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Agronomy & Case Study on Irrigated Rice

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Globally, about 100 million hectares of irrigated lowland rice systems produce around 75% of the world's rice. Due to prolonged periods of flooding, these systems are by far the major source of CH₄ emissions from rice. Research conducted in the 1990s revealed a high degree of spatial and temporal variability of methane emissions that was caused more by location-specific management practices than soil or climate¹. Consequently, numerous potential agronomic interventions have been proposed and studied in the past three decades to address methane emissions from rice. A recent global synthesis of 54 agronomic and soil interventions summarized the available evidence below (Fig. 1)².

Water-saving irrigation technologies cut CH₄ emissions by about 50% and GWP by 41%, but resulted in a slight yield decline (-3%) (Fig. 1), which illustrates potential challenges for wider adoption by farmers. However, there are also significant differences among water management practices. Intermittent irrigation offered the best balance (no yield loss, 53% CH₄ reduction), whereas non-flooded systems (e.g.,

aerobic/sprinkler/drip-irrigated rice) achieved even greater emission reductions but incurred larger yield losses (-9%). Alternate Wetting and Drying (AWD) has been widely promoted in Asia in recent years^{3,4} and is also the cornerstone of existing CH₄-mitigation standards, but its adoption has been hindered by specific constraints, including lack of control over water, land ownership, irrigation system management, or weak farmer engagement⁴. The success of AWD is closely linked to the quality of irrigation infrastructure and management. Local environmental and operational conditions significantly influence community capacity to implement and sustain AWD practices. Farmers utilizing gravity-fed irrigation systems often depend on rigid, authority-mandated rotational water schedules that do not align well with AWD requirements. Variations in elevation and soil types further challenge the standardization and scalability of AWD methodologies. In contrast, even simple practices such as a mid-season field drainage can nearly halve CH₄ emissions (Fig. 2), and may even increase crop yield.⁵

