Rice Cultivation Systems in Latin America: Diversity and Climate Vulnerability

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Citation: Suarez, R. (2026). Rice Cultivation Systems in Latin America: Diversity and Climate Vulnerability. *Journal of Environmental Management and Tourism, 17*(2), 90-94. https://doi.org/10.14505/jemt.v17.2(82).02

Article info: Received 17 March 2026; Received in revised form 25 March 2026; Accepted 12 April 2026; Published 29 May 2026.

Abstract: Rice cultivation systems in Latin America exhibit substantial heterogeneity driven by geographic, climatic, technological, and institutional factors. These differences shape productivity outcomes, exposure to climate risks, greenhouse gas emissions, and producers' adaptive capacity. This article provides a system-oriented analysis of the main rice production systems in the region, distinguishing among irrigated, partially irrigated, and rainfed systems, as well as mechanized, semi-mechanized, and traditional (no mechanized) production models. It examines how water management, mechanization, cropping intensity, and socioeconomic conditions interact to influence climate vulnerability and the feasibility of adaptation and mitigation strategies. The analysis highlights the importance of differentiated system-sensitive climate-smart agriculture pathways aligned with local production contexts and producer realities across Latin America.

Keywords: rice cultivation systems; Latin America; climate vulnerability; irrigated rice; rainfed agriculture; climate-smart agriculture; food security; agricultural sustainability; water management; methane emissions.

JEL Classification: Q13; Q15; Q16; Q18; Q54.

Introduction

Rice is a staple crop and a strategic component of food security and rural livelihoods in Latin America. Rice production in the region unfolds across a wide spectrum of agroecological environments, water availability conditions, farm sizes, and technological intensities. From highly mechanized irrigated lowland systems to rainfed and traditional subsistence-oriented practices, this diversity profoundly influences productivity, resilience to climate variability, and environmental performance.

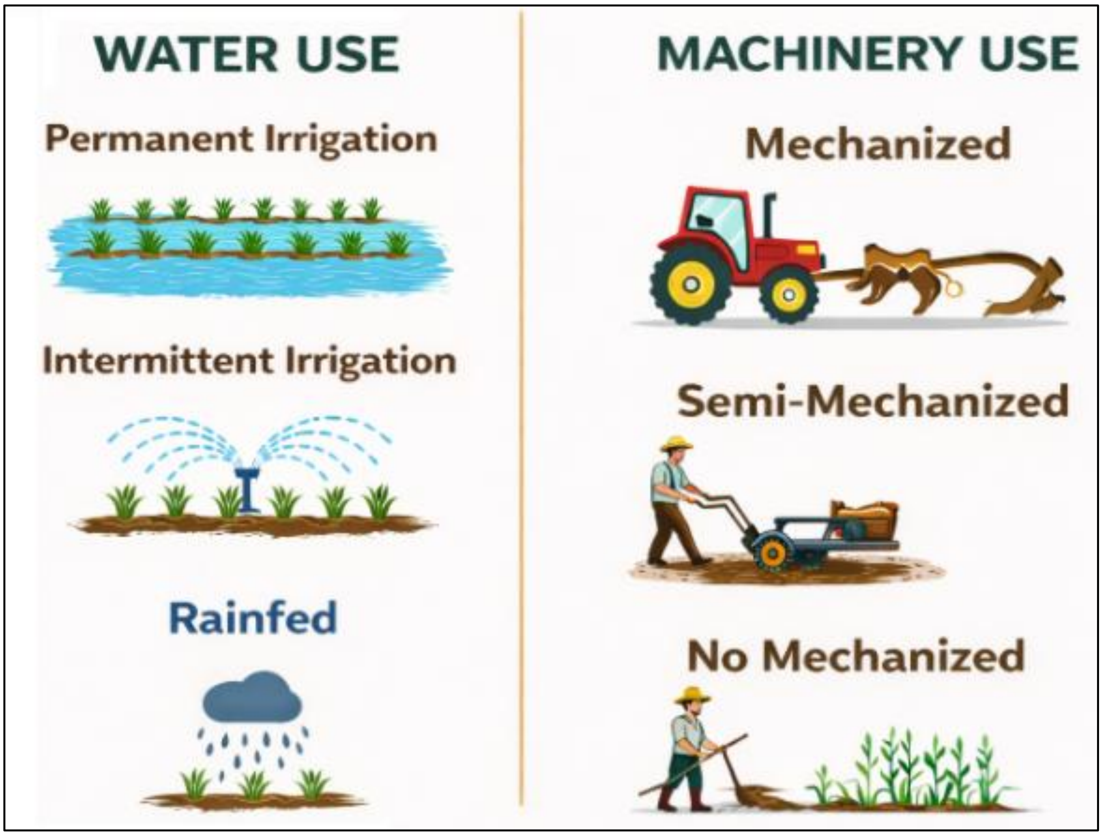
This article synthesizes the main rice cultivation systems in Latin America and analyzes their differentiated vulnerabilities and opportunities for climate-smart transformation.

