



Water Use Efficiency on Rainfed Farming

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Rainfed agriculture supports nearly two-thirds of the world's cultivated area and remains the backbone of food and livelihood security for resource-poor farmers across semi-arid and sub-humid regions. Unlike irrigated systems, rainfed farming depends entirely on erratic and often insufficient rainfall, making water the single most limiting input to crop productivity. Improving water use efficiency (WUE), defined as the ratio of biomass or economic yield produced per unit of water consumed, is therefore central to enhancing the resilience and productivity of rainfed cropping systems. This review synthesizes existing knowledge on the physiological, agronomic, and management determinants of WUE in rainfed farming, including in-situ moisture conservation, crop and cultivar selection, soil management, mulching, nutrient management, and the application of deficit irrigation principles where supplemental water is available. The review also examines emerging tools such as precision agronomy, drought-tolerant genotypes, and conservation agriculture practices that collectively contribute to better utilization of limited rainfall. Findings indicate that an integrated approach combining soil, crop, and water management interventions offers the most sustainable pathway to improving WUE under rainfed conditions, particularly as climate variability intensifies water scarcity in dryland regions.

Introduction

Rainfed farming systems occupy a substantial proportion of the world's arable land and contribute significantly to global food grain production, particularly in regions where irrigation infrastructure is limited or economically unfeasible. These systems are characterized by high dependence on the quantity, distribution, and intensity of rainfall, which is frequently erratic, leading to recurring problems of moisture stress, yield instability, and crop failure. With increasing climate variability and growing pressure on freshwater resources, the efficient use of available rainwater has emerged as a critical research priority. Water use efficiency is a key indicator that links water input to crop output, and it can be assessed at multiple levels including leaf-level transpiration efficiency, crop-level water use efficiency, and field or watershed-level efficiency that accounts for losses through runoff, deep percolation, and evaporation. Improving WUE in rainfed systems does not necessarily require additional water; rather, it involves optimizing the capture, storage, and utilization of the rainwater that is already available. This review aims to consolidate current understanding of the factors influencing WUE in rainfed farming and to outline practical strategies that can be adopted to enhance productivity per unit of water in dryland agriculture.

Concept and Components of Water Use Efficiency

Water use efficiency in rainfed systems is generally partitioned into three components: rainwater capture (the proportion of rainfall that infiltrates the soil rather than being lost as runoff), water storage (the capacity of the soil profile to retain moisture within the root zone), and water utilization (the efficiency with which stored moisture is converted into biomass and economic yield through transpiration relative to non-productive losses such as soil

evaporation). Improving any one of these components without addressing the others provides only marginal gains, underscoring the need for an integrated management approach.

In-Situ Moisture Conservation Practices

In-situ moisture conservation techniques aim to maximize rainwater infiltration and minimize runoff at the point of rainfall. Common practices include contour farming, graded bunding, broad bed and furrow systems, ridge and furrow planting, and tied ridging. These structures slow the velocity of surface runoff, allowing more time for water to infiltrate into the soil profile. Field-level studies across semi-arid tropics have consistently shown that such practices reduce soil erosion while improving available soil moisture during critical crop growth stages, particularly during intermittent dry spells.

Soil Management and Mulching

Soil organic matter content, structure, and bulk density strongly influence the soil's water-holding capacity and infiltration rate. Practices such as conservation tillage, minimum tillage, and the incorporation of crop residues improve soil aggregate stability and reduce evaporative losses. Mulching, whether through crop residues, plastic films, or live mulches, has been widely reported to reduce soil temperature fluctuations and suppress direct evaporation from the soil surface, thereby conserving moisture for plant uptake and improving the proportion of water used productively through transpiration.

Crop and Cultivar Selection

Selection of drought-tolerant and short-duration crop varieties allows the crop cycle to align more closely with the rainy season, reducing dependence on residual moisture during terminal drought periods. Traits such as deep and extensive root systems, reduced leaf area, efficient stomatal regulation, and osmotic adjustment contribute to higher transpiration efficiency under limited moisture conditions. Millets, sorghum, pigeon pea, and certain pulse crops are widely cultivated in rainfed regions owing to their inherent drought tolerance and comparatively higher water use efficiency relative to water-intensive cereals.

Nutrient and Crop Management

Balanced nutrient management, particularly adequate phosphorus and potassium availability, enhances root proliferation and improves the plant's capacity to extract soil moisture from deeper layers. Timely sowing aligned with the onset of monsoon rains, optimal plant population, and appropriate intercropping or sequence cropping systems further contribute to better utilization of available moisture by reducing non-productive evaporative losses and improving canopy cover early in the crop cycle.

Conservation Agriculture and Watershed-Based Approaches

Conservation agriculture, based on minimal soil disturbance, permanent soil cover, and crop diversification, has been shown to improve long-term soil moisture retention and resilience to dry spells. At a broader scale, watershed management interventions, including check dams, farm ponds, and percolation tanks, help to capture excess runoff for supplemental irrigation during critical growth stages, effectively converting purely rainfed systems into partially irrigated systems with markedly improved water use efficiency.

Authors Perspective

Based on the evidence synthesized in this review, it is evident that improving water use efficiency in rainfed farming cannot be achieved through a single technological intervention but requires a systems-based approach that simultaneously addresses rainwater capture, soil moisture conservation, and crop-level water utilization. In the author's view, greater emphasis should be placed on integrating traditional in-situ moisture conservation practices with modern tools such as drought-tolerant genotypes and watershed-based supplemental irrigation, particularly given the increasing unpredictability of monsoon patterns due to climate change. There is also a need for greater farmer participation in the design and adoption of these practices, as locally adapted solutions tend to be more sustainable than externally imposed

technologies. Future research should prioritize the development of low-cost soil moisture monitoring tools and decision-support systems tailored to smallholder rainfed farmers, enabling more precise and timely management decisions that further enhance water productivity.

Conclusion

Water use efficiency is a central determinant of productivity and resilience in rainfed farming systems, where rainfall remains the only source of crop water and is often insufficient or poorly distributed. This review highlights that improvements in WUE are best achieved through the integration of in-situ moisture conservation, soil and residue management, drought-tolerant crop selection, balanced nutrient management, and watershed-based water harvesting. Adopting such integrated strategies can substantially reduce the vulnerability of rainfed agriculture to moisture stress and climate variability, thereby contributing to sustained food security and improved livelihoods for farmers in dryland regions. Continued investment in research, extension, and farmer-centered innovation will be essential to translate these strategies into widespread field-level adoption.

Authors Contribution

[DHARANI. A] conceptualized and drafted the manuscript.

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