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No.2

Accelerating Intermittent Irrigation for Low-carbon and Resilient Rice Production Systems in Asia

progress, challenges and opportunities

Yuji Enriquez, Katherine Nelson, Bjoern Ole Sander, Bas Bouman, Valerien Pede, Mamoru Watanabe

Green Asia

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Abbreviations and acronyms

AWD – Alternate Wetting and Drying
CCAC – Climate & Clean Air Coalition
CDM – Clean Development Mechanism
CER – Certified Emissions Reductions
CH_4 – Methane
CO_2 – Carbon Dioxide
DA – Department of Agriculture
GHG – Greenhouse Gas
GRiSP – CGIAR Research Program on Global Rice Science Partnerships
IoT – Internet-of-Things
IPCC – International Panel for Climate Change
IRRC – Irrigated Rice Research Consortium
IRRI – International Rice Research Institute
JIRCAS – Japan International Research Center for Agricultural Sciences
MD – Multiple Drainage
MiDi – Midseason Drainage with Intermittent Irrigation
MRV – Measurement, Reporting and Verification
MSD – Mid-season Drainage
N - Nitrogen
NAMA – Nationally Appropriate Mitigation Action
NARES – National Agricultural Research and Extension Systems
NDC - Nationally Determined Contributions
NIA – National Irrigation Administration
N_2O – Nitrous Oxide
PhilRice – Philippine Rice Research Institute
SDC – Swiss Development Cooperation
SOC - Soil Organic Content
SRP – Sustainable Rice Platform
UNFCCC – United Nations Framework Convention on Climate Change

Abstract

Rice is not only crucial to the food security of a majority of the world's population, but it also has an important role in regulating water scarcity and has a huge potential in mitigating the effects of climate change. Despite this, the potential of rice production systems to bring sustainable outcomes is abated by its increasing vulnerability to extreme weather events and high-emission practices. Intermittent irrigation practices, characterized by (i) single drainage or single aeration, such as midseason drainage, and (ii) multiple drainage or multiple aeration, such as Alternate Wetting and Drying (AWD), midseason drainage followed by intermittent irrigation, and other AWD variants, are low-cost innovations that reduce farmers' irrigation needs and methane emissions. AWD, for example, reduces water use by up to 30%, which improves farmers' adaptive capacity in water-scarce situations, and substantially reduces methane emissions from rice paddies on the average by 45% compared to continuously flooded rice. Significant efforts to adapt these practices in Asia and Sub-Saharan Africa have been ongoing since early 2000s. While intermittent irrigation attained a discernable footprint in the policies and programs of national and local governments, progress in making it a dominant farmer practice in irrigated rice has been so far limited due to multiple technical, economic, and social factors. Despite that, entry-points for narrowing the gap exist, such as pursuing integrated approaches to water management and pricing, remote sensing for the monitoring, reporting and verification of AWD adoption, and carbon credit schemes. These do not only help overcome the barriers to scaling intermittent irrigation but also make rice production systems more profitable, climate resilient, and low-carbon emitting.

1: Introduction

World food security depends on rice. Rice feeds about half of humanity; it is the poorest people's main source of calories and protein and is a source of livelihood for about three billion people (Chauhan et al. 2017; GRiSP 2013). It goes without saying that rice is one of the most important economic agricultural activities for developing countries (GRiSP 2013). Most of this rice is consumed in Asia — a region with sharp growth in greenhouse gas (GHG) emissions and natural resource limitation. With the worsening typhoons and drought brought about by climate change, rice production systems are increasingly suffering from significant crop losses, threatening the provision of ecosystem goods and services (IPCC 2021).

Despite rice's clear importance for food security, flooded rice production is a significant water user and GHG emitter. Irrigated rice alone uses 40% of the world's irrigation water and covers 30% of all irrigated cropland (Dawe 2005; Enriquez et al. 2021). Worldwide agriculture contributes 56% of all non-carbon dioxide (CO_2) emissions, of which 10% is attributed to methane (CH_4) from rice production (ibid). This number is even higher for most of Southeast Asia where rice contributes 43% of the total agricultural emissions on the average (Fig. 1).

Addressing the climate goals set by the United Nations will require an increased focus on the agriculture sector to reach the under-invested rural and developing regions of the world (UNFCCC 2017). CH_4 is a powerful but short-lived climate pollutant (with Global Warming Potential, GWP[1], 28 times that of CO_2) that is responsible for nearly half of the net global warming to date. However, finance for CH_4 abatement measures represented less than 2% of the total climate finance flows in 2019/2020 (CPI 2022). Rapidly reducing CH_4 emissions from energy, agriculture, and waste can achieve near-term gains in our efforts in this decade for decisive action. It is also regarded as the single most effective strategy to keep within reach the goal of limiting warming to 1.5°C. Rice is arguably the most cost-effective strategy with the highest CH_4 mitigation potential in the near-term.

