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Natural resource management for environmental sustainability in Indian agriculture

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Environmental sustainability is fundamental to ensuring the long-term viability of Indian agriculture in the face of climate change, natural resource degradation, and increasing food demand. Natural resource management (NRM) plays the central role in the environmental security, sustainable productivity, animal and soil health, food security, etc. The article highlights the role of various NRM approaches in relation to both environmental sustainability and crop productivity. These approaches not only strengthen environmental sustainability but also improve farm productivity, profitability, and resilience to climatic stresses.

Keywords: Biodiversity, Climate smart agriculture, Location specific technologies, Soil health

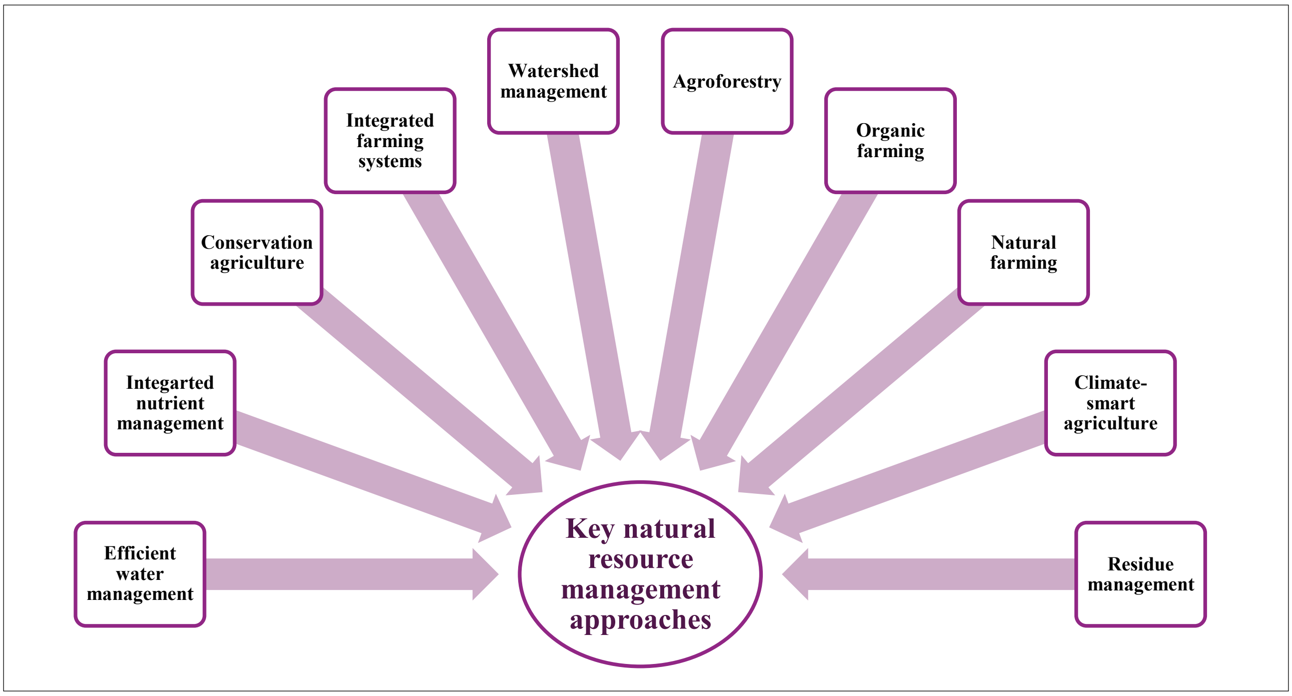
INDIAN agriculture has played a pivotal role in enhancing crop productivity, profitability, food, nutritional security, and rural livelihoods through the adoption of improved agricultural technologies and management practices. However, the intensive input-driven production systems adopted during the Green Revolution era have resulted in several environmental concerns. Excessive tillage, monocropping, residue burning, overexploitation of groundwater, deforestation, and indiscriminate use of agrochemicals have contributed to the soil degradation, decline in soil organic carbon, depletion of groundwater resources, deterioration of soil fertility, biodiversity loss, environmental pollution, and increased greenhouse gas emissions. These challenges threaten the long-term sustainability of agricultural production systems and the ecological balance.

