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SOIL MOISTURE CONSTRAINTS IN RAINFED AGRICULTURE: MITIGATION STRATEGIES FOR SUSTAINABLE CROP PRODUCTION UNDER THE CHANGING CLIMATE

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ABSTRACT

Soil moisture stress in rainfed agriculture poses a major threat to crop productivity and sustainability, especially under climate change. Erratic rainfall, dry spells, and rising temperatures worsen moisture loss, reduce infiltration, deplete nutrients, and harm microbial activity. These factors lead to declining yields and soil health. Effective mitigation strategies include mulching, conservation tillage, cover cropping, rainwater harvesting, and micro-irrigation. Soil amendments like compost and biochar improve moisture retention, while agroforestry stabilises ecosystems. Weather-based crop planning and drought-resilient crops enhance adaptability. Sustaining productivity requires integrated water management, climate-smart practices, farmer training, and policy support for long-term resilience and food security.

KEYWORDS: Climate change, Moisture, Rainfed, Resilience, Sustainability

INTRODUCTION

Rainfed agriculture plays a crucial role in global food security, particularly in regions with limited access to irrigation. Some estimates suggest that rainfed agriculture occupies about 67% of the net sown area, supporting 40% of the population. Rainfed regions contribute around 40% of the total food grain production in India. These areas are particularly significant for certain crops, producing: 95% of coarse cereals, 91% of pulses, 80% of oilseeds, 65% of cotton and 53% of rice (CRIDA 2011, Rao, 2019)

Rainfed agriculture in India is spread across diverse climatic and agroecological zones, each with distinct rainfall patterns and soil characteristics. In arid and semi-arid regions such as Rajasthan, Gujarat, Maharashtra, Karnataka, Andhra Pradesh, and Tamil Nadu, rainfall is less than 750 mm annually, making soil moisture retention crucial for crops like millets, pulses, oilseeds, and cotton. Dry sub-humid regions, including Madhya Pradesh, Chhattisgarh, Jharkhand, Odisha, and parts of Uttar Pradesh, receive 750-1200 mm annual rainfall, supporting crops like rice, maize, pulses, oilseeds, and wheat. Humid and per-humid regions, found in northeastern states, West Bengal, and Kerala, receive more than 1200 mm of

rainfall, favouring the cultivation of rice, tea, rubber, and spices. In hilly and mountainous regions such as the Western Ghats, Eastern Ghats, and the Himalayas, highly variable rainfall patterns influence the production of horticultural crops, maize, and pulses.

THE SOIL WATER CONSTRAINS OF THE RAINED AREAS UNDER THE CHANGING CLIMATE

Soil available moisture content is significantly influenced by changing climatic conditions, which directly affect plant growth and drought resilience. Rising temperatures increase evaporation from the soil surface and enhance plant transpiration, leading to faster depletion of soil moisture. Changes in rainfall patterns, such as irregular precipitation or extreme weather events, also impact soil moisture retention. Heavy rainfall can cause surface runoff, preventing adequate infiltration, while prolonged dry spells reduce groundwater recharge and soil moisture storage. The effect of climate change on soil moisture availability varies with soil texture. Sandy soils, with their low water-holding capacity, lose moisture quickly through leaching, making them highly vulnerable to drought. Clayey soils, although capable of retaining more water, tend to develop cracks under dry conditions, leading to water loss. Loamy soils, which offer a balance between water retention and drainage, are generally more resilient to climatic variations. In contrast, shallow and gravelly soils, often found in hilly or degraded lands, have limited moisture storage capacity, making them particularly sensitive to changing climate patterns.

CLIMATE SMART MANAGEMENT STRATEGIES FOR SUSTAINABLE CROP PRODUCTION

SOIL MOISTURE CONSERVATION TECHNIQUES

Soil moisture conservation is vital for sustaining crop productivity in rainfed agriculture, where water availability is limited and erratic. Effective techniques include in situ conservation, rainwater harvesting, and soil amendments. In-situ methods like mulching, conservation tillage, contour farming, and cover cropping help reduce evaporation, improve water infiltration, and enhance soil moisture. Mulching retains moisture and suppresses weeds, while conservation tillage preserves soil structure and boosts infiltration. Contour farming reduces runoff and erosion, and cover crops improve soil health and moisture retention. Rainwater harvesting techniques—such as farm ponds, percolation tanks, and check dams—capture excess runoff, recharge groundwater, and provide supplementary irrigation during dry periods, improving moisture availability and crop yields. Soil amendments, including organic matter, clay, zeolites, and super absorbent polymers (SAPs), enhance soil structure and water-holding capacity. Organic matter boosts microbial activity and moisture retention, while SAPs like hydrogel help plants access water during dry spells. Integrating these strategies is crucial to building resilience in rainfed systems. Together, they

improve soil moisture, mitigate drought stress, and support sustainable crop production amid climate variability.

