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Climate Smart Agriculture – A Path Towards Sustainable Crop Production

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Climate smart agriculture (CSA) is an integrated approach to manage different landscapes like croplands, livestock, forests and fisheries to address the interlinked challenges of food security and climate change. Agriculture is facing so many challenges to fulfil the demands of our ever-growing population. A growing global population and changing diets are driving up the demand for food. Production is struggling to keep up as crop yields level off in many parts of the world, ocean health declines and natural resources including soils, water and biodiversity are stretched dangerously thin. By 2050, the world will need to produce about 70% more food to meet the requirements of an estimated 9 billion people and this will be the most difficult challenge to face the food security. The challenge is further intensified by agriculture's extreme susceptibility to climate change. Climate change's negative impacts are already there and being felt, in the form of rising temperatures, weather unpredictability, shifting agro-ecosystem boundaries, invasive crops and pests and more frequent extreme weather events. On farms, climate change is reducing crop productivity/yields, the nutritional quality of major cereal crops and decreasing livestock productivity. Substantial investments in adaptation will be required to maintain and/or enhance current farm yields and to food quality.

1. Introduction

Climate change (CC) is considered as one of the major environmental problems of the 21st century and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather conditions, or in the distribution of weather around the average conditions (i.e., more or fewer extreme weather events). Agricultural productivity can be affected by climate change in 2 ways: first, directly, by affecting plant growth development and yield due to change in rainfall/precipitation and temperature and/or CO_2 levels and second, indirectly, there may be considerable impact on agricultural land use due to snow melt, availability of irrigation, frequency and intensity of inter- and intra-seasonal droughts and floods, soil organic matter transformations, soil erosion, distribution

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and frequency of infestation by insect-pests, disease or weeds, decline in arable areas (due to submergence of coastal lands), and availability of energy. Agriculture is a major part of the climate problem. It currently generates 19-29% of total greenhouse gas (GHG) emissions. Without action, that percentage could rise substantially as other sectors reduce their emissions. Additionally, 1/3 of food produced globally is either lost or wasted. Addressing food loss and waste (FLAW) is critical to help meet climate goals and reduce stress on the environment, as FLAW and CC are directly proportional.

Progress has been significant in climate science and the direct and indirect influences of climate on agricultural productivity. With the likely growth of the world's population toward 10 billion by 2050, demand for food crops will grow faster than demand for other crops. The prospective climate change is global warming (with associated changes in hydrologic regimes and other climatic variables) induced by the increasing concentration of radiatively active greenhouse gases. Climate models project that global surface air temperatures may increase by 4.0–5.8^{0}C in the next few decades. These increases in temperature will probably offset the likely benefits of increasing atmospheric concentrations of carbon dioxide on crop plants. Climate change would create new environmental conditions over space and time and in the intensity and frequency of weather and climate processes. Therefore, climate change has the potential to influence the productivity of agriculture significantly. Climate variability has also become a reality in India. The increase in mean temperature by 0.3–0.6 ^{0}C per decade since the 1860s across India indicates significant warming due to climate change. This warming trend is comparable to global mean increases in temperature in the past100 years. It is projected that rainfall patterns in India would change with the western and central areas witnessing as many as 15 more dry days each year, whereas the northern and north-western areas could have 5 to 10 more days of rainfall annually. Thus, dry areas are expected to get drier and wet areas wetter. It is projected that India's population could reach 1.4 billion by 2025 and may exceed China's in the 2040s. If agricultural production is adversely affected by climate change, livelihood and food security in India would be at risk. Because the livelihood system in India is based on agriculture, climate change could cause increased crop failure and more frequent incidences of pests. Therefore, future challenges will be more complex and demanding. This chapter focuses on the variability of climate change and its probabilistic effects on agricultural productivity and adaptation and mitigation strategies that can help in managing the adverse effect of climate change on agricultural productivity, in particular for India (Chauhan et al., 2014).

2. Achieving the Triple Win of Climate Smart Agriculture (CSA)

CSA aims to simultaneously achieve three outcomes:

i. **Increased Productivity:** Produce more and better food to improve nutrition security and boost incomes, especially of 75% of the world's poor who live in rural areas and mainly rely on agriculture for their livelihoods.

ii. **Enhanced resilience:** Reduce vulnerability to drought, pests, diseases and other climate-related risks and shocks; and improve capacity to adapt and grow in the face of longer-term stresses like shortened seasons and erratic weather patterns.

iii. **Reduced emissions:** Indian agriculture is also contributing large quantity of greenhouse gases (GHG) (Figure 1). Pursue lower emissions for each calorie or kilo of food produced, avoid deforestation from agriculture and identify ways to absorb carbon out of the atmosphere.

