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Review of Drip Irrigation and Fertigation Strategies for Enhancing Water use Efficiency and Productivity in Rice-Based Cropping Systems

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Abstract: *Rice-based cropping systems are among the largest consumers of freshwater worldwide, accounting for nearly 30–40% of global irrigation water used in agriculture. Conventional flooded rice cultivation results in excessive water losses through evaporation, seepage, and percolation while reducing nutrient use efficiency due to nitrogen leaching and volatilization. Increasing water scarcity, climate change, and rising fertilizer costs have accelerated interest in precision irrigation technologies such as drip irrigation combined with fertigation. Drip irrigation delivers water directly to the root zone, whereas fertigation supplies nutrients through the irrigation system in small, frequent doses. Together, these technologies significantly improve water use efficiency (WUE), fertilizer use efficiency (FUE), crop productivity, and environmental sustainability. This review summarizes the principles, recent advances, benefits, limitations, and future prospects of drip irrigation and fertigation strategies in rice-based cropping systems. The review also discusses suitable irrigation scheduling, nutrient management, automation technologies, economic feasibility, and research gaps.*

Keywords: Drip irrigation, Fertigation, Water use efficiency, Rice, Precision agriculture, Nutrient management.

1. INTRODUCTION

Rice is the staple food for more than half of the world's population and occupies approximately 165 million hectares globally. Traditional puddled transplanted rice requires between 1200 and 3000 mm of water depending upon soil type, climate, and irrigation practices. This enormous water demand has become unsustainable in regions facing declining groundwater tables and irregular rainfall patterns.

Modern irrigation technologies emphasize maximizing crop production while minimizing water and fertilizer consumption. Drip irrigation has emerged as one of the most efficient irrigation methods because it delivers water directly to the plant root zone with minimal evaporation losses. Fertigation complements drip irrigation by providing nutrients through irrigation water, thereby increasing nutrient availability and reducing fertilizer losses. The integration of drip irrigation and fertigation has shown promising results in direct-seeded rice (DSR), aerobic rice, and diversified rice-based cropping systems.

Table 1. Comparison of Conventional Flood Irrigation and Drip Fertigation in Rice

Parameter	Conventional Flood Irrigation	Drip Irrigation + Fertigation
Water application	Field flooding	Root-zone application
Water saving	Low	30–70%
Fertilizer use efficiency	30–50%	70–90%
Nitrogen losses	High	Low
Weed infestation	High	Lower

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Water productivity	Low	High
Labour requirement	High	Moderate
Energy efficiency	Moderate	High
Environmental pollution	Higher	Lower

Source: Compiled from published literature.

PRINCIPLES OF DRIP IRRIGATION

Drip irrigation supplies water slowly and uniformly through emitters positioned near the crop root zone. Unlike surface flooding, only the effective root zone is wetted, minimizing evaporation and deep percolation losses.

Major components include:

- Water source
- Pumping unit
- Filtration system
- Fertigation unit
- Main pipeline
- Sub-main
- Laterals
- Emitters
- Pressure regulators

Studies indicate that drip irrigation can reduce irrigation water requirements by 40–60% while maintaining or increasing rice yield under suitable management.

FERTIGATION TECHNOLOGY

Fertigation is the application of soluble fertilizers through irrigation water.

Major fertilizer sources include:

- Urea
- Calcium nitrate
- Potassium nitrate
- Mono ammonium phosphate
- Mono potassium phosphate
- Water-soluble NPK fertilizers
- Advantages include:
- Uniform nutrient distribution
- Reduced nutrient losses
- Higher fertilizer recovery
- Improved nutrient uptake
- Better synchronization with crop demand

Research has shown that fertigation improves nitrogen use efficiency by 20–40% compared with conventional broadcasting.