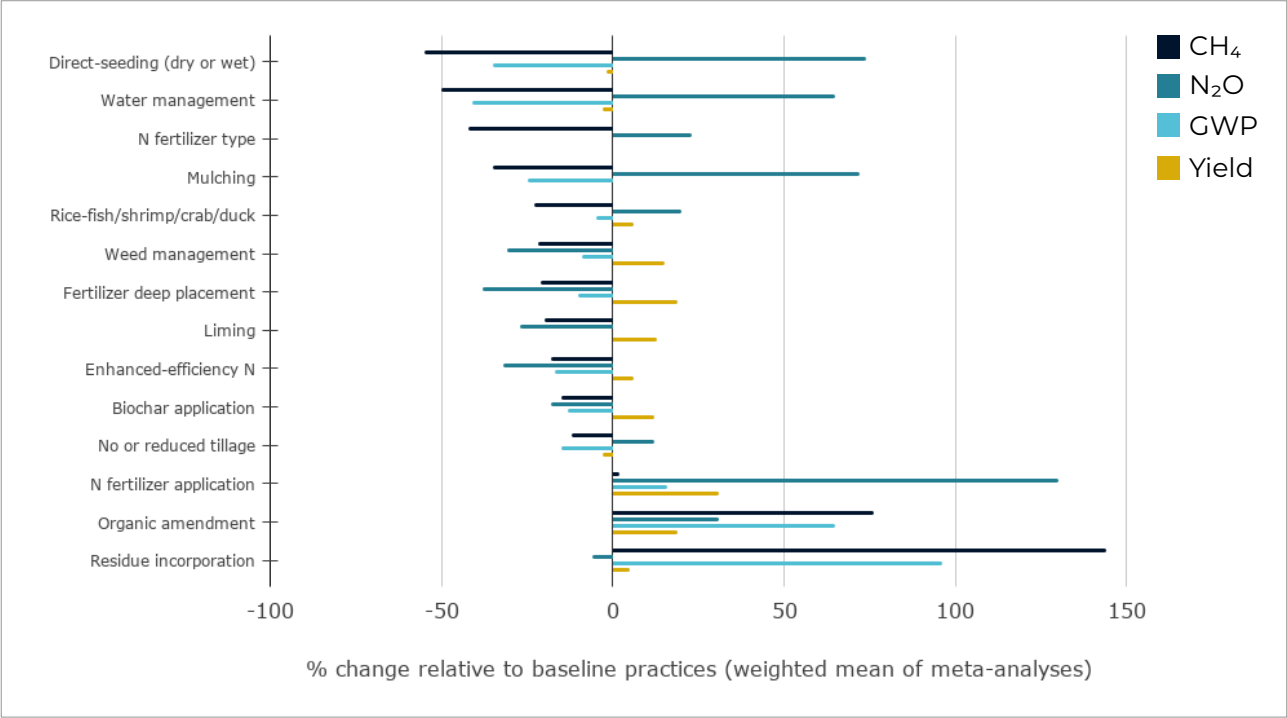


Figure 1: Global synthesis of impacts of agronomic practices and soil amendments on CH₄ emissions, rice grain yield, N₂O emissions and their overall global warming potential (GWP)².

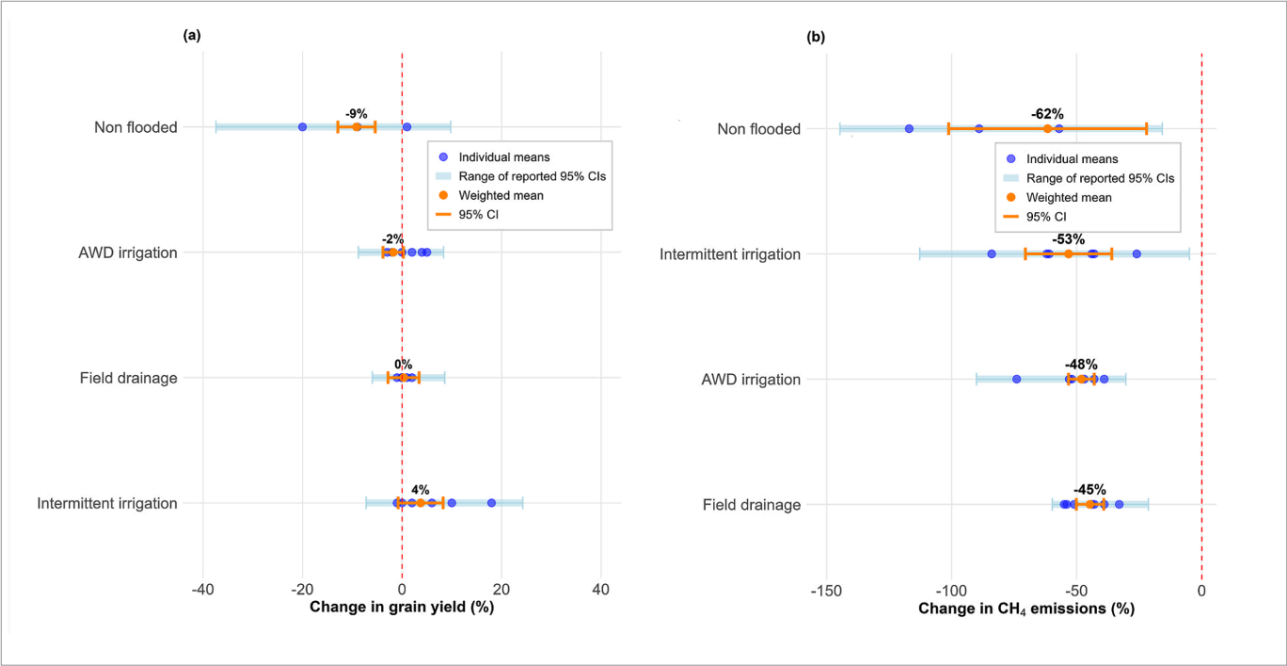


Figure 2: Effect of different water management practices on crop yield (a) and change in CH₄ emissions from rice².