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[1] GWP is a unit measure that allows for comparing the global warming effect of different gases to the earth's atmosphere where CO_2 has a GWP value of 1 (www.epa.gov).

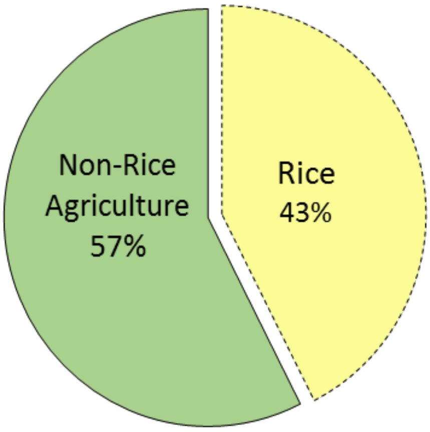

Figure 1. GHG emissions from agriculture in Southeast Asia
Source: UNFCCC NCs[2] *excludes Singapore, Brunei, East Timor, Malaysia

Because of the urgent need to cut emissions, countries and other actors have signed the Global Methane Pledge3 committing to slash CH_4 emissions by 30% in 2030 and these commitments have been incorporated into their Nationally Determined Contributions (NDCs). The need for mitigation and adaptation in rice has also been highlighted in recent National Communications to the United Nations Framework Convention on Climate Change (UNFCCC) where non-Annex I parties report agriculture and water management as their highest priority (UNFCCC 2019).

This report provides a brief overview and introduction of intermittent irrigation practices and how they contribute to achieving productive and sustainable food systems in Asia. The report also discusses the progress, challenges, learnings, and opportunities for scaling farmer adoption of this technology.

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[2] http://di.unfccc.int/ghg_profile_non_annex1 and latest NatCom data from major agricultural countries

[3] https://www.globalmethanepledge.org/

2: Background and history of intermittent irrigation

Water management has a crucial role in adapting rice to climate risks and reducing GHG emissions from rice cultivation. This is because lowland irrigated rice is susceptible to drought events and growing rice in irrigated lands, historically, entails continuous flooding of fields whereby anaerobic conditions trigger methanogenic bacteria that thrive in ponded soil to emit CH_4. Thus, by reducing the flooding intervals and inundated conditions, irrigation water use is lowered and the archaeal CH_4 production and emission is significantly inhibited.

Figure 2. Land preparation in flooded rice paddy

Figure 3 provides a graphical representation of how different irrigation techniques require varying amounts of water. As shown, continuous flooding, the dominant and traditional practice of irrigating rice in Asia, has the largest irrigation water requirement. This practice involves maintaining the rice field inundated with water at a level of 3 cm directly after transplanting or after directly seeded rice (mechanical or hand sown) has sprouted. The water level is then gradually increased to 5-10 cm to remain flooded until 7-10 days before harvest when the field is drained. This is widely considered by farmers to provide the necessary and sufficient growth environment for rice. The other end of the spectrum is aerobic rice, a way of producing rice without standing water in the field similar to upland crops like wheat. Aerobic rice is a production system in which especially developed “aerobic rice” varieties are grown in well-drained, non-puddled, and non-saturated soils. Aerobic rice requires direct seeding as its mode of establishment (Bouman et al. 2007).