Climate change has further intensified these challenges, with significant implications on agriculture, natural resources, food security, and environmental sustainability, particularly in developing countries such as India. Indian agriculture is highly vulnerable to climate variability because of its dependence on monsoon rainfall and the predominance of small and marginal farmers who constitute nearly 86% of the farming community. The increasing frequency and intensity of droughts, dry spells, floods, cyclones, hailstorms, heat waves, cold waves, and erratic rainfall events have adversely affected crop productivity, soil health, water resources, and ecosystem stability. In recent decades, changing rainfall patterns, declining monsoon reliability, and the increased occurrence of extreme weather events have further heightened the vulnerability of both rainfed and irrigated agro-ecosystems. According to the Intergovernmental Panel on Climate Change, global temperatures are projected to rise by 1.8–4.0°C by the end of the century, potentially exacerbating agricultural and environmental challenges. Studies indicate that a 1°C increase in temperature may raise crop water requirements by approximately 2% and overall water demand by nearly 10%. Climate change is also projected to reduce crop productivity in India by 4.5–9.0% during 2020–2039 posing serious threats to food, nutritional, and livelihood security and resilience of the systems.

To meet the growing food demand under conditions of shrinking natural resources, fragmented landholdings and increasing climate risks, adoption of sustainable and climate-resilient Natural Resource Management (NRM) practices has become imperative. Strengthening sustainable NRM is critical for achieving environmental sustainability, climate resilience, and long-term agricultural development in India.

Soil health management for environment sustainability

Sustainable NRM practices play a major role in improving soil carbon sequestration and reducing greenhouse gas (GHG) emissions in Indian agriculture. Soils act as major carbon sinks, and sustainable agricultural practices help increase soil organic carbon stocks while reducing emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

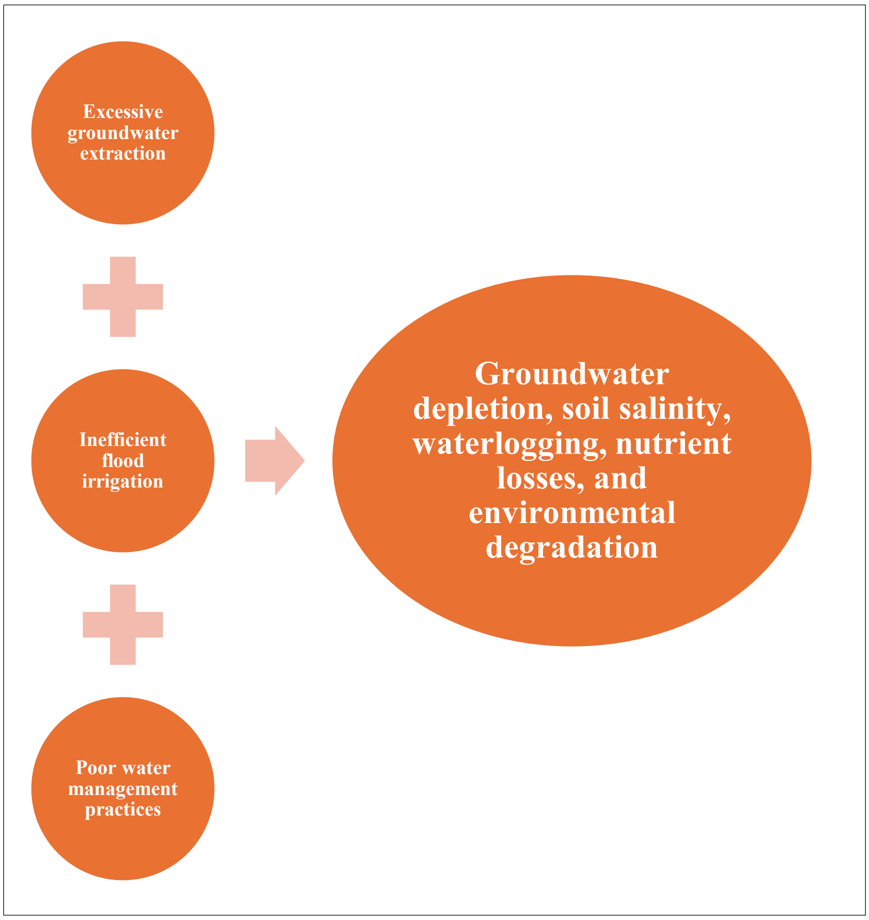


Healthy soil is essential for life on Earth to sustain productivity, provide ecosystem services, support biodiversity, socioeconomic structure, food security, and promote environmental health. However, excessive use of chemicals and intensive farming practices negatively impacted soil health, threatening future food production. Technology driven approach supported by appropriate policy backup such as gradual reform for balance fertilisation, nutrient based support, digital targeting will help toward environmental sustainability.