Practices such as no-till or reduced tillage lowered GWP by 15% without a yield penalty (Fig. 1). However, also changing crop establishment from transplanting to direct-seeding reduced methane emissions by 55%, but increased N_2O emissions by 74%, resulting in an overall GWP reduction of 35%. Biochar application reduced CH_4 , N_2O , and GWP by 13–18% and consistently delivered co-benefits, increasing yield by 12% (Fig. 1). This confirms results of another meta-analysis, which found reductions in CH_4 of 18% and rice yield increases of 11%⁶. However, the scalability of biochar is limited due to availability and high costs associated with producing, transporting, and applying it to rice fields. Evidence from India also suggests that the actual biochar benefits for rice farmers are much smaller than what is commonly reported in experimental studies conducted under controlled conditions⁷.

Incorporation of fresh crop straw and other organic amendments (e.g., manure, green manure) raised yields (by 5% and 19%), but sharply increased CH_4 emissions (by 144% and 76%) and GWP (by 96% and 65%, Fig. 1). Widespread adoption of intensified residue incorporation has recently been identified as a driver of GHG emissions from rice paddies⁸. Although straw removal is one of the most effective CH_4 mitigation options in the short term, it may also reduce soil fertility in the long term⁹, particularly through declines in soil organic carbon and soil potassium levels¹⁰. Early incorporation of crop residue during the fallow period, on the other hand, tends to avoid initial CH_4 flushes in the subsequent cropping season, while returning carbon and nutrients to the soil.

Inorganic nitrogen fertilizer significantly increased yields, but also raised N_2O emissions by an average of 130%. Its impacts on CH_4 emissions vary, depending on the type of fertilizer applied and its placement (Fig. 1). Innovations, including deep placement and enhanced-efficiency fertilizers, reduced N_2O

emissions by up to 38% and improved yields by 6%–19%, thereby reducing the overall GWP and GHG emissions. The choice of fertilizer also affects CH_4 emissions. Sulfate-containing fertilizers such as ammonium sulfate generally result in larger CH_4 mitigation benefits than any other fertilizers^{9,11}.

Integrated management systems (e.g., rice–duck, rice–fish) reduced CH_4 , though effects on N_2O were variable (Fig. 1). While several agronomic interventions show promise, evidence remains limited, with other interventions more site-specific (e.g., liming, weed and pest management).

Three main conclusions emerge from this review:

1. Most interventions have tradeoffs in terms of impacts on greenhouse gas emissions, crop yield, and economic feasibility,
2. Location-specific integration of several measures is required to achieve significant benefits, minimize tradeoffs, and capitalize on synergistic interactions, and
3. Water and crop residue management are of universal importance for reducing CH_4 emissions from rice, but their impact varies widely.

For example, field experiments in Central Luzon, Philippines demonstrated a positive interaction between effects of AWD and straw management on CH_4 emissions. The total seasonal CH_4 emissions were reduced by 73% by AWD (compared to continuous flooding) when the crop residue was incorporated and allowed to decompose during the dry fallow period. However, the reduction was less than 20% when it was incorporated during the start of wet land preparation¹².

Any assessment of system-level GHG emissions in rice needs to include direct emissions of CH_4

and N_2O , as well as changes in soil organic carbon (SOC) and energy use (e.g., fuel, fertilizer) that can positively or negatively influence the net capacity for climate change mitigation¹³. Field GHG emissions are generally the largest contributor to net system emissions in rice, and practices such as floodwater drainage (or water-saving irrigation) and residue removal are sound and nearly universally applicable options for CH_4 mitigation. On the other hand, increasing SOC also provides a GHG mitigation opportunity, for which long-term continuous rice cropping and practices such as residue incorporation (at the right time) and biochar application are suited. A reduction in energy inputs is mainly achieved by reducing tillage and optimizing the efficiency of nitrogen fertilizer use¹³.

The critical issue is therefore to optimize net system emissions through location-specific integration of management practices that reduce field GHG emissions, maintain or increase SOC, and increase energy efficiency¹³. Below we discuss how this principle could be applied to transforming irrigated double-cropping rice systems in Asia, towards highly-productive, low-emission rice systems. Similar solutions apply to other irrigated rice systems, and to many rainfed-lowland rice systems.