EFFICIENT WATER MANAGEMENT TECHNIQUES

Efficient water management is vital for sustaining food grain production in rainfed agriculture, where erratic rainfall and dry spells limit productivity. Key strategies include rainwater harvesting, micro-irrigation, and crop selection, all of which enhance soil moisture, improve water use efficiency, and boost crop resilience.

Rainwater harvesting methods—such as farm ponds, percolation tanks, and check dams—capture runoff and improve soil infiltration. In semi-arid India, farm ponds increased soil moisture by 20–30% and crop yields by 25%.

Micro-irrigation systems like drip and sprinkler irrigation deliver water directly to plant roots, minimising evaporation losses. Drip irrigation has reduced water use by 50% and improved wheat yields by 30–40%. Sprinkler systems support shallow-rooted crops like pulses, while deficit irrigation improves efficiency in crops like rice and maize.

Crop selection plays a key role in managing water scarcity. Drought-tolerant and deep-rooted crops like millets, sorghum, pigeon pea, and chickpea thrive under low-moisture conditions and enhance soil health. Studies show drought-resistant millet varieties yield 30–50% more than traditional types.

Integrating these methods can boost water use efficiency by 40–50% and crop yields by 25–50%, supporting climate-resilient, sustainable food grain production in rainfed regions.

APPLICATION OF ORGANIC MANURES

Enhancing soil organic matter (SOM) through compost and manure application significantly boosts water retention and crop resilience in rainfed agriculture. Organic amendments like farmyard manure (FYM), compost, and green manure improve soil structure, porosity, and aggregation, which enhance water infiltration and reduce evaporation. SOM acts like a sponge, holding 10–20 times its weight in water (Hudson, 1994), ensuring a steady supply of moisture during dry periods.

Studies show FYM application increases soil moisture by 10–30% and reduces evaporation losses by 15–25% (Blanco-Canqui and Lal, 2009). Improved soil porosity allows water to penetrate deeper, promoting root growth and access to subsoil moisture, which enhances drought tolerance and yield stability (Ghosh et al., 2020).

Recommended FYM doses vary: 10–15 t/ha for sandy soils, 7–10 t/ha for loamy, and 5–7 t/ha for clay. In Central India, 10 t/ha of FYM improved wheat yields by 30% and soil moisture by 25% (Sharma et al.,

2017). Compost at 12 t/ha increased sorghum moisture storage by 20–35% (Patil et al., 2019), confirming its value in moisture-limited systems.

AGROFORESTRY SYSTEMS

Agroforestry, the integration of trees with crops and livestock, enhances soil moisture, reduces erosion, and improves biodiversity, making it ideal for rainfed agriculture. Deep-rooted trees access subsoil moisture, reduce evapotranspiration, and increase organic matter, improving resilience to drought (Mahmud et al., 2024). Systems like agri-silviculture (e.g., Acacia, Neem, Khejri with crops) in Rajasthan and agri-horticulture (mango, pomegranate with cereals) in Maharashtra demonstrate success under moisture stress (Singh et al., 2020). Silvi-pastoral systems with fodder trees like Hardwickia binata are effective in arid zones.

Agroforestry improves soil moisture by 15–30% and increases yields by 25% in low-rainfall years (Yadav et al., 2019). Trees create favourable microclimates, enhance water retention, and support nitrogen fixation. Beyond agronomic benefits, agroforestry diversifies income and sequesters carbon, aiding climate change adaptation. Promoting agroforestry offers a nature-positive solution for sustainable food production in rainfed systems.

BIOCHAR APPLICATION

Biochar, a carbon-rich material from pyrolysed biomass, enhances soil fertility and moisture retention, making it ideal for rainfed agriculture (Lehmann and Joseph, 2024). Its porous structure improves soil aeration, aggregation, and water-holding capacity, aiding crops under drought. Biochar increases soil moisture by 10–30% and reduces evaporation losses by 20–25% (Abel et al., 2013; Mukherjee and Lal, 2013). Application rates vary by soil type: 5–15 t/ha for sandy, 3–10 t/ha for loamy, and 2–5 t/ha for clay soils. It promotes microbial activity and root growth, enhancing drought resilience. Combined with compost or manure, biochar supports sustainable dryland farming.

CONCLUSION

Rainfed agriculture faces major challenges due to low and erratic soil moisture, intensified by climate change. This limits crop growth, nutrient availability, and soil health. To address these issues, integrated soil and water management is essential. In-situ moisture conservation methods like mulching, conservation tillage, and cover cropping reduce evaporation and improve infiltration. Rainwater harvesting through farm ponds and check dams boosts water availability, while micro-irrigation systems optimise water use during critical crop stages. Soil amendments such as biochar, compost, and manure enhance soil structure and moisture retention. Agroforestry systems offer long-term resilience by improving microclimates, organic matter, and soil moisture. By integrating these strategies, rainfed

agriculture can become more resilient and productive, ensuring food grain production even under moisture-limited conditions.

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