While built on existing knowledge, technologies, and principles of sustainable agriculture, CSA is distinct in several ways. First, it has an explicit focus on addressing climate change. Second, CSA systematically considers the synergies and trade-offs that exist between productivity, adaptation and mitigation.

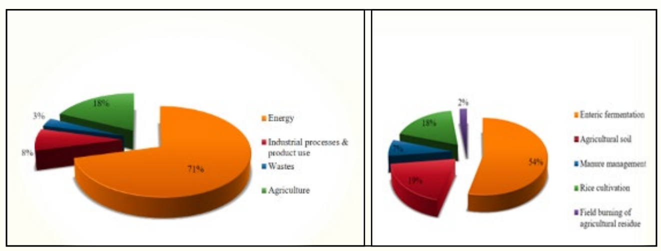

Figure 1: Distribution of GHG emissions by different sectors and sub-sectors in India (Anonymous, 2018)

The target of CSA could be achieved by adopting and implementing different agro-ecological approaches like:

1. Conservation agriculture
2. Agroforestry
3. Water management

4. Nutrient recycling through crop residue
5. System of crop intensification (SCI)

3. Conservation Agriculture

According to Food and Agriculture Organization (FAO), conservation agriculture (CA) is a concept for resource-saving agriculture crop production, which is based on enhancing natural and biological processes above and below the ground. It aims is to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs (Farooq and Siddique, 2015; Sarkar et al., 2021). CA is promoted as futuristic crop production technology not only for climate change effect but also for long term sustainability due following benefits.

• To stabilize/reverse widespread degradation of resource base

• Declining factor productivity (water, nutrient, energy, labour and pesticide)

• Deteriorating soil health (physical, chemical and biological)

• High surface runoff and erosion

• High global warming potential

• To enhance water-use efficiency for rainfed and irrigated crop production systems

• To Improve crop productivity through high input use efficiency

• To Decrease cost of production

• To improve livelihood of farmers

• Maintenance of favorable resource base for present as well as future generations

3.1. Three Principles of Conservation Agriculture

Minimum soil disturbance: This system named as conservation tillage (Friedrich et al., 2012). Direct seeding or planting (zero tillage, reduced tillage, etc. Figure 3) of crops led to less fuel consumption, reduces GHGs emission, environmentally safe, reduction in the input cost by 80%, compaction of the soil, water loss by runoff and prevent soil erosion (Das, 2013).

Permanent soil cover: Soil cover is one of the most critical factors in ensuring the success of CA (Figure 4). Drop in soil organic matter due to limited return of organic biomass owing to residue burning has been identified as one of the key factors for declining productivity of cropping systems. Permanent soil cover with residue brings many favorable changes in microclimate like maintaining optimum soil temperature, less evaporation, interference in the weed growth, reduce soil and water runoff and improvement in the soil physical, chemical and biological properties.

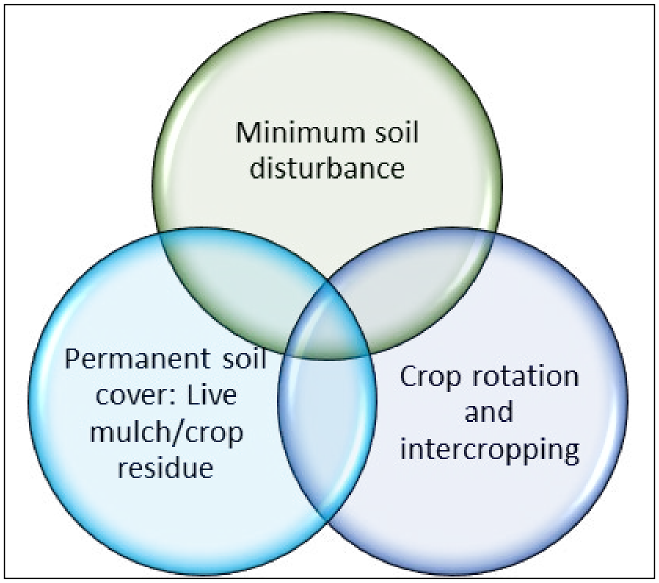

Figure 2: Three Principles of Conservation Agriculture

Figure 3: Growing of barley, wheat, chickpea and greengram in zero tillage

Vegetable pea is heavily infested with weeds, which can cause yield losses up to 39%. Only pre-emergence herbicide is not enough to control diverse weeds. Integration of other options with herbicides may provide effective weed management. The application of pendimethalin 0.5 kg a.i. (active ingredient) ha^{-1} as