CASE STUDY

TRANSFORMING IRRIGATED RICE-RICE SYSTEMS IN ASIA

Among the different types of irrigated rice systems in the world, intensive rice-based systems found in the humid tropical and subtropical environments of Asia are of particular importance for food security and methane emissions. Such cropping systems are mostly located on flood plains along major rivers, terraces, inland valleys, and coastal plains in the humid and subhumid subtropics and tropics. Rainfall ranges from 1000 to more than 2000 mm per year. The warm climate and

access to water allow farmers to grow two to three short-duration rice crops per year (Fig. 3).

Rice is grown in the drier season with low rainfall and high solar radiation and in the humid (monsoon) season with lower yield potential due to cloudy conditions and high rainfall. Soils vary widely, but are mostly of heavier texture and relatively good quality for growing rice.

Double cropping rice monoculture became common in China about 1000 years ago, but it spread rapidly since the mid-1960s, when high-yielding rice varieties with shorter growth duration and expansion of irrigation became available¹⁴. These systems are the backbone of global rice production, accounting for at least 40%, primarily in countries such as China, Vietnam, Indonesia, Thailand, the Philippines, Malaysia, Myanmar, Bangladesh, and India. Farmers generally use irrigation, seed of newer varieties, fertilizers, and crop protection products. Mechanization varies, but is common for land preparation and harvest. More recently, direct-seeding or machine-planting has replaced the traditional manual transplanting of rice seedlings in many areas. Drone application of seed, nutrients, or pesticides is on the rise. Yields vary, but are mostly in the 4-8 t/ha range.

Figure 4 illustrates a typical seasonal pattern of methane emissions from an irrigated rice field in these regions, showing how the variations in daily CH_4 emissions are driven in part by the growth stage of the rice plants. Although there is significant variation in cropping intensity, varieties, planting, harvest, and soil, water, and crop management, the common feature of these systems is a long annual period under flooded or very wet soil conditions, which may span from wet land preparation ("puddling") to shortly before harvest of each crop, but may also include very wet fallow periods between crops. Although

Region	Cropping system	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Central Thailand / Luzon, Philippines	Rice–Rice	DS rice						WS rice						
Mekong Delta, Vietnam	Rice–Rice–Rice	DS rice			WS rice			Rice						
Red River Delta, Vietnam	Rice–Rice–(Maize)		Spring-rice				Summer-rice					Maize		
West Java, Indonesia	Rice–Rice	WS rice				DS rice								
Central Java, Indonesia	Rice–Rice–(Maize)	Rice					Maize			Rice				
Cauvery Delta, South India	Rice–Rice–(Pulses)		Pulses				WS rice					DS rice		
Southern China	Rice–Rice				Early-rice				Late-rice					

Figure 3: Examples of intensive, irrigated rice systems in Asia. In some cases farmers may also grow a third rice or non-rice crop (DS - dry season; WS - wet season).

