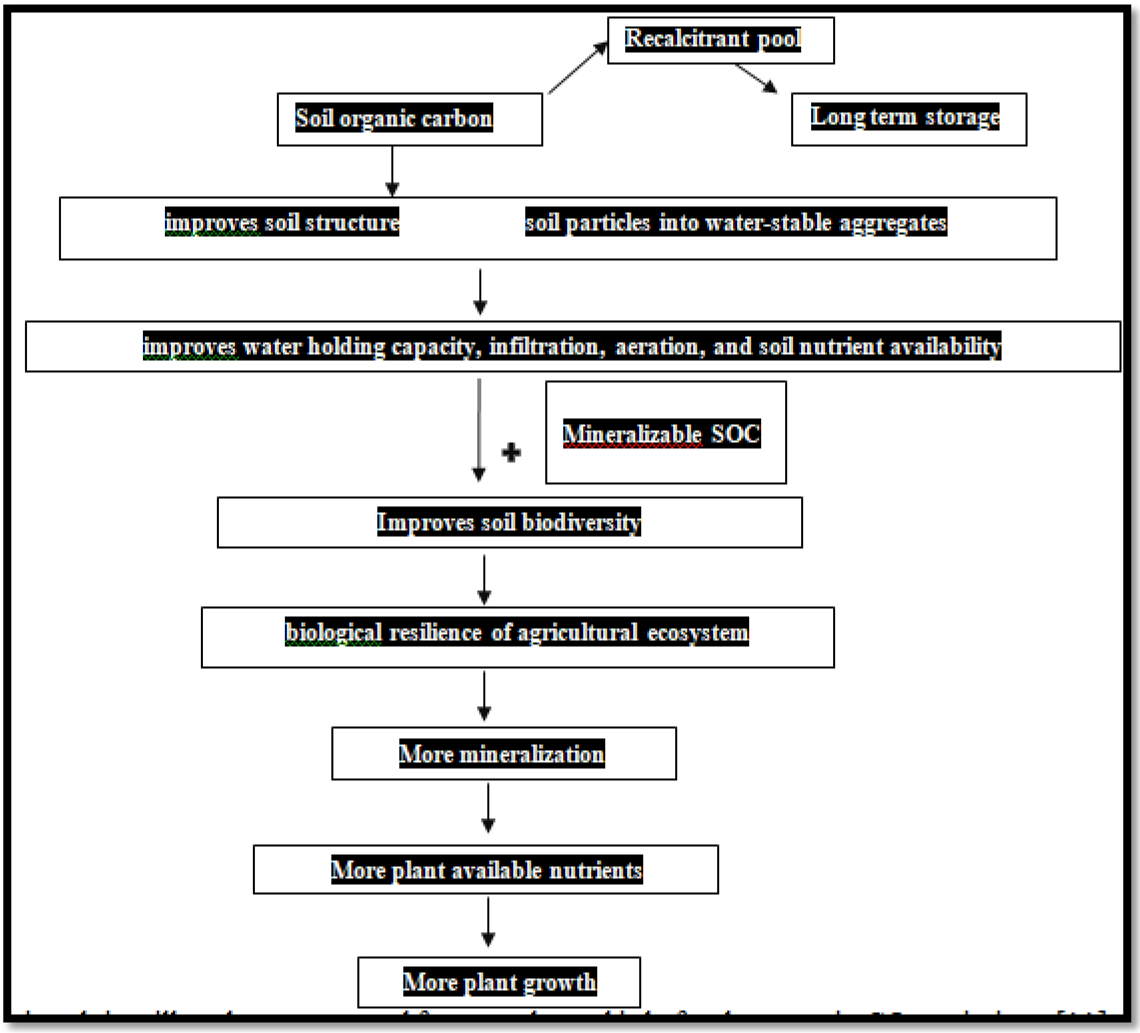


V. PRINCIPLES OF SOIL MANAGEMENT IN CSA

The principles of soil management practices under CSA are as follows:

1. **Prevention of land degradation:** When soil deteriorates, it becomes more susceptible to the adverse effects of climate change. Unsustainable land management methods, on the other hand, contribute to soil degradation. Intensive tillage, extensive mono-cropping, uneven fertilizer use, improper irrigation managements, crop residue burning, and degradation of forest lands are some of these practices. Degraded soil causes significant losses of soil organic matter, which increases soil erosion [4]. Furthermore, land degradation itself is a key contributor to climate change [2]. About 31% of all anthropogenic GHG emissions are considered to be related to land use and land use changes.[2]. Degraded soils are additionally more vulnerable to the adverse consequences of poor management and climate change. Land degradation affects biodiversity, soil organic carbon and soil erosion, all of which enhance climate change susceptibility. Restoration of damaged soils on a large scale is critical for carbon sequestration and maintaining the productive capacity of soil. The two main conditions for boosting soil organic C accumulation are increasing soil organic matter and decreasing soil erosion. More policy support and investment are needed to discover and promote appropriate agricultural systems and management practices that concurrently reverse or minimise degradation, absorb carbon, maintain biodiversity and proper ecosystem function, reduce GHG emissions, and assure sustainable productivity [2].

Figure 2: Role of organic Carbon and its implications in CSA



2. **Controlling soil erosion*:*** Soil erosion is accelerated by intensive tillage, which accelerates carbon emissions from the soil. Different erosion control measures should be adopted in CSA to achieve the goals of CSA. Conservation agriculture e.g., zero-tillage, minimum- or no-tillage, proper soil and water conservation, strip cropping with erosion controlling and erosion permitting crops, controlled grazing, contour farming, planting windbreaks perpendicular to the prevailing winds, planting across the slope, bench terracing, are some of the effective measures that can be adopted to reduce erosion. Recently geotextiles have shown to reduce soil erosion and boost biomass production in various places of the world [16, 17].

3. **Managing soil organic matter:** Soil organic matter is considered as the heart of soil**.** Furthermore, heterotrophic respiration accounts for half of carbon emissions, but soil

biological activities are responsible for all nitrogen (N) emissions from soil systems. No-tillage and cover crops, in particular, can help to control the emission of biogenic greenhouse gases (GHGs). Since 1750, land-use changes involving tillage have accounted for around one-third of anthropogenic CO_2 emissions [11]. However, soil C stocks are affected by the agro-climatic zone as well as the type and intensity of application (Fig.2).

4. **Improving water storage:** Rainfall, soil depth, soil texture (clay content), and soil structure all influence water storage in the soil. Soil management can have an impact on infiltration and the soil's ability to reduce evaporation and store water. Soil surface conditions, soil structure, SOM content, aeration, porosity, and bulk density can all benefit from ground cover management. Improvements in these qualities have an impact on water storage capacity, infiltration rates, and plant water availability. These enhancements also improve rainfall efficiency and increase production. In dry lands, they also reduce erosion, soil particle dispersion, and the risk of water logging and salinity. As a result, soil management concepts take these into account as well.

5. **Boosting nutrient management:** With agricultural intensification, organic manure (compost, plant residues) have been largely replaced by inorganic or synthetic fertilizers. The fertiliser industry recognized that the manufacture, distribution, and use of fertilisers contributes directly and indirectly to GHG emissions, mainly CO_2 and N_2O. [2]. Crop rotation diversification and improved fertilizer, seed, and pesticide management systems can improve the efficiency of input application. This decreases the quantity of external inputs wasted and thus the number of inputs required.

Table 1: Mitigating Options in Carbon Management

Low mitigating potential option	Medium mitigating potential option	High mitigating potential option
Agroforestry	Pasture cultivation system after deforestation	Reducing deforestation rate
Windbreak shelter break	Converting marginal ag land to grassland and forest	Restoring degraded soil
Agro industrial waste for fossil fuel substitution	Adopting reduced tillage, conservation agriculture	Growing energy crops for fossil fuel substitution
Recycling animal waste	Reducing fallow period in rainfed farming	
Nitrification inhibitors	Crop diversification	
Increased fertilizer use efficiency		
Integrated farming system		
Legume based cropping		

Modified from [18]

6. **Different soil management practices for climate change adaptation, mitigation and increasing resilience:** Farmers can respond to the probable negative consequences of the negative consequences of climate change by using proven soil management strategies. These measures also help to minimise GHG emissions from agricultural fields and build

resilient farming systems. Nevertheless, food security and climate change mitigation could both benefit from a policy that rewards adaptation of climate-smart management techniques. Mitigation and adaptation strategies are seen as separate but they are actually complementary targets that should be achieved in climate policy and in general mitigation to be followed by adaptation [4].