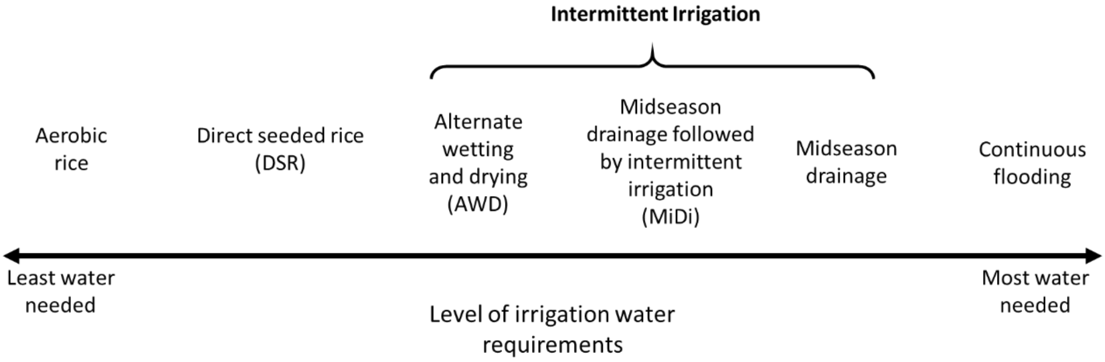

Figure 3. Spectrum of water requirements of irrigation techniques

Dry direct seeding is a crop establishment method that replaces the conventional practice of growing seedlings in a nursery and then transplanting them into flooded fields. Preparation involves puddling with an approach where the seeds are directly sown into a non-puddled and unsaturated field. Dry direct seeding saves water and labor costs for transplanting and can be done through mechanized operation. It is important to differentiate it from ‘wet direct seeded rice’ where seeds are sown in a puddled and saturated field and intermittent irrigation and drainage is practiced during the season. In dry direct seeded rice, the field lacks a hardpan so that maintained flooded periods are not possible. The latter is a non-flooded system and requires a different management approach entirely, whereas the former can be managed very similarly to a traditional continuously flooded regime (with the exception of periodic drainage/s).

Intermittent irrigation[4] sits at the middle. It involves periods of flooding, then a drainage period followed by re-flooding the field. It is crucial to ensure there is enough soil water content below the soil surface so that the roots have access to water. Several variants of intermittent irrigation exist under multiple names that follow similar guiding principles (Table 1). Single drainage or single aeration is one

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[4] Intermittently irrigated: fields have at least one aeration period of more than three days during the cropping season; (a) Single aeration: fields have a single aeration during the cropping season at any growth stage (except for end-season drainage); (b) Multiple aeration: fields have more than one aeration period during the cropping season (except for end-season drainage). (CDM Methodology AMS-iii.AU v4.0)

drainage event sometime during the vegetative stage, as in the case of Mid-season drainage (MSD). Multiple drainage (MD) or multiple aeration is characterized by more than one drainage event during the vegetative stage. Midseason drainage followed by intermittent irrigation (MiDi) is an extended drainage event followed by flooding and drainage at short intervals. Safe alternate wetting and drying (safe AWD) is characterized by continuous drainage and rewetting starting two weeks after transplanting (except during flowering) where soil water content is monitored and re-flooded before it goes beyond 15 cm below the soil surface, thus avoiding any yield penalties. In the week before and after flowering, the field should remain flooded.

In addition, rice production packages such as the Standard of the Sustainable Rice Platform (SRP), System of Rice Intensification (SRI), and the 'One Must Do, Five Reductions' (1M5R) practice all incorporate a reduction of water usage through recommended in-season drainage that falls into one of the above intermittent irrigation regimes.

2.1: Single drainage or single aeration

2.1.1: Mid-season drainage (MSD)

Single drainage, or single aeration, is the practice of draining the field at least one time during the vegetative growth stage for a minimum of 3 days. MSD, on the other hand, requires a single aeration extended until the rice plant shows visible moisture stress (Uprety et al. 2012). With regards to on-farm implementation, MSD may be considered a more practical alternative to practices which employ multiple drainage events, as it requires less overall maintenance and less risk of yield loss (Carrijo et al. 2017).

Table 1. Comparison of different intermittent irrigation practices.

	Single aeration or Single drainage[a]	Safe AWD[b]	MiDi[c]
Description of the approach	A single drainage event for a minimum of 3 days during the vegetative stage.	Alternating between flooding and drainage periods throughout the season, except for the week before and after flowering. A PVC tube pipe may be used to measure and maintain a "safe" threshold water depth of up to 15 cm (below sub-surface soil) before re-flooding of the field.	Day-dependent irrigation method. Timing and duration of irrigation is based on growth stages. After draining for 1-2 weeks between later tillering and panicle differentiation, intermittent irrigation is applied.
Approx. year introduced	n/a	Early 2000s	7th Century in China
Reported benefits	• Reduced GHG emissions by 29%[a] • No yield penalty	• Reduced water use by 30% • Reduced GHG emissions by 45%[a] • No yield penalty	• Reduced non-productive tillers [c] • Avoidance of lodging; enhanced weather-resistance • Improved field workability by compacting soil • Increased rice yield [c] [5]
Region of adoption	Southeast Asia	Southeast Asia (Philippines, Thailand, Vietnam, and Bangladesh)	East Asia

Sources: (a) IPCC (2019); (b) Sander et al. (2017); Richards & Sander (2014), Enriquez et al. (2021); (c) Minamikawa et al. (2019), Gou et al. (2017).

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[5] Evidences of yield increase from MiDi, however, are only observed in China. More studies and replications in Southeast Asian countries are needed to further verify the validity of this finding for MiDi and AWD.

