Strategies for Climate Action and Sustaining Rice Productivity in Eastern India

Understanding systems diversity as the foundation for change

Agricultural development in Bihar and adjacent states in eastern India is a priority because of its importance to rural livelihoods and its potential impact on food security and economic development within and beyond the region. Nevertheless, eastern India is a complex mosaic of production environments, especially for rice, implying that there is no single approach to spur development. Policymakers must recognize that strategies for growth must proactively address negative impacts on the environment, including greenhouse gas emissions.

In close collaboration with national partners (such as the Indian Council of Agricultural Research [ICAR], Bihar Agricultural University), and international partners (such as CGIAR), the Tata–Cornell Institute for Agriculture and Nutrition (TCI) has worked to devise sustainable intensification strategies that recognize and respond to production systems' diversity in eastern India.

TCI-supported research shows that precision nitrogen fertilizer recommendations can significantly increase productivity while increasing efficiencies and reducing nitrous oxide emissions. Research on methane demonstrates that the production context defines the magnitude of the emissions challenge as well as the solutions to address them. Technologies, like alternate wetting and drying (AWD), will likely have a minor role in reducing current emissions but may provide the cornerstone of mitigation efforts, as irrigation use rises to close yield gaps

Nitrogen

Since the 1960s, India has made remarkable strides in enhancing agricultural productivity to reduce food insecurity and rural poverty and now exports around 40% of globally traded rice. Success has been driven by a variety of factors, including highly subsidized nitrogen fertilizer. These subsidies constitute around a quarter of all spending on agricultural development and food support programs in India. However, inexpensive fertilizer also disincentivizes conservation, and India remains a global hotspot for nitrogen pollution.

Unsurprisingly, the Government of India is eager to reduce expenditure on nitrogen subsidies and has launched the PM Program for Restoration, Awareness Generation, Nourishment, and Amelioration of Mother Earth

(PM-PRANAM) initiative in 2023, which provides financial incentives to states. Although the motivation to reduce nitrogen use is clear, the strategies for doing so are less apparent. Initial analyses of on-farm survey data collected by the Cereal System Initiative for South Asia (CSISA) and ICAR revealed that the problem of nitrogen overuse is not universal. Some farms use too much nitrogen and could safely lower application rates. Others are nitrogen-limited and would incur significant yield penalties if policies to reduce urea subsidies were uniformly applied. In many cases, farms with the lowest yields appear to be generating the highest levels of nitrogen pollution.

TCI-supported research provides an action roadmap for enhancing nitrogen use efficiency by drawing insights and developing prediction models with data from the Landscape Crop Assessment Survey (LCAS).

Results indicate that 50% of rice farmers in Bihar could safely reduce nitrogen rates without compromising yields, but there is a strong geographic dimension for solution targeting, with farmers in northern Bihar generally benefiting from *higher* nitrogen rates. At the state level, predictive modeling suggests that precision nitrogen recommendations could increase annual rice production by more than 500,000 metric tons. However, achieving this goal would require an additional 220,000 metric tons of fertilizer. In contrast, by jointly addressing nitrogen and irrigation co-limitations to yield, a similar production gain would be possible with a much lower investment in nitrogen. Targeting only around 20% of farms for practice change would lead to significantly higher yield (+0.4–1.0 metric tons per hectare) and profitability ($50–$100 per hectare) gains for those changing practices. This approach is anticipated to more than double nitrogen use efficiency for new investments in nitrogen with commensurate reductions in nitrous oxide emissions.