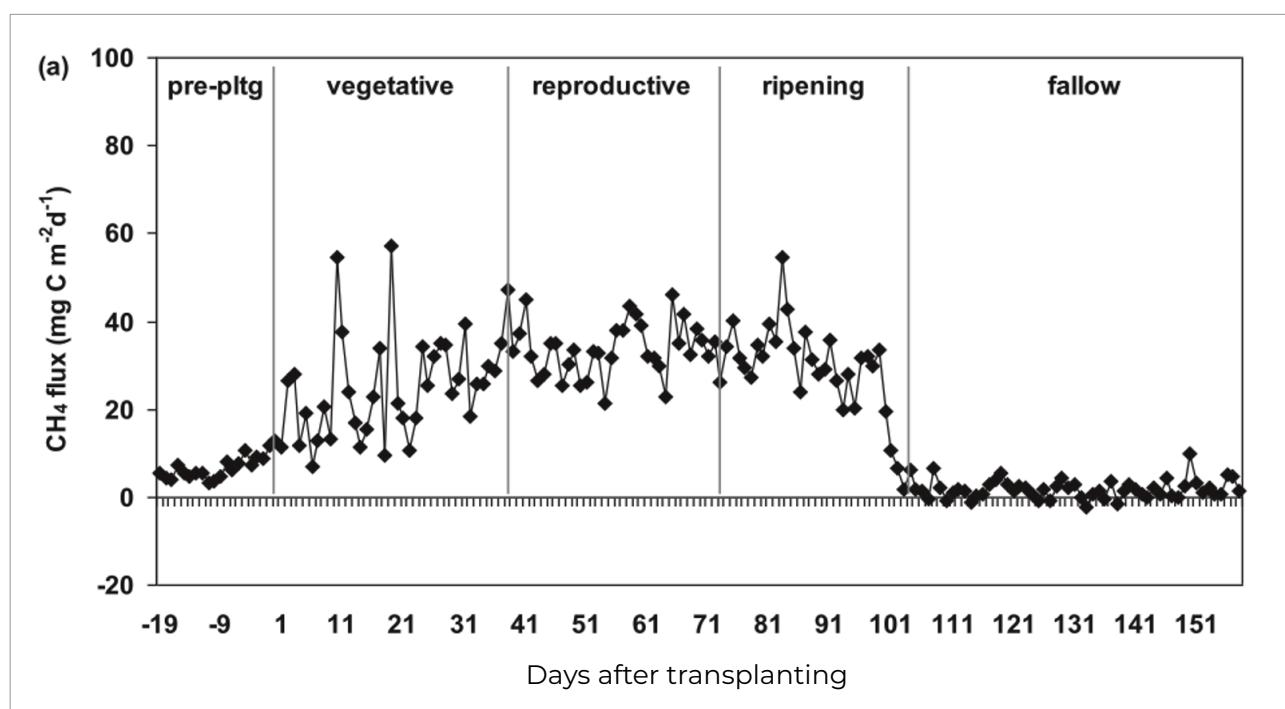


Figure 4: Seasonal variations in daily CH₄ fluxes in an irrigated rice field at International Rice Research Institute (IRRI), Philippines during the different growth stages of the rice plant¹⁵.

there may be short periods of drainage during each crop cycle, with two irrigated rice crops grown in sequence, such rice fields emit significant amounts of CH₄ for about 200 days per year, or even more.

Consequently, under such conditions total methane production and emissions are high. Achieving a sustainable reduction in methane emissions while also meeting other production objectives requires integrated management changes during each crop cycle and during non-flooded periods, as illustrated in Figure 5.

Numerous agronomic practices need to be changed to achieve the desired outcomes in terms of reducing CH₄ emissions, system productivity, resource efficiency and soil health:

Soil amendments and methane-reducing agents: These can remove major soil constraints. If available and economical, use amendments that may reduce methane emissions and

provide other benefits for soil health, such as well-decomposed organic matter, biochar, gypsum, phosphogypsum, new strains of soil microbes, and methane inhibitors.

Tillage and land leveling: Dry land preparation instead of flooding the soil and wet tillage. Use laser-guided equipment to level fields in order to achieve good crop emergence, water control, and also weed control. This requires suitable machinery and can only be done in conjunction with changing crop establishment to direct-seeding.

Sowing: Instead of transplanting young rice seedlings (P), switch to dry direct-seeding or wet direct-seeding, although the latter will not reduce methane by much. Use good-quality seed of a new variety that is well-adapted to new management practices and environments, while maintaining or even increasing yields, and/or switch to a variety bred for lower methane emissions once those become available.