VI. CONSERVATION AGRICULTURE

Conservation agriculture is a concept which optimizes crop yield, economics and environmental benefits by enhancing biodiversity and natural ecosystem functioning. There are 3 basic principles of CA: Minimum soil disturbance, maximum soil cover by leaving and managing the crop residues on the soil surface, and crop diversification [20].

1. Adaptation benefits

- Maximum soil cover is one of the conservation farming methods that is used to prevent nutrient loss and soil erosion from wind and water.
- Conservation of water and nutrients boosts their use efficiencies and enhances crop production.
- The soil ecology becomes more resilient as a result of conservation agriculture.
- Maintaining crop cover helps in restoration of soil carbon.
- Crop rotation and crop diversification reduce pest and disease incidence in agricultural fields and leguminous species are utilised to restore soil nutrients.

2. Mitigation benefits

- Conservation agriculture reduces carbon dioxide emissions due to omission of tillage operations and minimum soil disturbances.
- Carbon sequestration: Following a sigmoid curve, sequestration potential reaches a maximum level of sequestration rates in 5 to 20 years [21, 22] and continues at diminishing rates until SOC stocks reach a new equilibrium in 20 - 30 years [11].

Table 2: Some Recent Conservation Agriculture-Based Studies for Deriving Adaptation and Mitigation Benefits

CA based treatment	Result	Area/cropping system	References
Strip tillage (ST) Vs Conventional tillage (CT)	Methane (CH_4) emission factor, flux, and GHG intensity were all lowered by ST relative to CT by 24-47 %, 20-32 %, and 31-47 %, respectively. When compared to CT, ST reduced the GHG intensity of the mustard crop by 55–61% and the GWP by 52–58%.	Bangladesh Agricultural Research Institute (BARI), Gazipur Rice-mustard-rice	[23]
Crop: Maize and wheat ICM1&2: 'business- as- usual' (conventional flatbed	ICM7&8 recorded highest (5 years avg.) maize grain yield. The five year average system yield in ICM 5-8 (in terms of maize grain equivalents, MGEY) were 9.5–14.3% higher over ICM1-4.	north- western planes of India. ICAR-Indian Agricultural Research Institute	[24]

ICM3&4: conventional raised bed (CTRB) (without residues), ICM5&6: conservation agriculture (CA)- based zero- till (ZT) flatbed (with residues) ICM7&8: CA- based ZT raised bed (with the residues).	Residue retention-based systems (ICM5- 8) contributed 7.1–14.3% higher soil organic carbon and 10.2–17.3% microbial biomass carbon in 0-15 cm layer than the ICM1- 4. 13.4-18.6% more sustainable yield index in ICM7&8 over ICM1- 4. Conservation agriculture based ICMs increased crop yields, enhanced farm profits, saved irrigation water, improved soil properties.	Wheat maize	
Sc1: Transplanted rice (TPR) + conventional tilled wheat with residue removal. Sc2: TPR+ zero tillage (ZT) wheat and mung- bean with partial residue retention Sc3: direct seeded rice (DSR) + ZT-wheat and mung bean with full residue retention, Sc4: ZT-maize + ZT-wheat and mung bean	Sc4 demonstrated the maximum humic acid content between 0 and 15 cm of soil depth (4.23 g kg^{-1}) and between 15 and 30 cm of soil (2.08 g kg^{-1}) indicating stronger soil organic carbon stability. In Sc3, more labile carbon and nitrogen were found. Prevalence of higher functional groups (O=C or CHO) in HA Sc4 >Sc3 >Sc2 >Sc1. Therefore, CA offers a more stable HA complex with soil particles, which will have long-term effects on soil carbon sequestration.	ICAR-CSSRI (Central Soil Salinity Research Institute), Karnal, Haryana, India.	[25]
Conventional tillage-CT, No tillage-NT , No tillage with crop residue retention -NTR. Cropping systems: jute-rice-wheat, jute-rice-lentil and jute-rice-mustard.	The highest SOC density was recorded in the NTR. Soil microbial biomass (SMBC): NTR>NT>CT Jute-rice-lentil (J-R-L) under NTR produced the highest jute equivalent yield (JEY) (7.33 t ha1).	ICAR-CRIJAF (Central Research Institute for Jute and Allied Fibres)	[26]

