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Sustainable Cropping Systems under Climate Change

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INTRODUCTION

Climate change has turned into one of the biggest challenges facing global agriculture, honestly. More heat, weird rainfall patterns, droughts that show up more often, plus floods heat waves, and also the growing arrival of pests and diseases are putting serious pressure on crop productivity and even food security. What happens is that these shifts lower soil fertility, reduce water availability, and weaken the stability of farming production systems, like the whole setup. Because of that, using sustainable cropping systems becomes essential so productivity can keep going while natural resources are still protected. Sustainable cropping systems basically mean making efficient use of land, water, nutrients, energy, and biodiversity to produce food without damaging the environment, even a little. In practice they blend climate-smart farming approaches that build resilience, help improve how resources are used, and limit greenhouse gas emissions. When farmers adopt these sustainable systems, they can raise crop yields, safeguard soil health, conserve water, support biodiversity, and keep agriculture steady for the long run while also adapting to climate change impacts in a more realistic, day to day way.

2. Sustainable Cropping Systems Definition

A sustainable cropping system is basically an agricultural production setup that keeps crop productivity high while conserving natural resources, and also protecting the environment, and at the same time making sure farming remains economically profitable for today's generation and the future ones. It blends environmentally friendly farming practices that boost soil fertility, improve water use efficiency, support biodiversity and strengthen climate resilience,

while also reducing pollution, land degradation, and the too-heavy reliance on external inputs. In other words, sustainable cropping systems try to keep agricultural output in step with ecological protection, so that long-term food security and sustainable rural development can actually happen.

Objectives

The main objectives of sustainable cropping systems are to raise crop yields, conserve soil and water, improve soil fertility and organic matter, lower greenhouse gas emissions, and make farming more climate-resilient. They also aim to encourage agricultural biodiversity, increase farmers' income, and support food, and nutritional security, all while keeping environmental sustainability in place.



Key Principles

Sustainable cropping systems sort of rely on efficient use of natural resources, especially soil and water conservation, but also on crop diversification and nutrient recycling via organic manures, plus crop residues. They tend to push integrated pest management (IPM) so as to lessen pesticide dependence, and they also support climate smart agricultural practices which help strengthen resilience

against climate change. In the same way, environmental protection, resource management that is more efficient, and the conservation of biodiversity are the basic principles that help keep long term agricultural productivity going, sustain an ecological balance, and protect sustainable livelihoods for farming communities.

3. Major Sustainable Cropping Systems

Sustainable cropping systems are agricultural practices that aim to keep production going while also conserving natural resources and building resilience to climate change, sometimes it feels like both at once. In general these approaches improve soil wellbeing, make better use of resources, and lower environmental damage.

1. Crop Rotation:

Crop rotation means planting different crops in a planned sequence on the same piece of land across separate seasons. By rotating cereals with legumes, oilseeds, or vegetables, soil fertility tends to rise because of biological nitrogen fixation. It also disrupts pest and disease cycles, reduces weed pressure, and supports steadier crop performance. Beyond that, it helps keep soil structure in place and supports nutrient balance overall.

2. Intercropping:

Intercropping is the growing of two or more crops at the same time on one field, arranged in a fairly definite row pattern. With this system land use becomes more efficient, and the crops can capture light and nutrients in a smarter way. There is also weed suppression, fewer attacks from pests or diseases, and more biodiversity too. Typical examples are maize-bean, and pigeon pea-soybean systems in many places.

3. Mixed Cropping:

Mixed cropping is when two or more crops are grown together, but without a fixed row arrangement, so it is less “planned lines” and more “together”. This setup reduces the chance that the whole harvest fails when drought, floods, pests, or diseases show up. It usually gives more dependable yields when weather conditions are uncertain, and it keeps farmers from depending on only one kind of outcome.

4. Relay Cropping:

In relay cropping, the second crop is started sowing before the first crop is taken off. This is done so there is a steady land cover, better use of residual soil moisture, more efficient use of the growing seasons, and a higher annual yield.

5. Conservation Agriculture:

Conservation agriculture relies on three core ideas: minimum soil disturbance, permanent soil cover using crop residues, and diversified crop rotations. With these, soil organic matter improves, moisture is conserved, erosion is reduced, and production costs are lowered, while climate resilience also gets stronger.

6. Agroforestry:

Agroforestry means you bring trees together with crops on the same field, and sometimes also keep livestock there. The trees give shade, enhance soil fertility via nutrient recycling, lock away carbon, cut down wind erosion, and help biodiversity. All of that supports sustainable farming in a more lasting way.

7. Integrated Farming System (IFS):

Integrated Farming System, or IFS, brings crop production together with other enterprises like livestock, fisheries, poultry, horticulture, beekeeping, or mushroom cultivation. By cycling farm wastes between the different components, resource-use

efficiency goes up. Income becomes more varied, production risks decrease, and overall environmentally sustainable agriculture is encouraged.



