

# Enhancing ecosystem services through sustainable agriculture

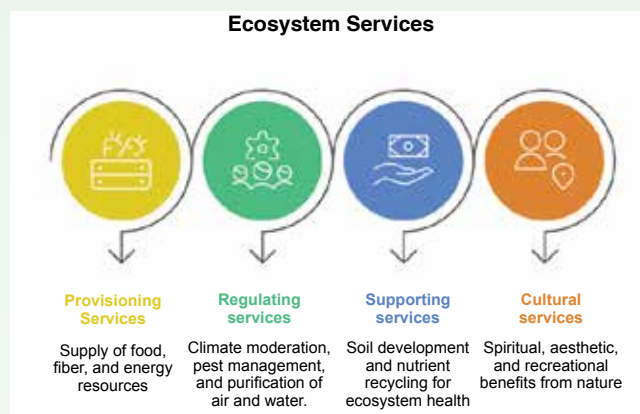
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*Sustainable agriculture enhances ecosystem services by improving soil health, conserving water, fostering biodiversity, and building climate resilience. Practices like agroforestry, conservation tillage, organic farming, and efficient irrigation promote carbon sequestration, reduce emissions, and secure food systems. Strengthening ecosystem services requires integrating climate-smart technologies, agroecological principles, and supportive policies. Investments in research, farmer training, and incentives such as payment for ecosystem services are vital. Bridging traditional knowledge with modern innovations, supported by strong policies and markets, will foster resilient landscapes, climate mitigation, and sustainable livelihoods.*

**Keywords:** Crop diversification, Ecosystem services, Sustainable Agriculture

**E**COSYSTEM services refer to the numerous benefits that humans derive from nature, and they are essential for both environmental health and agricultural productivity. These services are typically grouped into four main categories: Provisioning services, which cover the supply of food, fiber, and energy resources; Regulating services, including climate moderation, pest management, and purification of air and water; Supporting services, such as soil development and nutrient recycling; and Cultural services, which add spiritual, aesthetic, and recreational benefits. Agriculture is closely interlinked with these services; it relies on them while also influencing them. However, unsustainable farming and land use practices can destabilize ecosystems, weaken their resilience, and heighten the exposure of farms to climate variability and extreme events. Assessing the value of these ecosystem contributions is therefore critical for both ecological understanding and policy design aimed at sustainable food systems. Shifting towards sustainable farming approaches is key to ensuring long-term food security alongside ecological balance. Through the adoption of agroecological principles, conservation-oriented practices, organic methods, and climate-smart strategies, farmers can reinforce ecosystem services and strengthen the adaptive capacity of agricultural landscapes. This article explores sustainable farming practices that nurture ecosystem services, underlining their importance in building resilient food systems and safeguarding environmental sustainability.



## Key sustainable agricultural practices

Sustainable agricultural practices integrate ecological principles to enhance productivity while preserving environmental integrity. These practices help to increase productivity while safeguarding nature, enhancing soil fertility, conserving water, supporting biodiversity, and reducing climate impacts. The following approaches are essential for promoting sustainability in agriculture and for enhancing ecosystem services.

**Crop diversification and polycultures:** It represents an ecologically sound strategy that integrates multiple crop species within a single farming system to improve productivity, soil fertility, and resilience to climate variability. By moving away from monocultures,



Innovative practices of sustainable agriculture for improved ecosystem services

diversified systems enhance nutrient cycling, reduce pest and disease pressure, and prevent soil degradation, thereby strengthening ecosystem stability. Such systems also promote efficient use of natural resources like water, sunlight, and soil nutrients, contributing to higher long-term productivity and environmental balance. In addition to ecological advantages, diversification generates economic benefits by allowing farmers to shift from low-value traditional crops to more profitable options that suit local agro-climatic conditions and socio-economic needs. Cultivating cereals, pulses, oilseeds, and vegetables not only supports market demand but also improves food security, dietary diversity, and rural livelihoods. For instance, the rice-wheat cropping system in the Indo-Gangetic plains has led to environmental stress and economic inefficiencies. Replacing water-intensive crops with alternatives such as maize, pulses, oilseeds, mustard, chickpea, and mung bean offers a practical pathway toward sustainability. These crops reduce water use, enrich soil fertility, and provide higher economic returns, thereby promoting resource conservation, ecological resilience, and enhanced farmer income.

**Conservation tillage and cover cropping:** These are essential practices for sustainable soil management, offering both environmental and agronomic benefits. Conservation tillage reduces soil disturbance, helping retain organic matter, improve water infiltration, and minimize erosion, thereby enhancing resilience and soil structure. Cover cropping, using species like cowpea, clover or rye, provides continuous soil cover that prevents erosion, enriches fertility, suppresses weeds, and fosters beneficial microbial activity. Together, these practices improve soil's physical, chemical, and biological health while reducing reliance on

synthetic fertilizers. Importantly, they contribute to climate change mitigation by sequestering carbon—cover crops alone can store up to 0.22 tonnes of carbon per acre annually. By promoting nutrient cycling, conserving water, and enhancing biodiversity, these methods deliver critical ecosystem services. As climate-smart strategies, they strengthen long-term productivity, ensure food security, and advance sustainability in agricultural systems.