Figure 3: Relative emissions of methane (CH_4), nitrous oxide (N_2O) and global warming potential in conservation agriculture (CA) as compared to conventional practices. CA1: Zero-tilled (ZT) direct seeding in either crop in a system; CA2: ZT direct seeding in both crops in a system; R-W: rice-wheat cropping system; R: rice; W: wheat; LMF: moderately loamy fine soil; LM: medium loamy soil (source: [27])

VII. FERTILIZER MANAGEMENT STRATEGIES

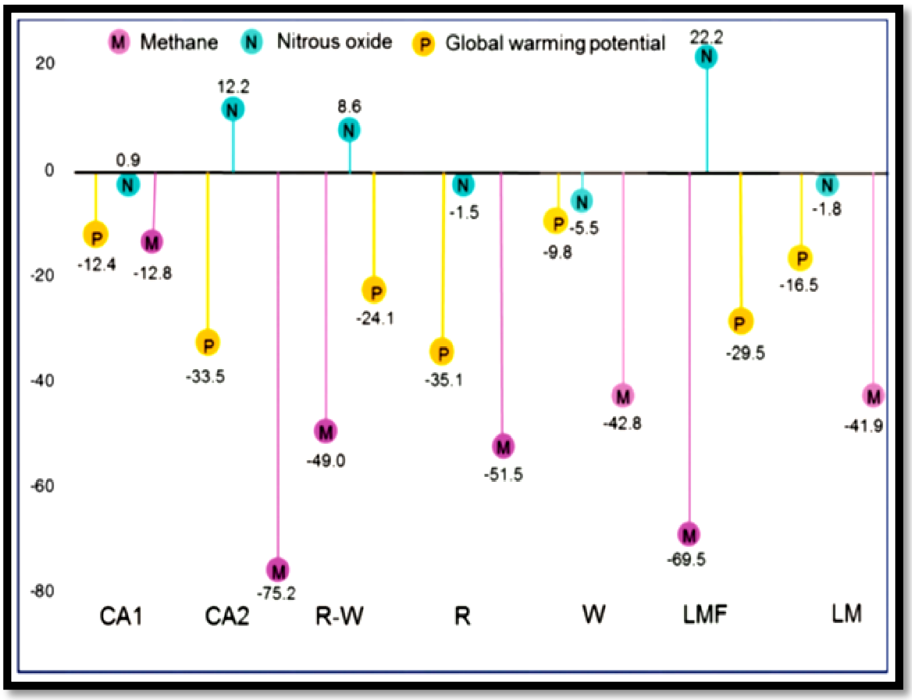
Some fertilizer management strategies which can be adopted in CSA are discussed below.

1. **Site-specific nutrient management:** In order to manage spatial variability of nutrients and improve nutrient use efficiency, it is a systematic approach based on the concept of "feeding crops" with nutrients as and when necessary. This will create synergy between nutrient demand and supply under various field crop production systems. [28].

2. **Smart Fertilizers:** Smart fertilizers are a novel type of fertilizer that is made up of microorganisms and nanomaterials and release nutrient in response to plant demand.

3. **Leaf colour chart:** The leaf colour chart was developed by International Rice Research Institute, Philippines. It is a qualitative measure of plant nitrogen status. Nitrogen utilization can be maximized by matching nitrogen supply to crop demand, as evidenced by changes in leaf chlorophyll concentration and colour.

4. **Indices based on remote sensing:** Various vegetation indices are developed to predict vegetation cover and greenness of vegetation. The greenness of vegetation is correlated to nitrogen status of plant thus, these indices can be helpful in nitrogen scheduling of crops. Some of the indices include Ratio Vegetation Index (RVI), Difference Vegetation Index (DVI), Green Vegetation Index (GVI), Normalized Difference Vegetation Index (NDVI), Atmospherically Resistant Vegetation Index (ARVI), Soil-Adjusted Vegetation Index (SAVI) etc. Need-based nitrogen application utilising remote sensing has been demonstrated in wheat and rice crops using NDVI which can save 15-20 % nitrogen without any yield penalty [29].



