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Sustainable intensification for improving the ecosystem services in rainfed agriculture

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Rainfed agriculture has to produce more food, fodder and income from uncertain rainfall while maintaining the soil, water and biological resources that sustain production. Sustainable intensification offers a pathway to achieve this balance by improving the efficiency of land, water, nutrients and biological resources rather than simply increasing external inputs. Rainwater conservation, crop diversification, soil-cover management, efficient nutrient use, agroforestry and integrated farming systems can simultaneously improve productivity and strengthen ecosystem functions. The TEEBAgriFood framework can help guide this transition by broadening the assessment of agricultural performance to capture how farming practices affect the natural, produced, human and social capital on which rainfed livelihoods depend. The future of rainfed agriculture lies in producing more from every drop of rain and every hectare of land while safeguarding the resource base and resilience needed for sustained production.

Keywords: Crop diversification, Resource-use efficiency, Sustainable intensification

RAINFED agriculture is not simply agriculture without irrigation. It is an agricultural system in which crop production depends strongly on the amount, distribution and timing of rainfall, as well as the capacity of the soil and crop to use that rainfall. India's rainfed areas support millions of farm families and contribute substantially to pulses, oilseeds, millets, cotton, maize and several other crops. Rainfed agriculture is practiced in 52% of net cultivated area in India and contributes to about 40% of country's food production, thus important for country's food security and economy. Climate change impacts are evident in rainfed agriculture in India. Yet these production systems are increasingly exposed to long dry spells, intense rainfall events, soil degradation and climatic variability.

The conventional response to low productivity has often been to increase external inputs. However, rainfed agriculture cannot always respond to higher fertiliser or seed inputs when the fundamental limitation is moisture. A high-yielding variety cannot express its potential if the soil dries during flowering; fertiliser cannot be effectively utilised when roots cannot access sufficient water; and intense rainfall may be lost as runoff rather than becoming available to crops. The question, therefore, is not simply how much more input can be applied, but how efficiently the available natural resources can be converted into farm production. This is the context in which sustainable intensification becomes important.

Sustainable intensification seeks to increase agricultural production without degrading the natural-resource base or causing unacceptable environmental impacts. Sustainable intensification is not a single technology or farming system. Rather, it is an approach in which agricultural production is increased while maintaining or improving natural, social and human capital. For rainfed agriculture, sustainable intensification implies productivity of rainwater, soil, nutrients, biomass and biological resources. The concept also changes the way we look at intensification. Intensification does not necessarily mean applying more fertiliser, irrigation or pesticides. A farmer can intensify production by growing two suitable crops instead of one, by retaining more rainwater in the root zone, by obtaining more yield from each kilogram of nutrient, or by integrating crops with trees and livestock.

Location specific soil and water management

For a rainfed farmer, rainfall is the most valuable input. However, rainfall received is not the same as rainfall effectively used by the crop. Water can be lost through runoff, evaporation and deep percolation. Soil compaction and poor surface condition can further reduce infiltration. Consequently, even a location receiving reasonable seasonal rainfall may experience crop moisture stress. Location-specific soil and water

Table 1. Resource use conservation for sustainable intensification in rainfed agriculture

Resource	Conventional concern	Sustainable intensification approach
Rainwater	Runoff and evaporation	*In-situ* and *ex-situ* water conservation and water harvesting and various land configuration
Soil	Soil and water erosion, degradation, declining organic matter	Mulching, residue management, conservation agriculture
Nutrients	Low recovery and nutrient losses	Balanced and efficient fertilisation
Land	Short cropping window/ Mono-cropping	Suitable crop sequences/ double cropping
Soil biological health	Declining microbial biomass and diversity, reduced biological activity, loss of beneficial soil fauna	Organic amendments, cover cropping, crop rotation, biofertilisers application, integrated nutrient management

management is essential for making rainfed agriculture more economical and sustainable, particularly under increasing rainfall variability and extreme rainfall events. Soil and water conservation and drought-proofing remain fundamental strategies for rainfed agriculture. In rainfed agriculture, it is very important to convert the rain received into moisture conservation for effective crop production. Harvesting the runoff water and storing it in farm ponds is a possibility in rainfed regions and the size of the pond depends on the rainfall, topography, and soils of the region. The harvested water during the *kharif* (rainy) season can be used either for supplemental irrigation during dry spells coinciding with critical crop stages in *kharif* or for establishment of *rabi* (winter) crops.