2.2: Multiple drainage (MD) or multiple aeration

2.2.1: Alternate wetting and drying (AWD)

AWD was conceptualized and developed by scientists at the International Rice Research Institute (IRRI) in the Philippines as early as the 1990s and was piloted in farmer's fields starting in the 2000s. While it takes after the logic of intermittent irrigation, AWD introduces a guiding principle and a cheap tool, which is a water tube made from PVC pipe or 'pani pipe' for easy monitoring of water depth level below soil sub-surface. This enables farmers to reliably control irrigation, wherein they schedule their irrigation days before the sub-surface water level reaches a crucial point to avoid incurring penalties in rice yields (Bouman et al. 2007; Palis et al. 2004).

The practice of AWD is defined by the periodic drying and re-flooding of the rice field in cycles ranging from 2 to 10 days to provide roots and soil biota with optimal amounts of water and oxygen (Fig. 4). To achieve the best outcomes, ponded water depth is monitored (a 30-centimeter-long plastic pipe or bamboo tube with drilled holes can be used as a level gauge) and the fields are re-flooded to a depth of 3-5 cm before sub-surface water levels reach -15 cm. This method is called "safe AWD" because it does not cause yield decline. Proper levelling of rice fields is necessary to ensure that no areas are excessively dry or wet, which could adversely affect yields.

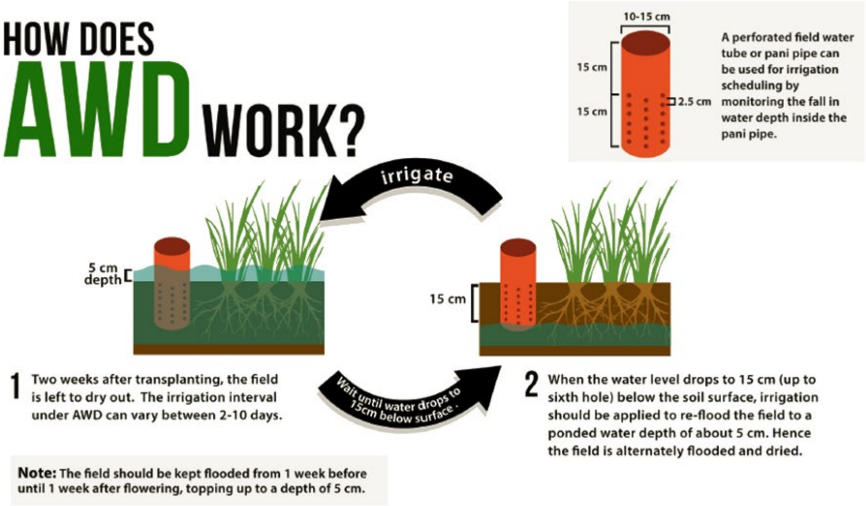

Figure 4. How does AWD work?
Source: IRRI (2019)

The benefits of AWD have been extensively studied. Over 60 peer-reviewed studies provide evidence that AWD can reduce emissions by 45% on the average and water use by up to 30% without reducing yields (Carrijo et al. 2017; IPCC 2019). In fact, a meta-analysis of these results covering 56 studies shows that AWD reduced water use by 25.7% across studies conducted in Asia[6], thereby increasing water productivity in terms of grain yield per unit of water (ibid).

Water use can be reduced by 30% with AWD, which reduces pumping costs, while improving farmers' adaptability in water-scarce conditions and ensuring the equitable distribution of water resources. As droughts are projected to increase in many areas of Southeast Asia, adoption of AWD at the entire irrigation systems scale can generate surplus at catchment level through the more efficient use of water for rice production. In some cases, AWD may increase the prevalence of weeds and this should be carefully considered when recommending this practice, especially in contexts where laborers are disproportionately female — if they are negatively impacted by such an increase in labor demands (Lampayan et al. 2015). Yield may be increased from AWD in some cases due to improved root growth and soil nutrient

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[6] We note that this meta-analysis included severe or unsafe AWD treatments that reduced rice yield and water use.

supply[7]; however, such increases may be an exception as many AWD studies show little to no effect on yield (Enriquez et al. 2021; Bouman et al. 2007).

Evidence of emission reduction at an average of 45% has been shown through the application of AWD (Sander et al. 2017; IPCC 2019). CH_4, which is 28 times more potent than CO_2 in trapping radiation in the earth's atmosphere, is the primary GHG emitted from flooded rice. Increased soil aeration cycles using AWD prevents CH_4 production and oxidizes CH_4 stored in soil pores preventing its release. The total mitigation potential from rice farming may be increased up to 80% if AWD is complemented with rice straw removal (Allen & Sander 2019). Improved timing of nitrogen (N) is advised to reduce potential increases in nitrous oxide (N_2O) associated with soil drying. Without this, research suggests that the mitigation potential of AWD is offset by 15% from increased N_2O (Sander et al. 2020). Other benefits of AWD on yield, human health, and environment are discussed thoroughly by Allen and Sander (2019).

