

Climate-Smart Agriculture and Soil Resilience

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INTRODUCTION

Climate-Smart Agriculture (CSA) is an integrated approach to farming that seeks to increase productivity, enhance resilience to climate variability, and reduce greenhouse gas emissions wherever possible. At the center of this approach lies soil, which acts as the primary medium for plant growth, water regulation, nutrient cycling, and carbon storage. When soils are healthy and biologically active, they function as natural buffers against climatic stresses such as droughts, floods, and temperature extremes. Therefore, building soil resilience is not only an agronomic necessity but also an environmental and socio-economic priority in the era of climate change.

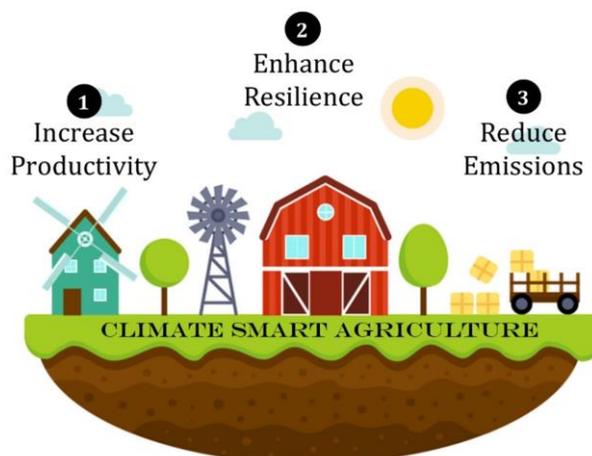


Figure 1: Climate Smart Agriculture.

3. Adaptive Practices in Climate-Smart Agriculture

Adaptive practices focus on improving soil structure, moisture retention, and biological activity to help crops cope with climate variability.

3.1 Conservation Agriculture

- **Minimum tillage** reduces soil disturbance and preserves soil structure.
- **Crop residue retention** improves organic carbon and moisture conservation.
- **Crop rotation** enhances nutrient balance and reduces pest cycles.

3.2 Agroforestry Systems

- Trees improve microclimate and reduce wind velocity.
- Leaf litter increases soil organic carbon and nutrient availability.
- Deep roots recycle nutrients from subsoil layers.

3.3 Organic Amendments

- Application of compost, farmyard manure, and biochar enhances soil aggregation and microbial activity.
- Improves water-holding capacity and nutrient buffering.

3.4 Cover Cropping and Mulching

- Protects soil from erosion and extreme temperatures.

- Enhances infiltration and reduces evaporation losses.

3.5 Precision Nutrient Management

- Site-specific fertilizer application prevents nutrient leaching and improves efficiency.
- Maintains soil chemical balance and reduces environmental pollution.

4. Drought Resilience through Soil Management

Drought represents one of the most severe threats to agricultural sustainability, and soil management plays a crucial role in mitigating its effects. Soils with higher organic matter content possess greater water-holding capacity, enabling crops to access moisture for extended periods. Practices such as mulching and reduced tillage decrease evaporation losses and maintain cooler soil temperatures.

Deep-rooted crops and diversified cropping systems improve the extraction of subsoil moisture, while rainwater harvesting and groundwater recharge techniques ensure better water availability. When soil structure is stable and porous, it allows efficient infiltration during rainfall events and stores water for future use, thereby enhancing drought tolerance at the farm level.

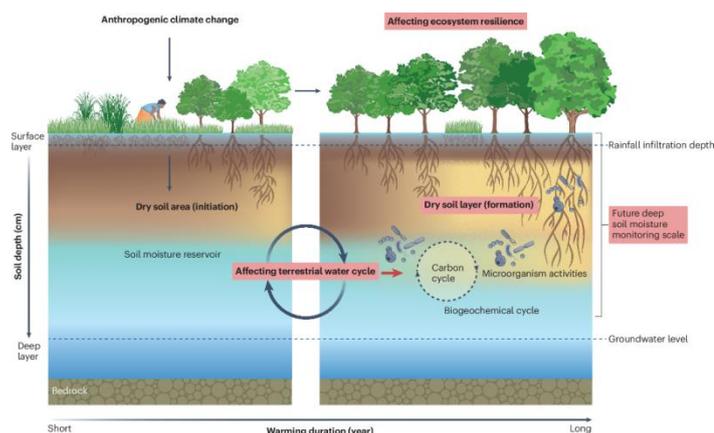


Figure 2: Impacts of Climate Change on Soil Moisture and Ecosystem Resilience.

5. Flood and Waterlogging Resilience

Excess rainfall and flooding can lead to nutrient loss, soil compaction, and root suffocation. Climate-smart soil practices mitigate these impacts.

- **Improved Drainage Systems:** Prevent prolonged water stagnation.
- **Raised Beds and Contour Farming:** Reduce runoff and erosion.
- **Soil Aggregation:** Enhances infiltration and reduces surface sealing.

- **Wetland-adapted Cropping Systems:** Suitable for flood-prone areas.

6. Carbon Sequestration and Climate Mitigation

An important dimension of climate-smart agriculture is its contribution to climate mitigation through soil carbon sequestration. Soils act as significant carbon sinks when managed sustainably. Practices such as reduced tillage, residue retention, agroforestry, and biochar application increase soil organic carbon stocks by incorporating plant residues and stabilizing carbon compounds within soil aggregates. Enhanced carbon storage not only reduces atmospheric carbon dioxide concentrations but also improves soil fertility, water retention, and microbial diversity. This dual benefit of productivity enhancement and emission reduction underscores the strategic importance of soil-centered climate solutions.

7. Policy Perspective and Institutional Support

7.1 Government Initiatives

Policies promoting sustainable land management, organic farming, and soil health monitoring are crucial. Subsidies for organic inputs, irrigation infrastructure, and soil testing services encourage farmers to adopt climate-smart practices.

7.2 Extension and Capacity Building

Farmer training programs, demonstration plots, and knowledge dissemination improve awareness of soil conservation techniques.

7.3 Research and Innovation

Investment in climate-resilient crop varieties, soil biotechnology, and digital soil mapping strengthens adaptive capacity.

7.4 International Frameworks

Global agreements on climate action emphasize sustainable soil management as a pathway for achieving food security and emission reduction targets.

8. Socio-Economic Implications

Healthy and resilient soils contribute directly to stable crop yields, reduced production costs, and diversified income sources. Farmers benefit from improved fertilizer efficiency, lower vulnerability to climatic shocks, and enhanced ecosystem services such as biodiversity conservation and water regulation. Over time, these advantages translate into greater livelihood

security and rural development, particularly for small and marginal farmers who are most vulnerable to climate variability.

CONCLUSION

Climate-Smart Agriculture represents a holistic framework that places soil at the heart of sustainable farming systems. By enhancing soil organic carbon, improving structure, and fostering biological diversity, CSA strengthens the natural capacity of soils to withstand environmental stresses. The integration of adaptive practices, supportive policies, and scientific innovation ensures that agricultural landscapes remain productive and ecologically balanced despite changing climatic conditions. Ultimately, recognizing soil as a living and dynamic resource is fundamental to achieving long-term agricultural resilience and global food security.

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