Source: <https://kaybeebio.com/>

4. Climate Change Impacts on Cropping Systems

Climate change has become one of the greatest threats to global agriculture, significantly affecting cropping systems, crop productivity, and food security. Rising greenhouse gas emissions have altered weather patterns, making farming more unpredictable and challenging. Sustainable cropping systems are essential to help farmers adapt to these changing conditions.

Major Challenges

Climate change affects agriculture through several interconnected factors, including:

- ❖ **Rising temperatures**, which shorten crop growth duration and reduce yields.
- ❖ **Erratic rainfall**, causing uncertainty in planting and irrigation schedules.
- ❖ **Frequent droughts**, leading to soil moisture depletion and water stress.
- ❖ **Floods**, which damage crops, cause waterlogging, and reduce soil fertility.

- ❖ **Heat stress**, especially during flowering and grain filling, lowering crop productivity.
- ❖ **Cold stress** and unexpected frost, affecting sensitive crops and delaying growth.
- ❖ **Increased pest and disease outbreaks** due to favorable climatic conditions for insects and pathogens.
- ❖ **Soil degradation**, including erosion, nutrient loss, and declining soil fertility.
- ❖ **Water scarcity** resulting from declining groundwater levels and irregular precipitation.
- ❖ **Declining crop yields**, threatening food security and farmers' livelihoods.

Effects on Agriculture

Climate change negatively influences crop growth and production by:

- ❖ Reducing seed germination and early plant establishment.
- ❖ Causing poor flowering, pollination, and fruit set.
- ❖ Lowering photosynthesis due to heat and moisture stress.
- ❖ Increasing nutrient deficiencies through reduced nutrient availability and uptake.
- ❖ Encouraging weed infestation, which competes with crops for water and nutrients?
- ❖ Accelerating soil erosion and the loss of fertile topsoil.
- ❖ Reducing soil organic carbon, thereby affecting soil health and productivity.
- ❖ Increasing production costs due to greater irrigation, fertilizer, and pest management requirements.
- ❖ Creating greater yield variability, making agricultural production less stable and increasing economic risks for farmers.

Adopting climate-resilient and sustainable cropping systems is therefore essential to reduce these impacts, improve resource-use efficiency, and ensure long-term agricultural productivity and environmental sustainability.

5. Climate-Smart Agricultural Practices

Climate-smart agricultural practices are kind of innovative, sustainable farming methods that help farmers adjust to climate change, boost agricultural output, and cut down greenhouse gas releases. In general, they support the more efficient use of natural resources while still looking after soil, water, biodiversity and the broader environment, so farming stays possible over the long haul.

1. Conservation Tillage

Conservation tillage is basically about keeping soil disturbance to a minimum or stopping it completely, while leaving crop residues on top of the soil. This helps hold soil moisture, reduces erosion, supports soil structure, boosts soil organic carbon, and it can even strengthen microbial activity a bit.

2. Cover Cropping

Cover crops are cultivated during the off-season to guard the soil against erosion, curb weeds, raise soil fertility, increase organic matter, and limit nutrient losses. They can also foster biodiversity, and in turn, they improve soil health, overall.

3. Mulching

Mulching means covering the soil with organic materials, like straw, crop residues, or leaves, or with synthetic options such as plastic films. It saves soil moisture, helps control soil temperature, suppresses weeds, reduces evaporation, and usually improves soil fertility too.

4. Water-Saving Irrigation

Efficient irrigation methods like drip and sprinkler irrigation deliver water based on crop needs, so they reduce water wastage, boost water-use efficiency, and help crop growth plus yield.

5. Integrated Nutrient Management (INM)

INM brings together organic manures, compost, green manure, crop residues, biofertilizers, along with chemical fertilizers, to give balanced nutrition, maintain soil fertility, improve nutrient-use efficiency, and also lower environmental pollution in the process.

6. Integrated Pest Management (IPM)

IPM uses biological control, cultural practices, resistant crop varieties, mechanical methods, and sensible pesticide use, to deal with pests economically, while keeping environmental and health risks as low as possible.

7. Precision Agriculture

Precision agriculture uses modern tools such as GPS, Geographic Information Systems (GIS), remote sensing, drones, sensors, Artificial Intelligence (AI) and the Internet of Things (IoT) to keep track of crop condition, fine-tune irrigation and fertilizer dosing, reduce input costs, and increase overall productivity. In addition, these climate-smart practices strengthen resilience conserve resources, and support sustainable agricultural progress even when climatic conditions keep changing.

6. Benefits of Sustainable Cropping Systems

Sustainable cropping systems bring a mix of environmental, economic, and social benefits, so farming becomes more productive resilient and, in a way, also more “green” in everyday reality. When farmers fold in climate-smart approaches, smart management of resources, and different conservation

methods, the whole system tends to hold up for the long run.