MD is a more recent approach being tested in An Giang Province in Vietnam located within the Mekong Delta (Uno et al. 2021). It is an adjusted version of the AWD technique which allows flexibility for farmers to decide, based on their judgement, on site-specific adjustments in depth threshold and timing of draining whether, for example, for N fertilizer topdressing or poor drainage conditions (ibid). A two-year field experiment found that applying MD can have 35% GHG emissions reduction from CH_4, without significant difference in N_2O emissions, and yield advantage of 22% from continuous flooding regimes (Uno et al. 2021). To date, this approach has only been introduced at limited farmer plots in An Giang Province.

2.2.2: Midseason drainage followed by intermittent irrigation (MiDi)

Based on historical records, MiDi is the first kind of intermittent irrigation practiced by farmers in Asia (Minamikawa et al. 2019). MiDi was documented in a Chinese agricultural book called "*Qimin Yaoshu*" as early as the 7th century, which suggested that soil aeration has a positive effect on rice yield.

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[7] For example, see through successful control of ineffective tillers and strong root growth (Guo et al. 2017); enhancing structures of canopy, source activity, sink strength, and enhanced remobilization of pre-stored C reserves from vegetative tissues to grains (Yang & Zhang 2010).

MiDi was also mentioned in "*Krisparasara*" in the Indian agricultural texts published in the 6th-8th century and, a few centuries later, found its way into Japanese records in 17th century in "*Seiryoki*" and in 18th century "*Noukagyouji*" books (Fig. 5). Moving into the modern times, MiDi became widely known and promoted by agricultural extension systems in China and Japan.

Figure 5. Front cover pages of agricultural textbooks in China from the 7th Century (*Qimin Yaoshu*, left) and in Japan from the 18th Century (*Noukagyouki*, right)

Source: Minamikawa et al. (2019, p. 26)

MiDi involves draining the rice field for 1-2 weeks between the stages of later tillering and panicle differentiation. This is followed with intermittent irrigation wherein the field is repeatedly drained for 3 days and re-flooded for 3 days until the final drainage (Fig. 6). According to Minamikawa (2019, p.23), MiDi provides some benefits to rice production such as:

- Curbing non-productive tillers through reduced mineralization of soil N;
- Reducing susceptibility to lodging and to weather by constraining the production of hydrogen sulfide and organic acids and enhancing root elongation;

- Making it easy for farmers to work in the field by improving soil compaction; and,
- Increasing rice yields over continuous flooding (based on a meta-analysis of studies conducted in China by Gou et al. 2017).

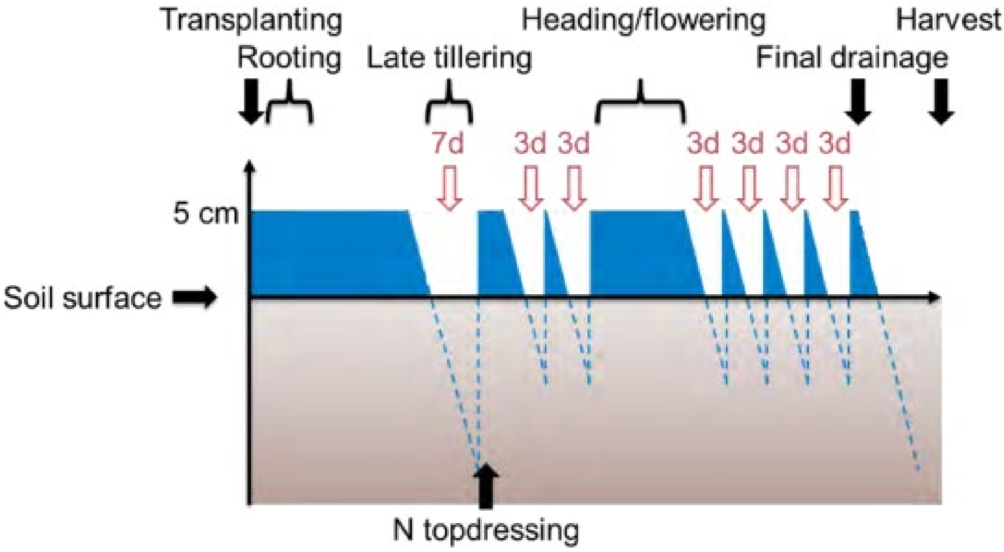

Figure 6. Midseason drainage followed by intermittent irrigation

Source: Minamikawa et al. (2019, p. 24)