Conservation Agriculture (CA) which is based on three interrelated principles of minimum soil disturbance, permanent soil cover, and crop diversification through rotations or associations offers a viable pathway towards environmentally sustainable and climate-resilient agricultural development in both irrigated and rainfed ecosystems. Long-term studies in India have demonstrated improvements in soil organic carbon stocks, microbial biomass, and overall soil quality under CA systems. Furthermore, reduced fuel consumption, lower machinery use, improved energy-use efficiency, and decreased residue burning contribute to climate mitigation effects by reducing greenhouse gas emissions and increased soil carbon sequestration.

A rainfed field experiment conducted at ICAR-CRIDA for 15 years revealed that zero tillage with residue retention improved soil moisture availability, reduced runoff and soil loss, enhanced soil health, and increased crop productivity and system resilience, highlighting its potential as a sustainable option for rainfed agriculture.

- Crop diversification, inclusion of legumes, and diversified integrated farming systems improve biological nitrogen fixation and nutrient-use efficiency, thereby reducing fertiliser requirements and associated greenhouse gas emissions.
- Reduction in residue burning under CA lowers



Causes and effects of improper water use emissions of carbon dioxide, methane, particulate matter, and other air pollutants that contribute to environment and human health problems.

- Agroforestry systems through integration of cover crops along with trees further enhance carbon sequestration potential and ecological sustainability.

Water management for environmental sustainability

Water is one of the most critical natural resources for agricultural production and food security and needs to be preserved for ensuring safer environment. Overexploitation of groundwater for irrigation has caused a rapid decline in groundwater levels in states such as Punjab, Haryana, Rajasthan, Gujarat, Telangana, and Karnataka. In this context, it needs to be addressed immediately for ensuring sustainable water resource development and management through adoption of efficient water management technologies.

Smart water management practices like irrigation scheduling based on the crop type, stage, weather and soil moisture conditions, mulching, deficit irrigation, and scientific irrigation scheduling improve water-use efficiency, and conserve limited water resources. By adopting optimum irrigation schedule, substantial amount of water can be saved and the yields can be increased. Several studies have shown that the alternate wetting and drying or intermittent irrigation with ponding depth of 6 ± 2 cm of water in the rice fields three days after disappearance of previously ponded water is the optimum irrigation schedule for the entire period of rice growth. This practice of intermittent irrigation could save 23–65% of water as compared to traditional method of growing rice under continuous submerged condition in different agro-ecological conditions of India.

Rainwater harvesting has gained importance due to increasing rainfall variability and declining groundwater resources. Water conservation can be achieved through both *ex situ* and *in situ* moisture conservation practices.

Sustainable water management practices

Pressurised irrigation systems, viz. rainguns, sprinklers, and micro-sprinklers, and micro-irrigation systems, viz. drip and sub-surface drip are efficient irrigation methods with application efficiency ranging between 80–95%. Drip irrigation method has water-use efficiency (WUE) around 80–95% and saves large amount of water (20–40%) as compared to surface irrigation, which usually has a WUE in the range of 30–50%.

The added advantage of drip irrigation is that fertiliser and plant protection chemicals can also be applied with the irrigation for enhanced fertiliser use efficiency (15–50%).