Figure 4: Mulching in chickpea, okra and baby corn for higher productivity

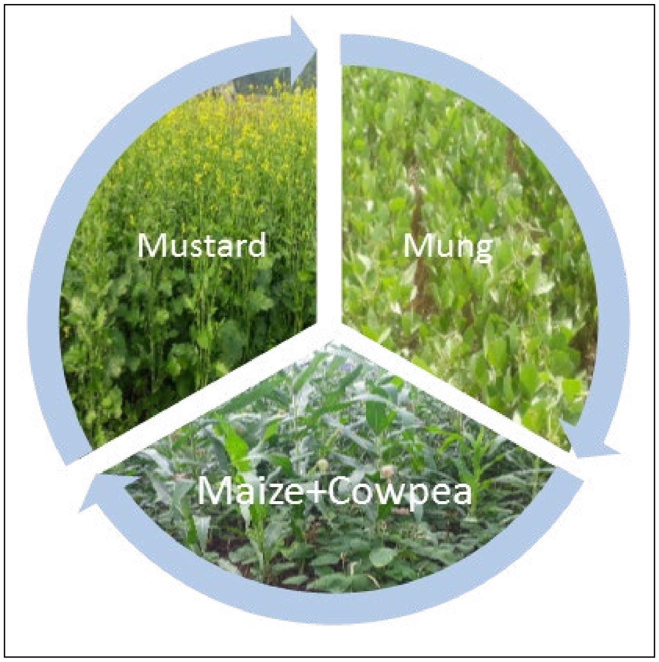

Figure 5: Inclusion of oilseeds and pulses for higher productivity and sustainability

pre-emergence+residue 2 t ha^{-1} followed by imazethapyr 0.075 kg a.i. ha^{-1} as post-emergence gave comparable pea yield with weed-free control, which was79.6% and 77.3% higher, respectively in first and second year than that in unweeded control (Kaur et al., 2020).

Benefits of soil cover:

• Increased water infiltration

• Suppress weed flora

• Decreased water evaporation

• Increased water available to crops

• Less soil erosion from both water and wind

• More biological activity

• More soil organic matter and available nutrients

• Moderated soil temperatures

Crop rotation/diversity (diversity of species):

• Growing of different types of crop every season helps to improve soil structure and thus water holding capacity (Figure 5).

• Rotating of deep-rooted and shallow rooted crops that makes use of previously unused soil moisture

• It reduced greenhouse gas emissions.

• It increased soil carbon content and higher soil carbon content helps combat climate change

• Crop rotation plays a key role in reducing the risk of nitrate.

4. Agroforestry

Agroforestry, an ecologically and environmentally sustainable land use, offers great promise towards mitigating the rising atmospheric CO_2 levels through carbon sequestration. Agroforestry is gaining a higher position and becoming a specialized science with integration of both crops and forestry science. The sustainable land use farming practices are involved in various life forms of plants/trees with livestock on a single piece of land creating more diversification with multiple outputs, enhance biomass productivity, reduce atmospheric carbon dioxide (CO_2) through absorption and fixation and protect the environment through ecosystem services. In modern day, the adoption of agroforestry is continuously rising due to their biophysical, socio-economical, cultural and environmental services in the tropical condition. In the era of climate change, it gives diversifying food and fruits under different type of agroforestry models (AFM) and can solve the food and nutritional problem of the people in society. In India, agroforestry is being practiced in about 28 m ha (Anonymous, 2021) but,

Table 1: Economics of cropping systems as influenced by crop diversification under drip irrigation

Cropping System	System productivity in terms of okra equivalent yield (t ha^{-1})	Cost of cultivation (Rs. ha^{-1})	Gross return (Rs. ha^{-1})	Net return (Rs. ha^{-1})	B:C ratio
Bottle gourd- Veg.Onion – Veg. onion	22.55	142950	338300	195350	1.37
Baby corn -Palak -Okra	29.39	148758	440850	292092	1.96
Okra-Garden pea-Babycorn	20.97	149696	314550	164854	1.10
Bottle gourd -Sarsosaag -Bottlegourd	18.94	117916	284100	166184	1.41