**Agroforestry systems:** Agroforestry is a sustainable land use approach that integrates trees, shrubs, and crops within farming systems to deliver ecological and economic benefits. By improving soil structure, enhancing water regulation, and sequestering carbon, agroforestry plays a critical role in climate change mitigation and adaptation. It also enriches biodiversity by providing habitats for pollinators, birds, and other beneficial organisms, while generating additional income from timber, fruits, fodder, and medicinal plants. Research

highlights its strong carbon storage potential in both tree biomass and soils. For example, poplar based systems in Punjab sequester nearly 8.9 Mg C/ha/yr, while teak and Acacia based systems in eastern and northern India also demonstrate high carbon capture. By improving soil fertility, diversifying farm outputs, and strengthening resilience, agroforestry emerges as a climate smart practice that enhances ecosystem services while supporting sustainable agriculture and rural livelihoods.

**Efficient irrigation and rainwater harvesting:** Sustainable agriculture in water stressed regions requires efficient water management. Advanced irrigation technologies such as drip and sprinkler systems minimize water loss, maintain ideal soil moisture, and enhance crop yields while conserving resources. Complementing these, rainwater harvesting and storage helps water availability during dry spells. Together, these strategies significantly improve water-use efficiency, reduce dependency on overexploited groundwater. Beyond water conservation, efficient irrigation enhances soil health and improves nutrient cycles. By maintaining balanced soil moisture, these practices also foster ecosystem services like nutrient retention, and carbon sequestration. Efficient irrigation and rainwater harvesting not only sustains productivity but also strengthens agroecosystem resilience.

**Organic farming and biopesticides:** Unlike conventional systems, organic farming avoids synthetic fertilizers and pesticides, relying instead on composting, crop rotation, green manures, and biological pest control to maintain fertility and crop protection. Biopesticides, derived from bacteria, fungi, or plant-based extracts, provide eco-friendly pest management while reducing chemical residues and safeguarding beneficial

organisms. These practices improve soil microbial diversity, foster nutrient cycling, and contribute to ecosystem stability. Importantly, organic systems help mitigate climate change by lowering greenhouse gas emissions linked to fertilizer production and application. By promoting ecological resilience, improving food safety, and conserving natural resources, organic farming and biopesticides serve as vital tools for advancing sustainability in agriculture and reinforcing ecosystem services.

**Precision nutrient and water management:** Adopting precision nutrient and water management is vital for creating resilient and sustainable farming systems. By incorporating bio fertilizers and site-specific nutrient application, nutrient uptake can be improved and greenhouse gas emissions can be lowered. Smart tools such as SPAD meters, leaf colour charts, and Greenseeker enable optimized nitrogen use, reducing nitrogen application by 12–25% in rice-wheat systems without compromising yields, thereby reducing pollution and conserving resources. Precision water management plays an equally critical role. Practices like direct-seeded rice (DSR) eliminate puddling, conserve water, cut labour costs, and significantly reduce methane emissions compared to traditional rice systems. Similarly, intermittent wetting and drying (IWD) techniques conserve irrigation water while lowering methane release from paddy fields. Together, these strategies not only boost crop productivity but also improve nutrient cycling, protect soil and water quality, and enhance ecosystem services, ensuring long-term sustainability.

**Climate smart agriculture (CSA):** CSA integrates innovative practices and technologies to combat climate change, enhance productivity, and ensure sustainability. Its core objectives include improving food security, strengthening resilience to climate variability, and reducing greenhouse gas emissions. In India, two widely recognized CSA innovations are the Laser land leveller and the Happy seeder, both recommended for smallholder climate adaptation. The Happy seeder, a zero-tillage seed drill, eliminates residue burning, thereby reducing labour costs by 80%, irrigation demand by 20–25%, and herbicide use by 50%. By retaining rice residues as mulch, it enriches soil organic matter, conserves moisture, and improves seedbeds. Studies show it can increase farm profits by 20% and cut emissions by 78% compared to residue burning. The Laser land leveller further promotes sustainability by improving water efficiency through uniform distribution, collectively enhancing ecosystem services and climate resilience.

**Biodiversity conservation:** Pollinators such as bees, butterflies, and birds are vital for food production and maintaining ecological balance. Pollinator-friendly practices like planting wildflower strips, reducing pesticide use, and diversifying crops, help secure food supplies while conserving habitats. Preserving natural areas within farms sustains pollinators and natural pest predators, improving both crop yields and ecological

resilience. Ecological corridors that connect fragmented landscapes further strengthen biodiversity and ecosystem health. However, large-scale monocultures, such as continuous rice-wheat systems, have led to soil degradation, stagnant yields, greenhouse gas emissions, and pest outbreaks. To address these challenges, Integrated Farming Systems (IFS) promote diversified approaches including agroforestry, cover cropping, and polyculture. Examples such as rice-fish-duck farming enrich soil microbial diversity through natural organic inputs like compost and manure. Integrating trees within farms also provides windbreaks, enhances biodiversity, and generates additional income. By combining productivity with ecological care, IFS supports sustainability while enhancing critical ecosystem services.