3: Status of dissemination, challenges and learnings

3.1: Progress of dissemination of AWD in Asia

Since the early 2000s, IRRI, together with its national agricultural research and extension system (NARES) partners worked to pilot, adapt, replicate, and create an enabling environment for farmer adoption of AWD. The Irrigated Rice Research Consortium (IRRC), implemented in four phases between 1997 and 2012 with funding support from the Swiss Agency for Development Cooperation (SDC), aimed to provide a platform to facilitate the dissemination and adoption of best natural resource management practices, including AWD, for lowland irrigated landscapes in several Asian countries (Rejesus et al. 2014). IRRC scaled-out the AWD technology in nine Asian countries namely, Bangladesh, China, India, Indonesia, Laos, Myanmar, Philippines, Thailand, and Vietnam. By the time of its completion, IRRC is said to have reached 1 million Asian farmers with its technologies (Rejesus et al. 2013). From 2012 onwards, several projects from IRRI, such as Closing Rice Yield Gaps in Asia (CORIGAP), and other international development organizations and development banks have taken up AWD as a climate-smart innovation in Asia and Sub-Saharan Africa.

Stories of success

Philippines. AWD was introduced in the 2000s as a consequence of water shortages induced by the El Niño phenomenon. Rough estimates suggest that it is practiced on only 5% of the irrigated area. Most irrigation systems are gravity systems where farmers pay a fixed irrigation fee per hectare each season and have a few economic incentives to adopt AWD. Although cost-effective, in some cases gravity irrigation schemes are inefficient in water use or unreliable in supply. Where farmers can afford and benefit from the use of individual pumps, AWD adoption is high. A recent suitability assessment by IRRI showed that 60% of the irrigated rice area is suitable for AWD and could reduce around 15% of the country's annual emissions from the agriculture sector (Sander et al. 2017).

To adapt to increasingly scarce water resources, the Philippine Government attempts to disseminate AWD in all national irrigation systems. The Philippine Department of Agriculture (DA) issued an Administrative Order in 2009 on the

‘Guidelines for the adoption of water-saving technologies in irrigated rice production systems in the Philippines’. These technologies are not restricted to AWD in a strict sense and include other approaches or use other terminology like ‘controlled irrigation’. Policy measures have largely focused on improvements in irrigation infrastructure and rehabilitation of older irrigation schemes. In addition, other yield-increasing strategies were propagated such as the use of new varieties (hybrid and inbred), high-quality seeds, and integrated and sustainable crop management technologies. For instance, the Organic Agriculture Act of 2010 provides production support services including distribution of rice seeds to farmers. The government also aimed to provide more financial support to farmers, for instance the provision of soft loans for the establishment of shallow tube wells and surface water pumps (Sander et al. 2017). In addition, in 2016 the National Irrigation Administration (NIA) implemented a policy to adopt AWD in all the national irrigation systems (which are usually maintained jointly with Farmer Irrigator’s Associations). These efforts are supported by commodity-oriented programs such as the National Rice Program, which looks at production, extension and communication, and research and development. While not explicitly climate change policies, these programs channel climate change on local-level agricultural policies.

In the last decade, major rice growing countries in Asia witnessed the proliferation of dissemination and extension support for intermittent irrigation, particularly AWD. Based on studies available, the rates of farmer adoption of AWD in these Asian countries vary by quite a bit (Table 2).

Table 2. Adoption rates for intermittent irrigation approaches in Asia.

Country	Adoption rate	References
Bangladesh	Rajashi and Rangpur Divisions – 29% (AWD)	Kürschner et al. (2010)
China	40% (AWD)	Li & Barker (2004)
Japan	87% (MiDi)	Minamikawa et al. (2019)
India	Northern – 31% (AWD) Eastern – 6% (AWD) Southern – 13% (AWD) Northwestern – >80% (AWD)	Palanisami et al. (2020); Richards & Sander (2014)
Philippines	5% (AWD)	Enriquez et al. (2021)
Vietnam	An Giang Province and Can Tho Province – 35% (AWD) An Giang Province – 52% (AWD)	Connor et al. (2021) Yamaguchi et al. (2019)

It is important to note, however, the gross incomparability of the available studies on AWD adoption rate estimates because they widely vary in the criteria definition of what constitutes AWD, sampling, method, geographic scope, and date of research findings. Despite that, what can be learned from the data is that while some progress has been made in expanding water management practices that are better for the climate (such as in the northwestern region of India and in Vietnam), there is still a lot of work needed to be done to accelerate the adoption of AWD and other intermittent irrigation approaches in developing countries in Southeast Asia to benefit both farmers and the climate.