Environmental Benefits

Sustainable cropping systems help protect soil and water by cutting down erosion, making water use more efficient and also limiting runoff. They build up soil fertility by using organic manures, rotating crops, growing cover crops, and practicing conservation tillage. Over time these actions boost soil organic matter, strengthen soil structure and keep beneficial microorganisms active. At the same time crop diversification together with agroforestry supports biodiversity, because it provides shelter and food for useful insects, birds, plus soil organisms. Sustainable practices also lower greenhouse gas emissions by avoiding excessive fertilizer, saving energy, and increasing carbon sequestration. In addition, they help stop land degradation and maintain the long-term productivity of farms and fields.

Economic Benefits

Sustainable cropping systems can raise overall crop performance and make yields more steady, while production costs often go down too, mainly because water, fertilizers, pesticides, and energy are used more carefully. When resource-use efficiency improves, farm profits tend to rise and farmers rely less on expensive outside inputs. Also, better crop quality and diversified production can open better market opportunities, which usually mean improved income for growers and steadier economic sustainability over time.

Social Benefits

These systems help with food and nutritional security by keeping crop production stable even when climatic conditions shift or do that sort of thing. They also

bring rural employment, bolster climate resilience, and lift farmers' livelihoods via sustainable income channels. At the same time, sustainable cropping systems encourage community involvement, raise environmental awareness, and support sustainable rural growth, so people can reach better living standards and resilient farming communities both now and later.

7. Best Management Practices

Sustainable cropping systems require the adoption of best management practices (BMPs) to improve productivity, conserve natural resources, and enhance resilience to climate change. These practices help farmers achieve higher yields while maintaining environmental sustainability and long-term soil health.

Efficient Crop Management

- ❖ **Use climate-resilient crop varieties** that are tolerant to drought, heat, floods, and major pests and diseases.
- ❖ **Follow proper crop rotation** to improve soil fertility, break pest and disease cycles, and enhance productivity.
- ❖ **Maintain soil cover throughout the year** using cover crops, mulching, or crop residues to reduce erosion and conserve soil moisture.
- ❖ **Apply balanced fertilizers** based on soil testing to ensure efficient nutrient management and prevent nutrient losses.
- ❖ **Use organic manures, compost, green manure, and biofertilizers** to improve soil structure, microbial activity, and long-term fertility.
- ❖ **Harvest rainwater** through farm ponds and water conservation structures to increase water availability during dry periods.

- ❖ **Adopt drip and sprinkler irrigation** to improve water-use efficiency and reduce irrigation losses.
- ❖ **Monitor pests regularly** and follow Integrated Pest Management (IPM) practices to minimize pesticide use.
- ❖ **Reduce excessive tillage** to conserve soil organic matter and improve soil health.
- ❖ **Practice crop residue recycling** to enhance nutrient cycling and reduce environmental pollution.
- ❖ **Use weather-based crop advisories** for timely decisions on sowing, irrigation, fertilization, and pest management.
- ❖ **Promote integrated farming systems** by combining crops with livestock, fisheries, or horticulture for efficient resource utilization.

Government Support

Governments support sustainable cropping through Climate-Smart Agriculture programs, the Soil Health Card Scheme, Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), the National Mission for Sustainable Agriculture (NMSA), crop insurance schemes, and farmer training and extension services. These initiatives provide financial assistance, technical guidance, and capacity building, encouraging farmers to adopt sustainable and climate-resilient agricultural practices.

8. Future Scope and Conclusion

Future Scope

The future of sustainable agricultural cropping systems is, dependent on innovative technologies that can push up agricultural output while keeping resource use efficient and, help in mitigating climate change. Artificial Intelligence (AI) in crop management will let farmers make wiser choices about irrigation, fertilizer, pest control, and even when

harvesting should happen. Then there's the Internet of Things (IoT), it makes smart farming more practical because farmers can monitor soil moisture readings, look at weather conditions, and check crop status using interconnected sensors. By using precision farming, where the Global Positioning System (GPS) fits together with geographic information systems (GIS) and sensor tech, farmers can apply the right amounts of water fertilizers and pesticides. Crop observation and spraying via drones can improve field coverage so that field monitoring is more efficient and there's a reduced need for labour, which matters a lot. Also, modern breeding methods along with biotechnology will help create climate resilient crop varieties, giving plants stronger defenses against drought, heat, salinity, flooding, and pest problems.

CONCLUSION

Sustainable cropping systems are essential for ensuring food security, environmental conservation, and economic sustainability under changing climatic conditions. Practices such as crop rotation, conservation agriculture, integrated nutrient and pest management, efficient irrigation, and precision farming improve soil health, conserve water, increase biodiversity, and enhance crop productivity. The adoption of climate-smart technologies, supported by government policies, research, and farmer education, will strengthen agricultural resilience and reduce environmental impacts. By integrating modern innovations with sustainable farming practices, future cropping systems can ensure long-term productivity, improve farmers' livelihoods, and contribute to global efforts for climate change mitigation and sustainable agricultural development.