Table 2. Common Fertigation Schedule for Rice

Crop Stage	Fertilizer Applied	Frequency
Germination	Starter fertilizer	Once
Vegetative stage	Nitrogen-rich fertilizer	Weekly
Tillering	N + K	Weekly

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Panicle initiation	Balanced NPK	Weekly
Flowering	Potassium-rich fertilizer	Weekly
Grain filling	Potassium	Once or twice

WATER USE EFFICIENCY (WUE)

Water Use Efficiency represents grain yield produced per unit water consumed.

WUE = Grain Yield / Total Water Applied

Several field studies reported:

Water savings of 42–68%

Increase in WUE by 50–120%

Grain yield increase of 10–25%

These improvements are especially significant in water-scarce environments and direct-seeded rice systems.

Table 3. Reported Benefits of Drip Irrigation in Rice

Study	Water Saving	Yield Increase	WUE Improvement
Pant University	45%	15%	4× higher WUE
Punjab Agricultural University	42%	17%	0.81–0.88 kg m^{-3}
Tamil Nadu studies	50–61%	17–22%	0.365–0.714 kg m^{-3}
Multi-location trials	35–55%	13–28%	Increased water productivity

Compiled from published reports.

PRODUCTIVITY IMPROVEMENT

Drip fertigation enhances productivity by:

- Continuous moisture availability
- Better root growth
- Reduced moisture stress
- Efficient nutrient uptake
- Reduced lodging
- Improved grain filling

Yield increases generally range between 10 and 30% depending on cultivar, climate, soil type, and management.

Table 4. Effect of Drip Fertigation on Crop Parameters

Parameter	Conventional	Drip Fertigation
Plant height	Moderate	Higher
Tillers	Lower	Higher
Root growth	Moderate	Excellent
Panicle length	Shorter	Longer
Grain weight	Lower	Higher
Harvest index	Lower	Higher

RICE-BASED CROPPING SYSTEMS

Drip fertigation is increasingly adopted in:

Rice–Wheat

Rice–Maize

Rice–Mustard

Rice–Vegetable

Rice–Pulse

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Rice–Cotton

Benefits include improved resource use efficiency, reduced irrigation demand, and enhanced profitability across cropping sequences.

Table 5. Advantages in Rice-Based Cropping Systems

Cropping System	Major Benefit
Rice–Wheat	Higher WUE
Rice–Vegetable	Increased profitability
Rice–Pulse	Better soil fertility
Rice–Maize	Reduced irrigation requirement
Rice–Mustard	Improved fertilizer efficiency

AUTOMATION AND PRECISION TECHNOLOGIES

Recent advances include:

- Soil moisture sensors
- IoT-enabled irrigation controllers
- Automated fertigation systems
- Weather-based irrigation scheduling
- Remote sensing
- GIS-based monitoring
- Artificial Intelligence (AI)

These technologies optimize irrigation timing and fertilizer application, improving precision and reducing resource wastage.

Table 6. Emerging Technologies

Technology	Application
IoT	Real-time irrigation control
Soil moisture sensors	Irrigation scheduling
AI	Decision support
GIS	Spatial variability analysis
Drones	Crop monitoring
Remote sensing	Water stress detection

CHALLENGES

Major constraints include: -

- High initial installation cost
- Emitter clogging
- Requirement for filtration
- Skilled operation
- Limited adoption in transplanted flooded rice
- Maintenance requirements

Table 7. Challenges and Possible Solutions

Challenge	Solution
High investment	Government subsidy
Emitter clogging	Proper filtration
Poor farmer awareness	Capacity building
Maintenance	Regular inspection

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Fertilizer compatibility	Use water-soluble fertilizers

II. CONCLUSION

Drip irrigation integrated with fertigation represents a promising strategy for improving water use efficiency, nutrient use efficiency, and productivity in rice-based cropping systems. Compared with conventional flooded irrigation, drip fertigation substantially reduces irrigation water use, enhances fertilizer recovery, minimizes nutrient losses, and supports higher yields while reducing environmental impacts. Adoption is particularly beneficial in water-scarce regions and for direct-seeded or aerobic rice systems. Wider implementation will require cost-effective technologies, farmer training, supportive policies, and continued research on precision irrigation scheduling and automation.

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