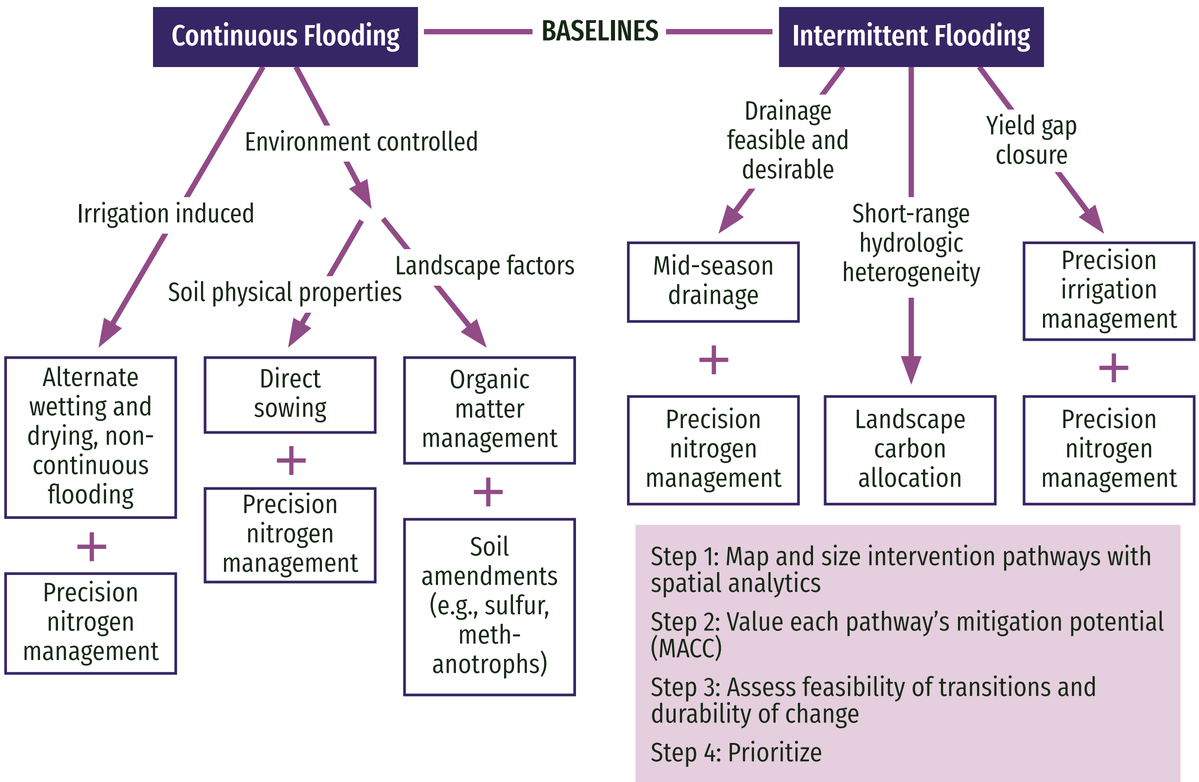
Methane

Methane (CH_4), primarily from rice production systems, is estimated to contribute around 50% of all direct greenhouse gas emissions from global croplands because of anaerobic soil processes from soil flooding. Consequently, water management is considered a primary lever for greenhouse gas mitigation from agricultural systems. Practices such as AWD have been broadly studied as mitigation strategies on agricultural experiment stations across Asia.

Rice production systems are typically categorized by a combination of land type and water management strategy, with irrigated lowlands composing most of the rice area in eastern India. For experimental purposes, irrigated lowlands are often assumed to be continuously flooded. Emerging efforts to characterize the diversity of hydrologic conditions in farmers' fields in Bihar reveal a more complex picture with significant spatial and

Diversity of Environments = Diversity of Solution Spaces

Water is the "master" variable for greenhouse gas emissions in rice: accurate baselines and effective mitigation begins with robust hydrologic characterization in time and space



temporal differences, often over short distances. Results also suggest that landscape factors often exert a stronger influence on field hydrology than soil properties or irrigation practices.

Hydrologic diversity in the rice systems of Bihar has profound implications for baseline greenhouse gas emissions, with methane from the wettest cohort of the studied fields estimated to exceed those from the driest fields by a factor of five., At present, baseline greenhouse gas estimates for rice in India rely on emission factors that do not adequately capture hydrologic diversity. The implications of poor baselines are profound—despite a proliferation of voluntary carbon markets and a focus on technologies such as AWD, most mitigation initiatives are likely supporting ineffective interventions that are not responsive to underlying hydrologic conditions, which often leads to a focus on the wrong rice geographies and, where emissions are truly high, to ineffective mitigation strategies.

TCI-supported research suggests that two interlinked steps are required to empower effective greenhouse gas mitigation in rice. First, novel methodologies are required for building multi-year hydrologic baselines. Second, rather than focusing on management technologies per se, knowledge of the baselines should be used to prioritize emissions hotspots, with technologies linked to specific production contexts. For example, organic matter management should be prioritized in persistently wet parts of the landscape where farmers exert little control over field hydrology. Researchers developed a conceptual framework for guiding greenhouse gas mitigation efforts that matches technologies to baseline hydrologic conditions. In a given region, each pathway can be assessed from the perspectives of baseline emissions, efficacy of mitigation options, and costs to help carbon markets, policymakers, and individual farmers reduce greenhouse gas emissions from rice.

Avoiding Unsustainable Development Trajectories

As regions like eastern India seek to intensify rice productivity, meeting future food demands will require increasing irrigation use and may be an unforeseen driver of higher global methane emissions. Recent model-based results suggest that if yield intensification is achieved with continuous flood irrigation, current baseline emissions (4.1 t CO_2-eq ha^{-1}) are anticipated to double (8.8 t CO_2-eq ha^{-1}), with more moderate increases predicted with precision irrigation practices such as AWD (7.0 t CO_2-eq ha^{1}). Robust strategies for achieving effective water management are needed to avoid the most damaging climate impacts of rice intensification.

In Bihar, water management strategies such as AWD may prove essential for avoiding the unintended costs of yield intensification that could greatly increase emissions in the region.

Zero-Hunger, Zero-Carbon Food Systems

This policy brief was produced as a part of TCI's project on Zero-Hunger, Zero-Carbon Food Systems. The project aims to support the reduction of GHG emissions associated with agriculture while improving productivity and benefiting farmer livelihoods.

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