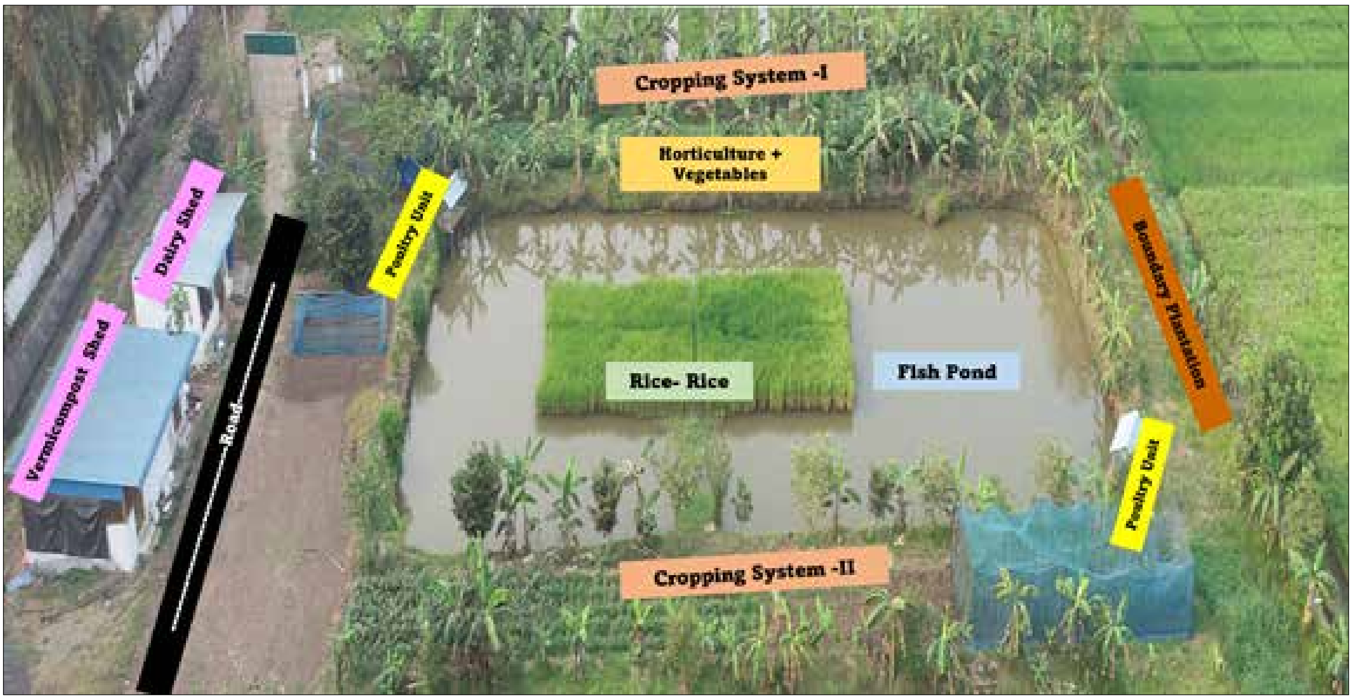
Sprinkler method of irrigation is suitable for almost all crops and on lands of wide range of topographic conditions. The application efficiency of sprinkler irrigation method is in the range of 70–80%. The water saving in sprinkler system varies in the order of 16–69% and increase in crop yield from 3–57% over the surface irrigation method.

Besides this, rainwater harvesting helps to reduce groundwater extraction and improve groundwater recharge. Under the National Institute for Research on Commercial Agriculture-Technology Demonstration Component (NICRA-TDC) programme, additional irrigation potential of about 340 ha in Karnataka, 280 ha in Punjab and 425 ha in Madhya Pradesh was created through water harvesting interventions. This harvested water helped to increase irrigated area. The supplemental irrigation during critical crop growth stages improved the crop productivity and stabilised crop yields under rainfed conditions, while improved groundwater recharge and bore well water levels by 8–10 feet in several locations was also observed. Besides providing irrigation to the crops, farm ponds

Integrated Farming System (IFS) Model

IFS models recorded increased productivity of 25.1 t/ha of rice equivalent (18.1–45 t/ha in different agro-climatic regions), achieved three to five-fold increase in farm income (mean of ₹2.72 lakhs/ha; ₹1.62–5.89 lakhs in different agro-climatic zones) over the conventional systems in a sustainable way. Long-term recycling of crop residues, animal wastes and compost improved soil organic carbon and nutrient availability. Recycling-based nutrient management reduced dependence on chemical fertilisers. It was observed that recycling resulted in saving of nutrients up to 55% of N, 84% of phosphorus and close to 90% of potassium requirement of the system.

IFS models integrating trees, livestock and organic recycling contributed to carbon sequestration and reduced greenhouse gas emissions (-1406 to -15675 kg CO_2 equivalent in different agro-climatic regions). Integrated crop + livestock + fishery systems enhanced water productivity and reduced wastage through recycling of farm resources. Diversified enterprises improved system resilience and biological diversity.