The article is structured as follows. The first section examines the main rice cultivation systems. The second section analyzes the socioeconomic profiles of rice producers. The third section explores system-specific vulnerabilities to climate variability. The last section presents the conclusions.

1. Main Rice Cultivation Systems

Agricultural production can be understood through two key dimensions: water use and machinery use (Figure 1). Systems may be irrigated, partially irrigated, or rainfed, while production models range from mechanized to semi-mechanized and traditional (no mechanized).

Figure 1. Rice Cropping Systems



Irrigated Lowland Rice Systems

Irrigated lowland rice systems based on permanent or near-permanent flooding dominate commercial rice production in Latin America and account for the majority of total regional output (Chirinda *et al.* 2018). These systems depend on controlled water delivery from rivers, reservoirs, and canal networks, typically maintaining flooded or near-flooded soil conditions throughout much of the cropping cycle.

A defining characteristic of irrigated lowland systems is their high and relatively stable yield potential, attributable to reliable water supply and the capacity to regulate critical stages of crop development (Bouman *et al.* 2007). However, this performance is highly contingent upon the availability, effective operation, and maintenance of irrigation infrastructure, as well as robust basin-level water governance mechanisms that ensure equitable and predictable water allocation (Bouman *et al.* 2007).

Compared with rainfed systems, irrigated lowland rice production typically involves higher levels of external inputs, including fertilizers, improved seed varieties, mechanization, and energy for water conveyance and pumping. While these inputs contribute to higher productivity and yield stability, they also increase production costs and intensify farmers' dependence on well-functioning input, credit, and service markets, thereby exposing producers to additional economic and institutional risks (FAO, 2015).

Prolonged flooded conditions create anaerobic soil environments that favor methanogenesis, making irrigated lowland rice a significant source of agricultural methane (CH_4) emissions (Yan *et al.* 2009). Importantly, the presence of irrigation infrastructure also provides a critical foundation for mitigation and adaptation innovations. Improved water management practices, most notably Alternate Wetting and Drying (AWD), have demonstrated substantial potential to reduce methane emissions, enhance water-use efficiency, and strengthen system resilience under increasing water scarcity and climate variability (Sander *et al.* 2015).

Rainfed Rice Systems

Rainfed rice systems rely entirely on natural precipitation, rendering them inherently vulnerable to climate variability, seasonal fluctuations, and extreme events such as droughts and floods (Pandey *et al.* 2010). These systems are typically found in regions with limited or nonexistent irrigation infrastructure and are commonly associated with smallholder producers.

Compared with irrigated systems, rainfed rice systems are characterized by lower and more variable yields, reflecting their strong dependence on the amount, timing, and spatial distribution of rainfall. Variability in the onset and cessation of the rainy season, as well as irregular intra-seasonal precipitation patterns, translates into substantial production risks from one season to the next (Pandey *et al.* 2010).

Capital investment and the use of external inputs such as fertilizers and agrochemicals tend to be lower in rainfed systems, reducing production costs but also constraining yield potential and limiting opportunities for intensification. The absence of controlled water infrastructure severely restricts farmers' ability to manage water stress and respond proactively to increasing climate variability. In this context, strengthening the resilience of water-related investments to climate shocks and extreme events becomes a critical component of effective adaptation planning (FAO, 2013).

Adaptation strategies in rainfed rice systems therefore tend to prioritize risk reduction and livelihood resilience rather than yield maximization. Key measures include the adoption of drought- and flood-tolerant and early-maturing rice varieties, improved soil and nutrient management, crop diversification, and income diversification (FAO, 2013; Zorrilla *et al.* 2013).

Partially Irrigated and Supplemental Irrigation Systems

Between fully irrigated and purely rainfed systems lies a continuum of partially irrigated rice production systems that combine seasonal rainfall with supplemental irrigation. These systems can buffer short-term rainfall deficits, reduce exposure to intra-seasonal dry spells, and lower production risk compared with fully rainfed systems, while requiring lower capital investment and less complex infrastructure than permanent irrigation schemes (Bouman & Tuong, 2001).