5. **SPAD meter:** SPAD (Soil-Plant Analysis Development) is a simple, fast, and portable diagnostic instrument for monitoring leaf nitrogen (N) status and optimising N topdressing time in rice.

6. **Nutrient expert:** It is a new precision nitrogen management technique that uses decision-support system software to improve crop yields, environmental quality, and overall agricultural sustainability. In collaboration with CIMMYT, the International Plant Nutrition Institute (IPNI) has created a Nutritional Expert (NE), a nutrient decision support system based on site-specific nutrient management (SSNM) principles
7. **Coated fertilizer:** Nitrification inhibitors, urease inhibitors, coated controlled release fertilizers are some other practices of climate smart agriculture which can reduce nitrogen losses by providing physical barrier or inhibiting urea hydrolysis and nitrification processes.

8. **Integrated Nutrient Management (INM):** INM refers to maximising the advantages from all potential sources of plant nutrients in an integrated manner in order to maintain the soil fertility and plant nutrient supply to an optimum level for maintaining the target crop productivity. INM can improves soil nutrients use efficiencies by a) making nutrients available from various on-farm organic resources b) reducing soil nutrients leaching through soil and water conservation.

- **Adaptation benefits of different fertilizer managements strategies**

  - It optimizes the use of organic matter in the forms of compost, animal manures or green manures etc., increases carbon sequestration, nutrients recycling, and increase water retention.
  - Maximizes nutrient use efficiency through various agronomic (e.g., crop rotations, intercropping with nitrogen-fixing crops etc.) and fertilizer managements (e.g., split-dose, slow-release fertilizers etc.).

- **Mitigation benefits of different fertilizer managements strategies**

  - The emission of N_2O can be reduced by decreasing the rate of nitrogen fertilizer application.
  - Adoption of slow release and controlled released nitrogen fertilizers, and use of urease and nitrification inhibitors can also plummet N_2O emission.
  - Application of manures at the right time, by right method and at right amount can trade-off the surge in CO_2 and CH_4 emission by sequestering carbon in soil.
  - Reduces greenhouse gases emission
  - Application of nitrogen fertilizers to synchronize the plant demand can also minimize nitrogen losses through volatilization and leaching.

VIII. BIOCHAR APPLICATION

Biochar is produced by pyrolysis (thermo-chemical conversion process) of any plant biomass (straw, wood, manure or leaves) in a limited or no oxygen environment at a temperature between 350 to 600 °C and it is fine grained, porous (high surface area), carbon rich material [30]. Due to its chemical inertness, it sequesters carbon at the application site and thus, short and long term harmful impacts to the environment can be minimized [31].

1. Adaptation benefits

- Due to chemical inertness, it cannot be decomposed easily by the soil microbes, thus helps in carbon sequestration.
- Biochar largely enhances soil biological activity and increase nutrient use efficiency.

2. Mitigation benefits

- It decreases labile carbon to recalcitrant carbon ratio which helps in reducing greenhouse gas emissions.
- Biochar is a viable alternative of residue burning practice followed in India, which causes severe air-pollution events in winter.
- Due to high CEC and AEC, biochar can adsorb nutrients thus reduce volatilization and leaching losses.

IX. ORGANIC FARMING

“Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects” [32].

1. Adaptation benefits

- It depends on crop rotation, residue incorporation, mulching, composts, and green manures to replace soil carbon and primarily avoids using inorganic fertilisers or pesticides which are harmful to humans, animals and environment.
- Organic farming results in higher soil organic matter content.