Table 2: Land use efficiency and water productivity of the cropping systems as influenced by crop diversification under drip irrigation condition

Cropping system	Total duration of the system (days)	Total water used by the cropping system (mm)	Income (Rs. ha^{-1} day^{-1})	Land use efficiency (%)	Water productivity (kg ha^{-1} mm^{-1})
Bottle gourd- Onion	163	484.57	1001.00	44.66	336.72
Baby corn -Palak	200	650.93	1322.54	54.8	406.35
Okra-Garden pea	179	625.93	191.16	49.04	54.67
Bottle gourd –Sarsosaag	175	582.57	821.19	47.94	246.68

if explored properly it has further higher potential to increase the land area under agroforestry. It was found that up to 65% of timber and 50% of fuelwood come from the agroforestry sector. Therefore, agroforestry has also the potentiality to reduce poverty, increase income generation and provide alternate economic sources. Along with other benefits, the practices of agroforestry are economically viable for the farmers which generate employment. Farmers have an option to select AFM as per their socio-physical conditions (i.e., land holding, economic condition, climatic condition, resource availability, market economy). From the ecological point of view, agroforestry may potentially maintain the soil quality and health which is linked with the fertility of soil and decomposition of soil organic matter. Thus, there is a nexus between soil fertility and crop productivity in various agroforestry systems (AFS). From a research point of view, there is a need for conservation of superior germplasm of agroforestry components along with their proper domestication and utilization. Research should be undertaken for maximizing the productivity of trees and crops under agroforestry for continuous benefits to farmers along with environmental protection and ecological security and sustainability.

5. Sustainable Water Management

Sustainable water means a nation that can be water self-sufficient: ensuring there is enough water to meet multiple needs, from agriculture to municipal and industrial. It also means water supply will remain consistent, despite climate change impacts, such as a lack of rainfall and drought, or too much rain and being flood resilient. Sustainable water also means that the economics stack up in matching supply and demand and the water delivery process is as efficient as possible. Water sustainability, meanwhile, can also mean energy neutrality by coupling traditional water treatment technologies with renewable energies. Sustainable water management means the ability to meet the water needs of the present without compromising the ability of future generations to do the same. Achieving sustainable water management requires a multidisciplinary and holistic approach in which technical, environmental, economic, landscape aesthetic, societal and cultural issues are addressed. On a global scale, having sustainable water means to provide each person on the planet with affordable access to the minimum 20 to 50 litres of daily water required to sustain life. Water sustainability also means effective and holistic management of water resources. UK regulator of water describes 'Sustainable water' as: "A sustainable water cycle in which we are able to meet our needs for water and sewerage services while enabling future generations to meet their own needs."

Sustainability of water resources in agriculture is achieved through determination of suitable irrigation systems and scheduling to apply proper amount of water at the right time to obtain optimum productivity and proper benefits from irrigation. This determination requires understanding of the water demand of the crops, soil characteristics, and climate factors. All these factors have major impact for the success and sustainability of any crop and water resources. There are lots of water management techniques through not only crop productivity increased but also expand irrigated area with same water resources. Such techniques include surface and subsurface drip irrigation, sprinkler system and furrow irrigation.

6. Nutrient Recycling through Crop Residue

Burning of crop residues is not only leads to loss of considerable amount of N, P, K and S but also contributes to the global NO_2 and CO_2 budget and destroy the beneficial micro-flora of the soil. Farmers are burning crop residue due to lack of efficient and user-friendly technologies for in-situ recycling. According to the Indian Ministry of New and Renewable Energy (MNRE), India generates on an average 500 m t of crop residue per year. The majority of crop residue is used as fodder but still a surplus of 140 m t out of which 92 m t is burned each year. In this way the present conventional agriculture production system is fronting with many problems like declining factor productivity, soil degradation, multi-nutrient deficiencies, low soil organic matter (SOM) etc. resulting in poor farm income and higher environmental pollution. These production constraints can be suitably addressed by proper crop residue management as it has diverse and positive effect on soil health. The crop residues act as a reservoir for plant nutrients, prevent leaching of nutrients, increase cation exchange capacity (CEC), provide congenial environment for biological N_2 fixation, increase microbial biomass and enhance activities of enzymes such as dehydrogenase and alkaline phosphatase. Increased microbial biomass can enhance nutrient availability in soil as well as act as sink and source of plant nutrients. Leaving substantial amounts of crop residues evenly distributed over the soil surface reduces wind and water erosions, increases water infiltration and moisture retention, and reduces surface sediment and water runoff. Regularly incorporation or retention of crop residue on soil surface led to build up of SOM, major nutrients and micronutrients in the soil. It has been seen that a starter dose of N at 15-20 kg ha^{-1} along with straw incorporation increases productivity of wheat and rice compared to the residue burning. Surface retention of residues increases soil NO_3^- by 46%, N uptake by 29%, and yield by 37% compared to burning.