### Benefits of sustainable agriculture for ecosystem services

#### *Enhanced soil fertility and structure:*

- Crop rotation, cover cropping, and reduced tillage build organic matter and improve soil health.
- Agroforestry and composting boost nutrient cycling and microbial diversity.

#### *Improved water quality and availability:*

- Conservation tillage and organic farming reduce runoff, erosion, and agrochemical pollution.
- Drip and sprinkler irrigation optimize water use and conserve groundwater.

#### *Carbon sequestration and climate mitigation:*

- Agroforestry and cover crops store carbon in biomass and soils.
- Reduced reliance on synthetic fertilizers lowers greenhouse gas emissions.

#### *Increased biodiversity and habitat stability:*

- Farmlands support pollinators, natural predators, and wildlife.
- Diverse cropping prevents pest outbreaks and strengthens ecological resilience.

#### *Strengthened food security and livelihoods:*

- Resilient farming improves yields under climate stress.
- Diversified systems provide multiple income streams and reduce risks.

### Challenges and barriers to adoption

#### *High financial burden:*

- Initial investments in technologies like precision tools, CSA equipment, and water-efficient irrigation are costly.
- Limited access to credit and uncertain short-term returns discourage smallholder adoption.

#### *Knowledge and skill constraints:*

- Farmers often lack awareness, technical training, and extension support to effectively adopt sustainable methods.
- Complex agroecological principles and slow knowledge transfer.

#### *Cultural and behavioural resistance:*

- Deep-rooted traditional practices, cultural beliefs, and scepticism about new techniques create

reluctance to change.

**Market and incentive limitations:**

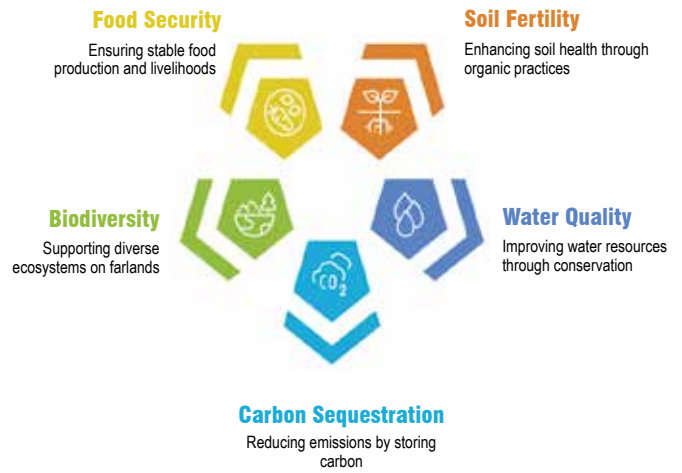
- Current market structures favour conventional farming.
- Lack of premium markets and incentives for sustainably produced goods reduces motivation.

**Uncertainty in outcomes:**

- Concerns over yield stability, market viability, and profitability discourage long-term commitment to sustainable farming.

**Policy and technical support**

- **Institutionalize payment for ecosystem services (PES):** Develop a national framework to reward farmers for ecosystem services like carbon sequestration, biodiversity conservation, and water-use efficiency.
- **Green/Carbon credit markets:** Strengthen the Green Credit Programme (GCP) and Voluntary Carbon Market (VCM) to generate tradable credits from climate-smart practices.
- **Government schemes with PES:** Redesign schemes like Rashtriya Krishi Vikas Yojana (RKVY) to link incentives with measurable ecosystem services (soil carbon, groundwater recharge, tree cover, and emission reduction).
- **Research and innovation:** Increase investments in precision farming, biofertilizers, water-efficient technologies, and resilient crop varieties aligned with PES objectives.
- **Partnerships and community action:** Promote public-private partnerships, farmer cooperatives, and knowledge-sharing networks for wider adoption of PES-based practices.
- **Blending knowledge systems:** Integrate traditional farming wisdom with modern technologies to



Sustainable agriculture's ecosystem benefits

enhance sustainability, resilience, and resource efficiency.

**SUMMARY**

Sustainable agriculture approaches/practices such as crop diversification and polycultures, conservation tillage and cover cropping, organic farming, use of biopesticides, efficient irrigation practices, rainwater harvesting and efficient utilization, climate smart agriculture practices, precision nutrient and water management and biodiversity conservation are essential for promoting sustainability in agriculture and for enhancing ecosystem services. To overcome the limitations in adopting these practices, certain policy and technical interventions are needed.

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