Table 2. Effect of one supplemental irrigation (5 cm) from harvested rainwater in farm ponds on yield of rainfed crops

Crop	Yield (kg/ha)	Yield increase due to irrigation (%)	Location
Sorghum	1,270	19	Anantapur
Sorghum	1,350	32	Bijapur
Maize	4,333	71	Arjia
Cotton	1,730	14	Kovilpatti
Soybean	2,050	14	Indore
Castor	1,320	31	Hyderabad
Wheat	2,143	25	Ballowal Saunkhri
Pea	2,207	44	Varanasi
Barley	3,001	32	Agra
Safflower	1,014	48	Parbhani

Source: Annual Reports of AICRPDA

Resilient crop varieties and crop diversification

In many rainfed regions, the land remains unproductive after the harvest of the first crop even though some soil moisture and growing period remain. A suitable second crop can convert this otherwise unused resource into additional production. Selecting resilient crop varieties is crucial for rainfed agriculture, as these varieties can withstand abnormal and adverse climatic conditions. New crop varieties are being developed to ensure better yields even in challenging situations like drought and extreme heat. These crops are specifically designed to address challenges such as drought, high temperatures, erratic rainfall, and dry sowing conditions. The use of resilient varieties helps farmers achieve stable production even when weather conditions are less than ideal. These varieties typically have deep root systems, enabling them to absorb water and nutrients from deeper soil layers, making them more capable of enduring prolonged climatic stress. Additionally, they not only deliver higher yields but are also more resistant to pests. Their adoption is a significant step toward improving farmers' livelihoods and ensuring food security in rainfed agricultural systems.

Crop diversification and bio-intensive farming practices strengthen resilience by spreading risks and optimising land use. Diversification is considered to be a good alternative to improve system yield with enhanced profitability. The farming system approach considers the components of soil, water, crops, livestock, labour, capital, energy and other resources, with the farm family at the centre managing agricultural and related activities and highly location specific in nature. Intercropping systems is one such system where we combine resilient crops like maize with legumes improves soil health, enhances nutrient recycling, and ensures stable yields even during adverse climatic conditions.

Integrated farming system

Traditionally, rainfed farmers encounter declining landholdings, soil degradation, nutrient deficiencies, climate variability, and limited investment that reduces the productivity and profitability of these systems. A farming system approach has therefore been advocated to enhance livelihood security, food security, sustainability, and resilience. However, resource-constrained small and marginal farmers generally prefer gradual, step-wise adoption of new technologies rather than major changes to their farming systems.



Crop diversification: Sorghum + pigeonpea and *Desmanthus*



Double cropping: Cowpea as first crop and sesame as second crop

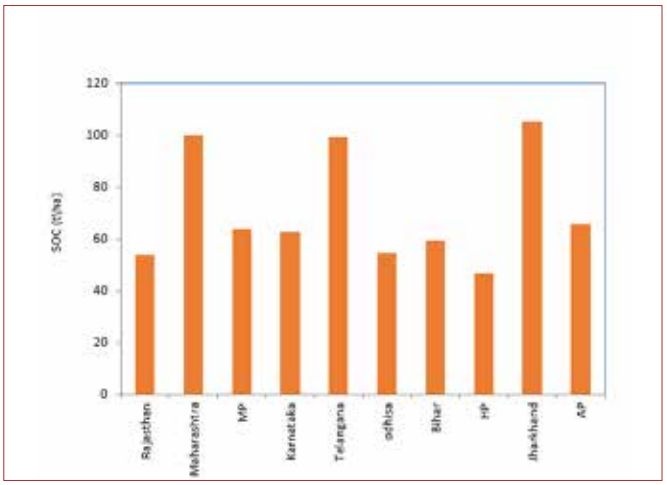
An integrated farming system (IFS) combines diverse crops such as cereals, legumes, oilseeds and tree crops with enterprises such as livestock, poultry farming on the same farm. This integration is reflected in the recycling of resources, wastes and by-products among farm components, thereby improving resource-use efficiency. Greater recycling enhances farm self-reliance, reduces dependence on external inputs, and contributes to the sustainability and resilience of the farming system. IFS is a holistic and system approach, in which natural mechanism of the system is explored by establishing compatible linkages among the various components, which make it sustainable.



IFS model in rainfed region of Alfisols

Agroforestry for enhancing ecosystem services

Agroforestry represents an important pathway for sustainable intensification of rainfed agriculture, as it enables farmers to diversify production while enhancing multiple ecosystem services from the same land unit. The integration of multipurpose and thermo-tolerant tree species with crops and pastures can improve soil organic carbon, carbon sequestration, nutrient cycling, microclimate regulation, biodiversity and soil and water conservation, while also providing additional sources of fodder, fuelwood, fruits, timber and farm income. Under the NICRA project, ICAR-Central Agroforestry Research Institute (CAFRI) assessed the carbon sequestration potential of existing agroforestry systems on farmers' fields across diverse agro-climatic regions using the CO_2FIX simulation model. Agroforestry systems in Rajasthan, Maharashtra, Madhya Pradesh, Karnataka, Telangana, Odisha, Bihar, Himachal Pradesh, Jharkhand and Andhra Pradesh recorded higher soil organic carbon than pure crop systems. Soil organic carbon under these agroforestry systems ranged from 53.47–104.84 t C/ha at 0–90 cm soil depth, demonstrating their potential to enhance soil carbon storage and regulate key ecosystem processes.