IRRI conducted a suitability mapping of AWD in a number of rice production areas in Southeast Asia such as the Philippines and the Central Plains in Thailand. Tables 3 and 4 show that 60% of the rice area in the Philippines is climatically suited for AWD as are the entire rice area in six provinces in the Central Plains of Thailand which translated to significant mitigation potentials for both countries (7.42[8] and 1.61 MtCO$_2$eq per year, respectively). It is important to note that the analysis focuses on enabling climatic factors and is done independent of whether there is adequate

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[8] Assuming GWP of methane equals to 28.

irrigation infrastructure or not. This illustrates the mitigation opportunity but also highlights the gaps and work that is still needed in scaling-out the use of AWD in Asia.

Table 3. Summary of climatic suitability of AWD in the Philippines.

Coverage of study	Average rice area (Million ha)	% rice area suitable (moderate and high suitability)			Potential GHG emission (Mt CO_2eq yr^{-1})
		Dry Season	Wet Season	Maximum	
Entire rice area in the country	4.503	96.7	34	60	7.42

Source: Sander et al. (2017)

Table 4. Summary of climatic suitability of AWD in the Central Plains of Thailand.

Coverage of study	Average rice area (Million ha)	% rice area suitable (moderate and high suitability)			Potential GHG emission ($MtCO_2$eq yr^{-1})
		Dry Season	Wet Season	Maximum	
Six provinces[9]	1.047	99	100	100	1.61

Source: Prangbang et al. (2020)

3.2: Enabling policies and researches

Policy frameworks that incentivize water saving and climate mitigation are necessary conditions for ensuring the widespread and sustained adoption of AWD. In developing countries in Asia, policies supporting dissemination and farmer adoption of AWD took shape in different forms. Among the key examples are:

- Philippines' DA's issuance of the guidelines for the adoption of AWD in irrigated rice production systems and the NIA's irrigation policy strategy to promote AWD in all national irrigation systems (Enriquez et al. 2021);

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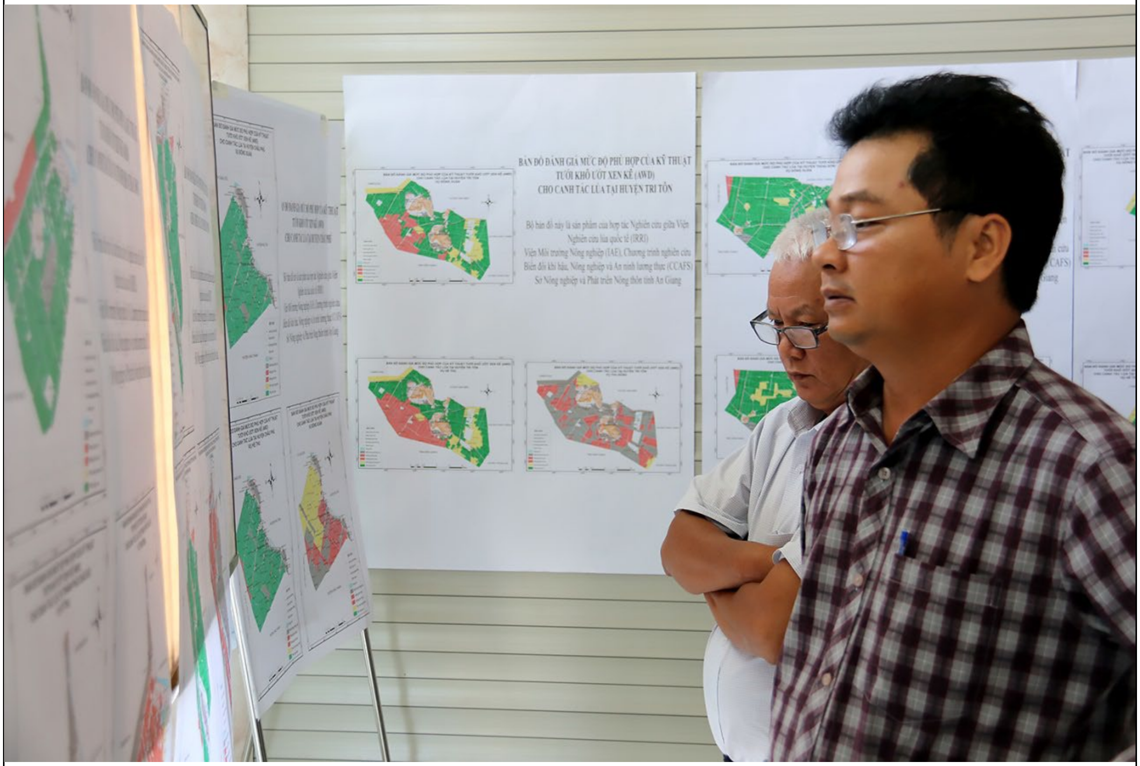
[9] Ang Thong, Ayutthaya, Chai Nat, Pathum Thani, Sing Buri, and Suphan Buri

