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System based approaches for enhancing climate resilience and risk mitigation in rainfed agriculture

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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. System-based approaches are the better options to tackle climate change. Integrated farming systems (IFS), resilient crop varieties and crop diversification, soil management, agroforestry systems and conservation agriculture are some of the proven systems for risk mitigation. Efforts have been made through national initiatives towards climate resilient rainfed agriculture and to enhance the adaptive capacity of farmers.

Keywords: Crop diversification, Ecosystem services, Farming systems, Regenerative agriculture

RAINFED agriculture, which relies predominantly on natural rainfall, supports millions of smallholder farmers across the globe. However, it is one of the most vulnerable agricultural systems to climate variability and extreme weather events. The changing climate has intensified challenges like erratic rainfall, prolonged dry spells, floods, and heat stress, threatening crop productivity and farmer livelihoods in dryland agriculture. In this context, system-based approaches, integrating diverse strategies and technologies, have emerged as vital tools for building resilience and mitigating risks in rainfed farming systems. Unlike piecemeal solutions, system-based approaches recognize the interconnectedness of natural resources, farming practices, and socio-economic factors. These approaches aim to enhance water-use efficiency, diversify cropping system, leverage technology through rainwater harvesting and efficient irrigation techniques for real-time weather forecasting and crop monitoring and promote community-based solution.

Integrated farming systems (IFS)

Integrated Farming Systems (IFS) represent a comprehensive approach to resource management by combining various farm components such as crops, livestock, poultry, aquaculture, and agroforestry. These components are interdependent, ensuring resource recycling and maximizing productivity. This approach helps in enhancing resilience and risk mitigation in following ways

- ***In-situ resource recycling***: Utilizing farm residues and by-products within the system to reduce dependency on external inputs.
- ***Biodiversity and synergies***: Enhancing on-farm diversity creates synergies, improves resilience to climate shocks, and ensures continuous income streams.
- ***Environmental benefits***: Practices like integrated nutrient management reduce greenhouse gas emissions, while agroforestry enhances carbon sequestration and biodiversity.

Rainwater harvesting

The importance of rainwater harvesting has increased in recent years due to the increased rainfall variability, heavy rains and depletion of groundwater levels. Rainwater harvesting and recycling through farm ponds, restoration of old rainwater harvesting structures in dryland/rainfed areas, percolation ponds for recharging of open wells, bore wells and injection wells for recharging ground water are taken up for enhancing farm level water storage in drylands. Watershed management is the flagship programme of the country to enhance the water resource availability, which aims at reducing the severity of erosion, drought, and floods, optimizing the use of land, water and vegetation, improving agricultural production and enhancing the availability of fuel and fodder on a sustained basis. 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 so 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. The advantages of supplemental irrigation are significant and considerable improvement in crop yields has been noticed at locations of various AICRPDA centres as given in Table 1.

Table 1. 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	1270	19	Anantapur
Sorghum	1350	32	Bijapur
Maize	4333	71	Arjia
Cotton	1730	14	Kovilpatti
Soybean	2050	14	Indore
Castor	1320	31	Hyderabad
Wheat	2143	25	Ballowal Saunkhri
Pea	2207	44	Varanasi
Barley	3001	32	Agra
Safflower	1014	48	Parbhani

Source: Annual Reports of AICRPDA Year

Resilient crop varieties and crop diversification

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 and diseases. 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 optimizing land use. Diversification is considered to be a good alternative to improve system yield with enhanced profitability. The farming system approaches consider 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 are highly location specific in nature. Intercropping systems is one such system where we combine resilient crops like maize with legumes, which improves soil health, enhances nutrient recycling, and ensures stable yields even during adverse climatic conditions. Strip cropping, developing new double droppings systems approach improves productivity. Another approach of integrating livestock in farming systems ensures alternative income sources, provides manure for soil enrichment, and improves resource recycling. For instance, integrating poultry and small ruminants with crops provides steady income and increases farm efficiency.

Soil management

Advanced nutrient management plans are being developed to increase carbon levels in the soil, improving its fertility and water retention capacity, which in turn enhances crop productivity. Following suitable management practices is crucial for rainfed agriculture. These include ploughing during appropriate moisture levels to prevent the formation of large clods and to improve soil structure. Reducing secondary tillage and adopting zero-tillage or ridge tillage systems, where crop residues are left as mulch on the surface, are also beneficial. Additionally, crop rotation, incorporating grains and legumes, and surface-covering crops enhance soil health. Organic fertilizers are used to improve soil biological quality, and light agricultural implements are employed to break soil crusts to improve seed germination and plant population. These practices maintain soil fertility and structure, contributing to the success of rainfed farming.