Soil organic carbon in agroforestry systems on farmer's fields (0–90 cm soil depth)

Land configuration

Land configuration is an important system-based approach for enhancing climate resilience and reducing production risks in rainfed agriculture by improving *in-situ* soil and water conservation. Configurations



Broad bed furrow + mulch in maize crop in rainfed Alfisols

such as broad beds and furrows, ridges and furrows, contour farming, compartmental bunding and graded bunds help regulate rainfall runoff, increase rainwater infiltration and storage and reduce soil erosion. Broad bed and furrow systems (BBF) are particularly effective in areas receiving intense rainfall, as they facilitate drainage during excess rainfall while retaining moisture in the root zone during dry spells. BBF along with mulch was also found useful in rainfed region, where it prevents the soil moisture evaporation, improve aeration and reduce weed. Similarly, contour-based configurations reduce the velocity of runoff and improve soil moisture availability, thereby buffering crops against intra-seasonal drought. Integration of suitable land configurations with mulching, crop residue management and improved cropping systems can further enhance water-use efficiency, stabilise crop yields and reduce vulnerability to rainfall variability. Thus, selection of land configuration according to soil type, slope, rainfall pattern and crop requirement provides a practical foundation for climate-resilient rainfed production systems.

Balanced fertilisation and integrated nutrient management

Rainfed soils are deficient in many macro- and micro-nutrients, correcting these deficiencies based on soil testing ensures that crop receive nutrients in right proportion. Balanced fertilisation along with site-specific nutrient management helps farmers to apply fertilisers judiciously and economically. Integrated nutrient management (INM) is another important practice in rainfed agriculture. It is a balanced approach that involves the combined use of inorganic fertilisers and organic nutrient sources, such as farmyard manure (FYM), vermicompost, biofertilisers, compost, crop residue retention, poultry manure, and green manure. In rainfed systems, sole dependence on inorganic fertilisers may not be sufficient to sustain soil health and productivity. Due to water limitations, these soils are often prone to multiple nutrient deficiencies and reduced nutrient-use efficiency. INM enhances soil biological activity, which ultimately increases soil organic carbon and improves nutrient-use efficiency. It also supplies essential nutrients and contributes to improved soil moisture retention. Long-term studies have demonstrated that the combined application of organic and inorganic nutrient sources can increase crop yields while improving soil properties and maintaining soil health under rainfed agriculture.

Soil biological health

Soil biological health is a critical part of sustainable intensification. Practices such as intensive tillage, continuous cultivation of the same crop, and excessive use of chemical fertilisers can reduce beneficial soil microorganisms and weaken soil fertility. Sustainable intensification focuses on improving the living part of the soil, which plays an important role in nutrient cycling, decomposition of organic matter, and disease suppression. Practices such as reduced tillage, residue retention, mulching, cover crops, and crop diversification help maintain microbial activity and diversity. Adding compost, farmyard manure, green manure, and biofertilisers increases beneficial microorganisms. These practices also support earthworms, nitrogen-fixing bacteria, and mycorrhizal fungi. Together, they improve nutrient availability, soil structure, water-use efficiency, and crop growth. Thus, maintaining soil biological health is essential for improving soil fertility, productivity, and resilience in rainfed farming systems.

SUMMARY

Sustainable intensification provides a promising pathway for improving productivity while simultaneously conserving and enhancing ecosystem services in rainfed agriculture. Rainfed systems can be intensified sustainably through the integration of crop diversification, improved land and water management, integrated nutrient management, agroforestry, integrated farming systems, residue management and climate-resilient practices. Such approaches can enhance soil health, water regulation, nutrient cycling, carbon sequestration, biodiversity and other supporting and regulating ecosystem services while reducing the environmental risks associated with agricultural intensification. The TEEBAgriFood framework provides a complementary approach by assessing these outcomes through changes in natural, produced, human and social capital, thereby making the environmental, economic and social benefits and trade-offs of farming systems visible. The emphasis should therefore shift from maximising production through external inputs alone towards producing more from available resources while maintaining the ecological functions of rainfed agroecosystems and strengthening sustainable livelihoods.

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