The performance of partially irrigated systems depends critically on the timing, reliability, and effective management of supplemental water supply, as well as farmers' capacity to adjust agronomic practices - such as planting dates, variety selection, and nutrient management - in response to evolving climatic conditions (Bouman & Tuong, 2001). Under conditions of increasing climate variability and uncertainty, these systems are likely to play a growing role as transitional and adaptive production models (FAO, 2016a).

Technological Intensity

Levels of mechanization vary widely across rice cultivation systems in Latin America and are linked to farm size, access to capital, labor availability, and market integration (Daum, 2022). Highly mechanized systems, often associated with large-scale commercial operations, incorporate technologies such as laser land leveling, precision seeding and transplanting, advanced harvesting equipment, and digital decision-support tools. These innovations enhance labor productivity, optimize water distribution, and facilitate the implementation of climate-smart practices (FAO, 2013).

As a result, mechanized systems tend to achieve higher yields and lower emission intensity per unit of output (Yuan *et al.* 2021). In contrast, semi-mechanized and non-mechanized systems remain more reliant on manual labor and basic equipment, with structural constraints limiting opportunities for productivity growth and climate risk management (Daum, 2022).

Cropping intensity

Cropping intensity varies widely across the region and exerts a strong influence on both productivity and environmental performance (FAO, 2016b). While some areas, particularly rainfed and semi-mechanized systems, support only one rice crop per year, other regions with irrigated and mechanized systems sustain two or even three cropping cycles annually. This increases total output but also intensifies pressure on water resources and nutrient balances (Dobermann & Fairhurst, 2000). These trade-offs underscore the need to align intensification pathways with sustainable resource management (Yuan *et al.* 2021).

2. Socioeconomic Profiles of Rice Producers

Rice producers in Latin America comprise a highly heterogeneous group, ranging from smallholders cultivating only a few hectares to large commercial enterprises managing thousands of hectares. These differences in scale and resource endowment strongly shape production strategies, adaptive capacity, and exposure to climate risks (FAO, 2014).

Mechanized irrigated systems are typically operated by commercial producers with greater access to certified seeds, improved varieties, extension services, and financial resources. In contrast, smallholder and traditional rice producers often face limited access to credit, insurance, climate information services, and technical assistance, constraining their ability to adopt climate-smart practices despite their importance for national food security (FAO, 2014).

Socioeconomic vulnerability further amplifies exposure to climate impacts and undermines resilience. Factors such as aging farmer populations, limited formal education, insecure land tenure, and persistently low incomes interact to constrain adaptive capacity across many rice-producing areas in the region (Birkmann *et al.* 2022).

3. System-Specific Climate Vulnerabilities

Rice cultivation systems exhibit differentiated vulnerability profiles shaped by their dependence on water resources, levels of technological intensity, and institutional contexts. Irrigated systems, while generally associated with higher yields, remain vulnerable to basin-scale water scarcity and governance failures, particularly during prolonged droughts (Bouman *et al.* 2007).

Rainfed systems are especially sensitive to rainfall variability and extreme climate events, resulting in pronounced yield instability and livelihood risks for smallholders (Pandey *et al.* 2010). Highly mechanized systems display greater farm-level resilience but remain exposed to systemic risks such as input price volatility, labor shortages, and supply-chain disruptions (FAO, 2016a).

Recognizing these differentiated vulnerabilities is essential for designing effective, equitable, and system-appropriate adaptation strategies (FAO, 2016a).

Conclusions

Rice cultivation systems in Latin America reflect deep heterogeneity in water management, technological intensity, cropping intensity, and socioeconomic conditions. This diversity fundamentally shapes productivity outcomes, climate vulnerability, and the feasibility of adaptation and mitigation interventions.

Effective climate action in the rice sector must therefore avoid one-size-fits-all approaches and instead pursue differentiated, system-sensitive pathways aligned with local production contexts and producer realities. Aligning water management innovations, technological development, capacity building, and policy instruments with the diversity of rice cultivation systems is critical to enhancing resilience, reducing emissions, and supporting sustainable and inclusive rice-based agrifood systems across Latin America.

Declarations

Declaration of Competing Interest: The author declares that he have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of use of generative AI and AI-assisted technologies: The author declares that he has not used generative AI and AI-assisted technologies during the preparation of this work.

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