Crop diversification: Sorghum + pigeon pea and Desmanthus

Horti-Pastoral system/agroforestry-based farming system

India has a rich tradition of farmers growing trees around fields and homes, significantly contributing to social, economic, and environmental well-being. In rural areas, particularly among the landless population, trees are a primary source of fuel and energy. Such agroforestry systems not only fulfill rural fuelwood demands but also protect crops from water and wind erosion through perennial components like trees and grasses. This system mitigates the impacts of erratic rainfall and stabilizes agriculture. Rainfed ecosystems benefit significantly from agroforestry practices (e.g. forest-grazing, crop-tree systems, agri-horticulture). In regions with limited irrigation, agroforestry systems help address water scarcity and diversify agricultural production. For instance, pairing tamarind with guinea grass is a successful example.

Conservation agriculture (CA)

Conservation tillage is defined as any tillage system that conserves soil water, reduces soil erosion, and leaves at least 30% of the soil surface covered with residues after a main crop is harvested. Minimum soil disturbance provides several benefits like maintaining optimum levels of respiration gases in the plant root zone, lesser oxidation of soil organic matter (SOM), maintaining soil porosity for water movement and restricting the re-exposure of weed seeds to sunlight thereby restricting their germination. In addition, it also facilitates microbes to produce stable soil aggregates for efficient infiltration that is referred to as 'biological tillage'. Zero tillage (ZT) has been found to be highly effective by means of increasing moisture retention, soil organic carbon protection and also reducing the cost of cultivation. Combining ZT or Conservation agriculture (CA) with various organic amendments like Farmyard manure (FYM), vermicompost, weed mulching and poultry manure etc. was found beneficial both economically and environmentally. Conservation tillage has also improved soil physical properties like bulk density, field capacity and porosity. Studies show that over a period of time, zero-tillage system has enhanced the Soil Organic Carbon (SOC) and soil nitrogen status over the conventional tillage. During the last two decades, as an alternative to tillage-based inefficient conventional agriculture, CA with site-specific technologies having similar or higher yields, higher profitability and use efficiency of external production inputs and natural resources, has emerged as a major sustainable intensification strategy and is being globally practiced over 200 Mha.

Soil moisture is the major limiting factor for crop growth in semi-arid tropics (SATs). Reduced tillage practices may have led to the loss of limited moisture available, due to uninterrupted capillary pores, thus limiting crop growth and yields. Long-term conservation tillage practices under semi-arid regions influenced the yields of different cropping systems viz. sorghum-sunflower annual rotation recorded 10% higher sorghum yields after 6 crops under CT over minimum tillage (MT), while sunflower under MT recorded 8% higher yields than CT after 4 crops; fingermillet - pigeonpea - horsegram rotation resulted in 42% higher sorghum yields under CT over MT, and the similar trend was observed in pigeonpea also with 95% higher yields under under CT over MT; under pigeonpea-castor system, CT recorded 47% and 29% higher yields in pigeonpea and castor, respectively over ZT and the yield gaps were narrowing down among the tillage treatments with advancement of years; sorghum-cowpea system resulted in 16 and 60% yield increase in sorghum and cowpea, respectively under MT over

Pearl millet crop under CA practices

CT. Improved soil properties like organic carbon, soil enzyme activity, microbial activity, porosity and structural stability with residue retention resulted in higher yield, under ZT + crop residues as compared to ZT alone over time. Studies on sorghum, black gram, and pigeon pea demonstrated that increasing residue levels significantly enhanced rain water use efficiency (RWUE) compared to no-residue scenarios. This improvement in RWUE directly translated to increased grain yields. For instance, in pigeon pea, anchored residues at 30 and 10 cm depths significantly boosted yields compared to no-residue treatments. Similarly, in black gram, retaining higher amounts of sorghum residue by adjusting harvest height positively impacted black gram seed yield. These findings highlight the crucial role of residue management in optimizing water use and enhancing crop productivity in these semi-arid regions.

Table 2. Change in rain water productivity (RWP) observed between conventional tillage (CT) and conservation agriculture (CA) in different cropping systems in semi-arid Alfisols

Cropping system	RWP (kg/m^3)		
	CT	CA	% increase in CA over CT
Pigeon pea-castor system	1.08	1.46	26
Sorghum	3.75	4.21	10.9
Black gram	0.97	1.02	4.9
Finger millet + pigeon pea	4.54	4.39	-3.3

SUMMARY

System-based approaches offer a comprehensive and sustainable pathway to enhance climate resilience and mitigate risks in rainfed agriculture. By integrating practices such as Integrated Farming Systems (IFS), rainwater harvesting, the use of resilient crop varieties, crop diversification, and soil management, farmers can adapt to the growing challenges posed by climate change. These approaches not only improve water-use efficiency and optimize resource utilization but also promote biodiversity and ecosystem health, ensuring long-term agricultural sustainability. As demonstrated through various examples, these strategies significantly improve crop yields, soil health, and overall farm productivity. Continued investment in research, community-based solutions, and policy support will be crucial to further strengthen the adaptive capacity of rainfed agriculture, ensuring food security and livelihoods for millions of farmers in climate-vulnerable regions.

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