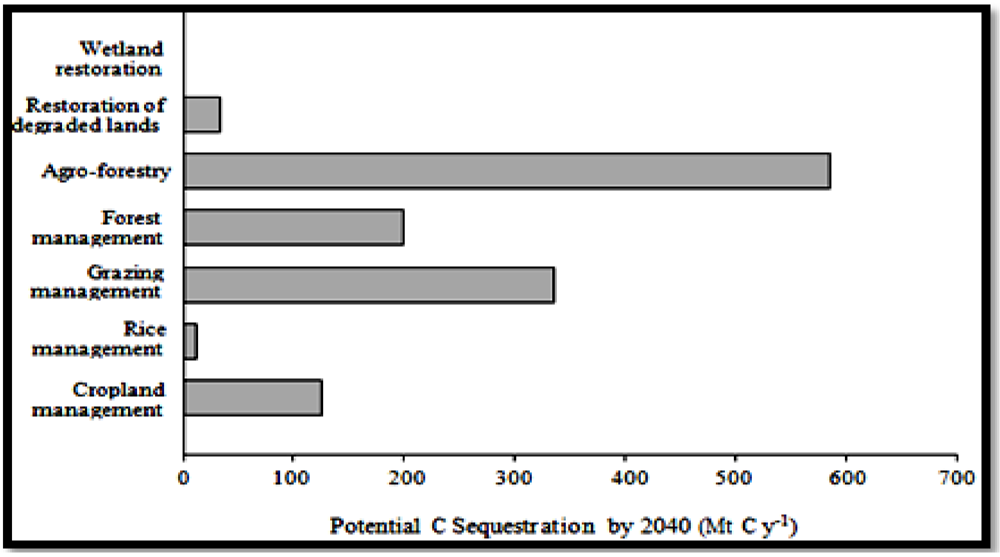
2. Mitigation benefit

- The alternative soil management practices in fallow seasons can promote soil carbon build-up and decrease the GHGs emissions.

X. AGROFORESTRY SYSTEM

The agro-forestry system is viewed as a sustainable land use management practice in developed as well as developing countries. The carbon content is distributed in five major pools in agroforestry system e.g., above ground biomass, root biomass, plant litter, soil microbes, and soil carbon. Tree cover increases carbon sequestration potential per unit land due to a) higher above ground biomass than herbaceous annual crops b) more lignin content which prevents faster decomposition in soil c) more extensive root system which explore the soil further from the trunk and also to a greater depth compared to field crops thus adds large amount of organic matter to a greater volume of soil [33]. Different strategies come under the umbrella of agro-forestry system e.g., silvi-pasture, agri-silviculture, riparian buffers, wind breaks, forest farming, alley cropping etc.

Figure 4: Carbon Sequestration Potential of Different Land use and Management Options (Adapted From [34])



Site specific adaptive characters of these systems offers a substantial amount of stability to the environment and also acts as a sink of GHG emissions and buffer to the climate change [35]. Kyoto protocol identified agroforestry system as a net greenhouse gas sink and developing as well as under-developed countries are giving more attention to the agroforestry system for achieving their carbon emission goals [36].

1. Adaptation benefits

- More biomass production of the tree component provides the soil with higher organic carbon and more nitrogen.
- Higher organic carbon augments the microbial functions and improves overall soil quality.
- Extensive and deep root system reduces soil erosion.

2. Mitigation benefit

- Due to high above and below ground biomass, perennial trees can sequester significantly larger amount of carbon in recalcitrant and stable pools than annual crops thus serve as a net sink of carbon emission.

XI. CONCLUSIONS

Climate-smart agriculture may be a win-win strategy in the modern world for meeting the population's demands for sustainable food while also paving the way for adaptation and climate change mitigation. In order to increase carbon sequestration and lower GHG emissions from agricultural land, it is essential to choose the right nitrogen and carbon management practices. The greenhouse gas emissions that contribute to global climate change can be decreased by using the proper kind of carbonaceous material and using nitrogenous fertilizers wisely. INM, organic farming, and conservation agriculture are among the several management techniques that may be effective in achieving the aim of food security in relation to carbon sequestration. Incorporating crop residues and organic matter in the soil is one of the best management practices for improving the soil organic carbon supply. In the temperate zone, reducing tillage intensity to encourage soil aggregation and improve SOC stock is a beneficial strategy, but it is also gaining acceptance in the tropics and subtropics. In drylands, residue retention and no-tillage also have a major favourable influence. To further reduce GHG emissions, more inorganic input-intensive manufacturing processes must be converted to integrated production systems. The soils have excellent buffering capacity. The surge in soil carbon emission and soil carbon sequestration, both are slow, undetectable processes over a long time. Common stakeholders are therefore not aware of the immediate effects. And, because of this lack of awareness among farmers, developers, and politicians, climate resilient soil management are severely constrained. In CSA, soil management is necessary to achieve the win-win situation through climate smart agriculture. This requires both creative concepts and long-term planning and policy.

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