



SMART IRRIGATION IN RICE CULTIVATION: AN ALTERNATIVE APPROACH TO RICE PRODUCTION

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The Global importance of rice

Rice (*Oryza sativa* L.) is one of the most important food crops in the world. It feeds nearly three billion people every day and serves as the staple food for more than half of the global population. South and Southeast Asia together produce and consume over 90% of the world's rice, making it central to food security in these regions.

Rice is not only a source of energy but also provides essential nutrients such as proteins, vitamins and minerals. It contributes about 21% of daily calories and 15% of protein intake in the human diet. For millions of poor households in Asia, rice supplies up to 50% of daily calorie needs and remains the backbone of rural livelihoods. Globally, more than 200 million farming families depend on rice cultivation as their primary source of income.

One of the remarkable features of rice is its adaptability. It is grown under diverse environments, from uplands to deep-water ecosystems, from rainfed fields to fully irrigated lowlands, and across climates ranging from tropical to temperate. Rice can be established through transplanting or direct seeding, and modern systems now include dry-seeded, wet-seeded and water-seeded methods.

Water Scarcity: A Growing Challenge for Rice Production

By 2050, the world population is expected to reach over 9 billion, significantly increasing the demand for food, especially rice. Traditionally, rice is grown using the transplanted puddled system, which requires continuous flooding of fields. Although effective for weed control and yield stability, this method is extremely water-intensive. On average, producing one kilogram of rice requires about 2,500 litres of water, making irrigated rice one of the largest consumers of freshwater globally. In fact, rice cultivation accounts for nearly one-quarter to one-third of the world's freshwater use. However, rapid urbanization, industrial growth and rising living standards have drastically reduced the share of water available for agriculture.

Water has now become an expensive and scarce resource, particularly in rice-growing regions. As a result, farmers and researchers are exploring water-saving technologies and alternative cultivation practices. Techniques such as alternate wetting and drying (AWD), direct-seeded rice, raised-bed cultivation, system of rice intensification (SRI) and aerobic rice systems have shown promise in reducing water use while maintaining yields.

Among these innovations, aerobic rice, grown under non-flooded conditions, represents a major shift from conventional practices. However, yields can be unstable under rainfed or water-limited conditions, highlighting the need for more precise and efficient irrigation methods.

Area and Production of Rice

Over the 25-year period, rice production has shown a strong and consistent upward trajectory, while the area under cultivation has increased more gradually with some fluctuations. This indicates significant improvements in productivity and production efficiency over time. (Fig 1). In 2000 to 2001, rice was cultivated over 44.7 million hectares. During the early 2000s, both area and production fluctuated due to variations in rainfall, irrigation availability and other climatic and management factors. A notable decline was observed in 2002-03, when the area dropped to 41.18 million hectares and production fell sharply to 71.82 million tonnes, largely reflecting the impact of adverse weather conditions.

From 2003-04 onward, rice production began to recover steadily. Although the cultivated area remained relatively stable—generally ranging between 42 and 45 million hectares for much of the period—production continued to rise. By 2008-09, production had increased to over 99 million tonnes, even though the area expanded only modestly. This growth suggests improvements in yield due to better varieties, improved irrigation facilities, fertilizer use and agronomic practices.

A significant acceleration in production is evident after 2010-11. Production crossed 100 million tonnes in 2011-12 and continued to rise almost every year thereafter. By 2016-

17, production reached nearly 110 million tonnes, and by 2018-19 it had increased further to 116.48 million tonnes, despite only minor changes in cultivated area. This period highlights the role of technological interventions, improved seed quality and better water management in enhancing rice productivity. The most remarkable growth is seen in the last five years of the series. From 2020-21 to 2024-25, both area and production increased substantially. The area expanded from 45.77 million hectares to 51.27 million hectares, while production surged from 124.37 million tonnes to a record 150.18 million tonnes.

Overall, the data clearly show that rice production growth has outpaced the expansion in cultivated area, emphasizing the urgent need for water-efficient and technology-driven irrigation systems to sustain future production under increasing resource constraints.