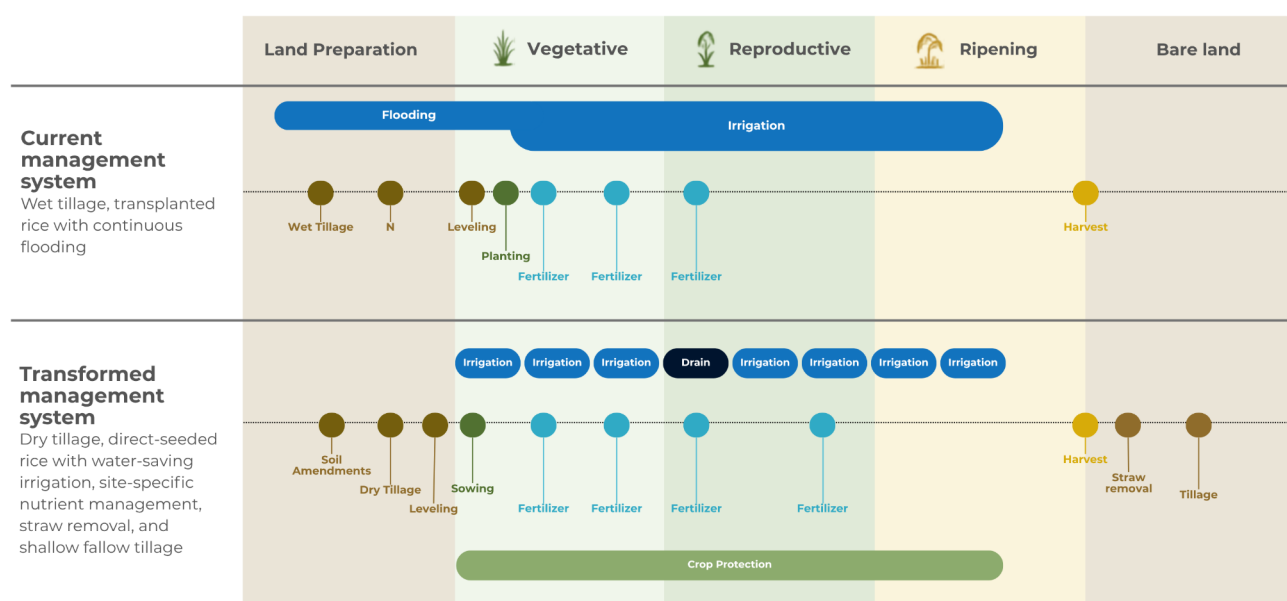


Figure 5: Integrated management changes to reduce methane emissions in irrigated rice-rice systems of Asia. Top: Current management system (wet tillage, transplanted rice with continuous flooding). Bottom: Transformed management system (dry tillage, direct-seeded rice with water-saving irrigation, site-specific nutrient management, straw removal, and shallow fallow tillage).

Fertilizer management: Follow a site-specific nutrient management (SSNM) approach to ensure nutrient supply is well synchronized with crop demand, thereby achieving high N use efficiency and balanced nutrition. Split N applications according to key growth stages to achieve high N use efficiency. In high-yielding crops, consider an optional late N application at heading stage for extra yield. If economical, use specific fertilizer products that improve N use efficiency and reduce gaseous losses of N as ammonia or nitrous oxide, such as controlled release fertilizers or fertilizers stabilized with urease or nitrification inhibitors. If available and economical, use ammonium sulfate as N source for at least some of the N applied.

Irrigation & Drainage: Use water-saving irrigation (e.g. AWD) and/or conduct mid-season drainage for better crop growth and soil aeration. Because methane formation primarily occurs under anaerobic soil conditions, the largest mitigation potential is generally found in changing water management from continuous flooding to intermittent irrigation during the key growth stages, a technique widely known as alternate wetting and drying (AWD)³. If that cannot be done – or in addition to it - do at least one mid-season field drainage to improve soil aeration during vegetative crop growth.

Crop protection: A shorter period under flooding, dry soil tillage, and non-flooded irrigation will change the dynamics of many weeds, diseases, and insect pests. For example, weed control is generally more difficult in direct-seeded rice, which uses less water, and may require new, more effective herbicides and/or herbicide-tolerant rice varieties. Throughout the growing season, follow an integrated pest and weed management strategy that is adapted to the new system.

Crop residue management: Where possible, remove the straw from the field after harvest and use it for livestock feed or other purposes, but account for the additional nutrient removal in the nutrient management plan.

Tillage: If feasible (not too wet soil), do a dry, shallow (5-10 cm) tillage shortly after harvest to incorporate residue and enhance soil aeration, thereby stimulating its decomposition before the next period of flooding.

In other irrigated or rainfed lowland rice systems, similar principles apply, and some interventions may be similar, but specific priorities and solutions will vary. Crop diversification – replacing one rice crop with a non-flooded upland crop such as maize – is another option. However, opportunities for that depend on soil and climatic conditions, access to markets for the new crop, and local know-how for growing it. Replacing rice on a large scale would also lead to an undesirable decline in rice supply.

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