The crop residues also play an important role in amelioration of soil acidity through the release of hydroxyls especially during the decomposition of residues with higher C: N, and soil alkalinity through application of residues from lower C: N crops, including legumes, oilseeds and pulses. The role of crop residues on carbon sequestration in soils would be an added advantage in relation to climate change and GHGs mitigation. Soil is intricately linked to the atmospheric–climate system through the carbon, nitrogen, and hydrologic cycles. Continuous submergence, higher organic C content and use of organic manure in puddled soil enhance the methane emission while crop residue retention in uplands or aerobic fields led to soil moisture conservation and reduces GHGs emission. Crop residue retention substantially reduced evaporation water losses coupled with improved soil characteristics essentially leads to higher crop yield in many cropping systems and climatic situations (Figure 6). Burning of crop residues also contributes to the global methane budget.Crop residues used as mulch in the crops like wheat, maize, sugarcane, sunflower, soybean, potato, chilli, etc which not only improve crop yield in dryland but also save them under water stress condition by conserving soil moisture and save irrigation water of about 7 to 40 cm. Wheat sowing with rice straw mulching in residual moisture reduces

Figure 6: Successful cultivation of greengram in zero tillage with crop residue retention

GHG emission and save about 20% irrigation water, which could save 80 KWh of electricity and reduce emission of 160 kg of CO_2 equivalent.

Apart from nutrient cycling, crop residue management practices also affect positively soil physical properties viz., soil moisture, temperature, aggregate formation, bulk density and hydraulic conductivity which indirectly enhanced the nutrients availability to the crop plants. Rice straw residues are highly siliceous, and have the potential of transforming electrochemical properties of acidic soils that reduces P fixation; improving base retention and increasing the soil pH. Residue incorporation results more microbial activity than residue removal or burning. Other plausible option of crop residues management lies in utilizing a portion of surplus residue for producing biochar as soil amendment to improve soil health, increase nutrient use efficiency and minimize air pollution. Managing crop residues offer sustainable and ecologically sound alternatives for meeting the nutrients requirements of crops and improving crop productivity.

7. System of Crop Intensification (SCI)

System of crop intensification (SCI) is an agroecological approach which not only improves crop productivity but also sustain the soil health. System of crop intensification approach can be followed in many crops like rice, wheat, sugarcane, mustard, maize, sorghum, finger millet, soybean, black gram, kidney bean, lentil, tomato, brinjal, chilli, potato, carrot and onion. System of crop intensification is aim to improve the productivity, profitability, sustainability, food security and resilience to climate change by altering the traditional practices of crop, soil, water and nutrient management. It is based on the cropping principles of significantly reducing plant population, improving soil conditions and irrigation methods for root and plant development. Basically, it is a climate-smart, agroecological methodology which aims to increase the productivity of crops by changing the management of plants, soil, water, and nutrients. The methodology of SCI practice includes four simple principles that interact in synergistic ways and increase crop productivity and sustainability:

➢ Establish healthy young plants carefully, taking care to conserve andnurture their inherent potential for root growth and associated shoot growth;

➢ Reduce plant populations significantly, giving each plant more room to grow bothabove and below ground;

➢ Enrich the soil with decomposed organic matter, as much as possible, also keepingthe soil well-aerated to support the better growth of roots and of beneficial soilbiota.

➢ Apply water in ways that favour plant-root and soil-microbial growth, avoidinghypoxic soil conditions that adversely affect both roots and aerobic soil organisms

Using the SCI method, smallholding farmers can produce higher yield and profitability from their land, labour, seeds, water, and capital, with their crops showing more resilience to the hazards of climate change.

Figure 7: SCI of maize +cowpea, mustard after maize and greengram after wheat

8. Conclusion

Climate change is a reality and it is one of the biggest challenges in front of the researchers, stake holders and the policy makers. The goal is to sustain the efficiency and productivity of our precious natural resources and farm inputs and at the same time to raise crop productivity and farmer's income to achieve the Sustainable Development Goals of United Nations of zero hunger and poverty in the changing climatic scenario.

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