Integrated farming system model developed for West Godavari district of Andhra Pradesh (*Source*: AICRP-IFS Centre, RARS, Maruteru)

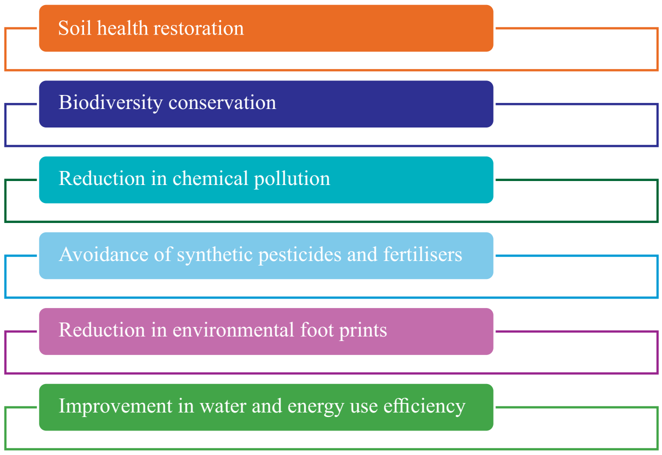
also support integrated farming activities such as fish rearing and livestock management, thereby improving farm income and livelihood resilience. *In situ* moisture conservation practices such as mulching, ridge and furrow and broad bed and furrow play a significant role in environmental sustainability by reducing runoff and soil erosion, improving groundwater recharge, conserving soil moisture, and enhancing soil health. These interventions improve rainfall-use efficiency, reduce land degradation, and strengthen the resilience of agricultural systems to climatic extremes, thereby supporting long-term productivity and natural resource conservation.

Integrated farming systems for environmental sustainability

Integrated Farming Systems (IFS) involve location and resource specific integration of crops, livestock, fisheries, horticulture, agroforestry, mushroom, poultry, apiary and other enterprises in a synergistic manner for efficient resource utilisation and recycling. The principle of 'Reduce, Recycle and Reuse' forms the core of IFS. Diversified farming systems under IFS provide opportunities for enhancing productivity, profitability and sustainability simultaneously.

Organic and natural farming for environmental sustainability

Organic farming is a production system that avoids or largely excludes synthetic fertilisers, pesticides, growth regulators and genetically modified organisms, and relies on crop rotations, organic manures, biological pest management and ecological processes. The natural farming is an agro-ecological farming approach based on on-farm biomass recycling, biological activation of soil, crop diversification and use of home-made biological formulations prepared from cow dung, cow urine and plant extracts.



Environmental contributions of IFS, organic and natural farming

While natural farming can maintain yields comparable to conventional and organic systems in several crops and regions, particularly under low-input and rainfed situations. Natural farming significantly improved soil health indicators including soil organic carbon, microbial biomass, beneficial microbial diversity, soil biological activity and soil moisture retention. Studies indicated increase in soil organic carbon from approximately 0.90–1.15% within three years in Himalayan regions. Bio-inputs such as *jeevamrit* and *beejamrit* contained abundant microbial populations including nitrogen fixers and phosphate solubilisers that enhanced nutrient cycling.

IFS results in 20–60% improvement in recycling efficiency, enhanced carbon sequestration and reduced climatic risks. Organic farming contributes 20–40% reduction in fossil energy use. Natural farming showed substantial enhancement in soil biological activity, including microbial populations up to 10^{10} CFU/mL in *beejamrit* and 28% increase in soil organic carbon within

2–3 years, besides reducing cultivation costs by 18–50%. Collectively, these farming approaches contribute to regenerative agriculture and strengthen resilience to climate variability, thereby supporting sustainable and climate-resilient agrifood systems.

SUMMARY

While past agricultural intensification has substantially improved food production, it has also placed considerable pressure on soil, water, biodiversity, and ecosystem health. Therefore, a transition towards resource-conserving and climate-resilient agricultural systems is essential for sustaining productivity while safeguarding the environment. Sustainable NRM approaches have demonstrated significant potential in improving soil health, enhancing water-use efficiency, conserving biodiversity, increasing carbon sequestration, and reducing greenhouse gas emissions. Government initiatives such as NICRA, PMKSY, NMSA, PKVY, and watershed development programmes have successfully demonstrated the benefits of these technologies across diverse agro-ecological regions. However, wider adoption requires addressing challenges related to small landholdings, declining groundwater resources, limited mechanisation, inadequate awareness, weak market linkages, and lack of location-specific technologies. Future efforts should focus on strengthening natural resource management, promoting climate-resilient and carbon-smart agricultural practices, expanding precision and digital agriculture, encouraging renewable energy use, and enhancing farmer capacity building.

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