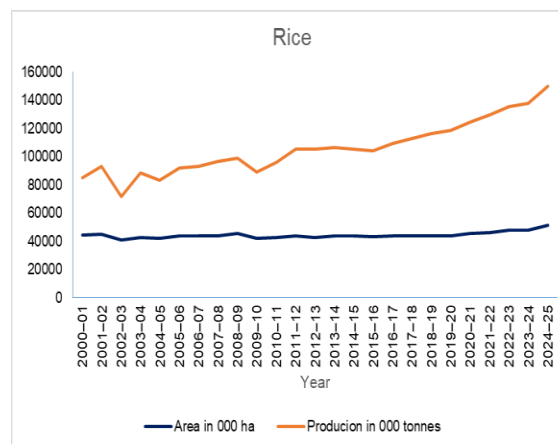


Fig 1: Trends in Rice Area and Production (2001-2024) (Indiastat.com)

Drip Irrigation: A Water-Saving Technology

Drip irrigation is a modern irrigation method where water is applied slowly and directly to the root zone of plants through a network of pipes and emitters.

Unlike traditional surface irrigation, drip systems deliver water in small, controlled amounts, minimizing losses due to evaporation and runoff.

Drip irrigation offers several advantages:

- Higher water use efficiency
- Improved crop yield and quality
- Reduced weed growth
- Efficient fertilizer application through fertigation
- Minimal soil structure damage
- Lower labor and energy requirements

Despite these benefits, drip irrigation also has limitations, including high initial costs, clogging of emitters, salt accumulation, and the need for regular maintenance.

Traditionally, drip irrigation has been widely adopted in high-value crops such as fruits and vegetables. Its application in rice, a densely planted crop, is relatively new. However, with growing water scarcity, drip irrigation is emerging as a promising option for aerobic rice systems, where fields are kept moist but not flooded.

Automated Drip Irrigation Systems

To further improve water efficiency, drip irrigation is now being combined with automation and smart technologies. In many parts of South Asia, irrigation is still managed manually, leading to overuse or inefficient application of water.

Automated irrigation systems aim to solve this problem by supplying water only when crops actually need it. These systems rely on soil moisture sensors, temperature sensors, humidity sensors and weather data. The sensors continuously monitor field conditions and send information to a microcontroller. When soil moisture drops

below a critical level, the system automatically switches on the irrigation pump. Once adequate moisture is restored, the pump turns off—saving both water and energy. Advanced systems use wireless sensor networks (WSN), Bluetooth or Wi-Fi technology, allowing farmers to monitor irrigation remotely.

Some systems even integrate artificial intelligence, fuzzy logic and decision-support models to optimize irrigation scheduling. Research studies have shown that automated drip irrigation can maintain crop yields while significantly reducing water use. Such smart irrigation systems represent a major step toward “more crop per drop”, a critical goal in modern agriculture.

Rice Cultivation and Greenhouse Gas Emissions

Rice farming is also closely linked to climate change through greenhouse gas emissions, particularly methane (CH₄), nitrous oxide (N₂O) and carbon dioxide (CO₂). Among these, methane is the dominant contributor from flooded rice fields.

Methane Emissions

Continuous flooding creates anaerobic soil conditions, promoting microbial processes that generate methane. Methane escapes into the atmosphere through diffusion, bubbling and transport via rice plants. As a result, conventionally flooded transplanted rice fields emit the highest levels of methane.

Nitrous Oxide Emissions

Nitrous oxide is produced during nitrogen transformations in soil through nitrification and denitrification. While flooded systems generally emit low N₂O, non-flooded or intermittently irrigated systems such as drip or aerobic rice may produce slightly higher N₂O emissions.

However, their overall climate impact is often much lower than that of methane-intensive flooded systems.

Carbon Dioxide Emissions

Carbon dioxide emissions from rice fields arise mainly from soil respiration, organic matter decomposition, fertilizer use and tillage operations. Compared to methane and nitrous oxide, CO₂ emissions from rice cultivation are relatively low and vary with crop growth stages.

Impact of Irrigation Methods on Emissions

- Research consistently shows that irrigation and cultivation methods strongly influence greenhouse gas emissions:
- Continuous flooding results in the highest methane emissions and global warming potential.
- AWD and early-season drainage significantly reduce methane without yield loss.
- SRI improves water productivity while lowering methane emissions.
- Aerobic and drip-irrigated rice systems emit far less methane than flooded systems.
- Drip irrigation combined with plastic mulch produces the lowest methane emissions, despite slightly higher N₂O release.

Smart Irrigation: A Climate-Friendly Path Forward

Smart irrigation technologies such as drip irrigation, AWD and automated control systems address two critical challenges simultaneously: water scarcity and climate change.

By avoiding continuous flooding, these systems improve soil aeration, suppress methane formation and reduce overall greenhouse gas emissions while conserving water.

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