- Thai Government's development of the Thai Rice National Appropriate Mitigation Actions (NAMAs), funded by the NAMA facility, to promote AWD and three other mitigation practices in rice production among 100,000 farmers with an overall goal to avoid 1.67 $MtCO_2eq$ of GHG emissions over 5 years (Thai RICE NAMA, 2022);

- Vietnamese Government's adoption of AWD into several policy frameworks such as: 2013 Presidential Decree (532-QD-TT-CLT) certifying the 1M5R practice, which incorporates AWD; inclusion of AWD and raising of ambitions for reduced emissions in rice in the 2022 update of its NDC; and the (on-going) development of the One Million Hectare Strategy for converting one million ha of rice farms into high-quality and low-carbon rice production systems; and

- Bangladesh Government's inclusion of AWD as a priority intervention in their National Adaptation Plan 2023-2050.

Vietnam. The Vietnamese government has substantial commitments to reduce GHG emissions with focus in the agricultural sector, which is predicted to account for almost 73% of emissions in the country by 2030, according to a UN fact sheet produced in 2013.



Recently, Vietnam has put enabling policies in place to reduce emissions in rice. Examples include the Green Growth Strategy and the 20/20/20 Plan to reduce agricultural emissions by 20% and increase productivity by 20% by 2020 using AWD as a key technology. Vietnam signed the Global Methane Pledge vowing to reduce CH_4 emissions by 30% by 2030, most of which come from the rice sector.

Additionally, Vietnam has initiated various local policies that enable provinces to get low-interest loans for training on water-saving technologies. In Vietnam, AWD is often included in "packages" of crop management recommendations, such as the 1M5R which provides higher profit to farmers. Also, the Standard of the SRP includes AWD and is being outscaled by contract farming companies in the Mekong Delta. Evaluating the success of these mitigation measures will be the primary challenge.

Mitigation research on AWD is also instrumental for galvanizing efforts. Apart from IRRI and its national partners, different international development and private sector actors (such as the United Nations Development Program[10] and Bayer[11]) are also scaling-out AWD in Asia and Sub-Saharan Africa through an effort to establish rice carbon farming in these regions. The potential of AWD to generate certified emission reduction (CER) credits, which developing countries and farmers can sell to buyers who want to offset their emissions is also recognized. This can create a new income stream for farmers that can provide incentive for adoption of AWD. This was made possible through the research done to develop a methodology for measuring "methane emission reduction by adjusted water management practice in rice cultivation" called AMS-III.AU which was approved by the UNFCCC as a Clean Development Mechanism (CDM) methodology. Despite that, more research is needed on the institutional arrangements and economics of carbon credit projects for intermittent irrigation.

In addition, IRRI further improved AWD by developing an Internet-of-Things-(IoT)-powered decision support tool – called AutoMon^{PH} – that automates the real-time monitoring of water depths and provides irrigation advisory service to farmers and irrigation managers through SMS and internet (Fig. 7)[12]. AutoMon^{PH} makes it easier to adopt AWD and to efficiently and sustainably manage water resources at irrigation systems level. This technology is still at early stages being benchmarked at different irrigation contexts — from pump-based to gravity-based systems where collective management of water is required (Enriquez et al. 2021).

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[10] https://www.undp.org/ghana/press-releases/ghana-authorizes-transfer-mitigation-outcomes-switzerland

[11] https://www.bayer.in/en/thisisbayer/sustainable-rice-project

[12] https://www.irri.org/automonph#:~:text=AutoMonPH%20is%20an%20Internet,real%2Dtime%20monitoring%20and%20reporting

Figure 7. SMS messages and IoT sensor of AutoMon^{PH}

3.3: Challenges and learnings

The two decades of scaling farmer adoption of AWD generated a lot of insights on the site- and country-specific challenges and success factors for intermittent irrigation in Asia. Being intentional in addressing key challenges for scaling AWD and optimizing and transferring learnings will be crucial for accelerating the transition of rice production systems to low-carbon and resilient pathways.

Challenges to the adoption of AWD are much more than a question of whether farmers can afford the low-cost PVC tube pipe. It is rather a combination of factors such as economic incentives, institutional enforcement, excludability of access to unintended users, scale mismatches, and quality of irrigation infrastructure (Enriquez et al. 2021). The following are the main cross-cutting challenges and learnings around the adoption of AWD:

- **Infrastructure and enforcement.** The adoption of AWD has been found to be effective in instances where infrastructure enables Irrigators' Associations to reliably control the flow and off-take structures and exclude people to prevent illicit tapping (Enriquez et al. 2021; Bouman et al. 2007). In the Philippines, AWD has experienced a comparatively quick uptake in pump-based irrigation collectives than gravity-based systems because farmers can reliably access irrigation water and they are required to pay for the amount per liter of fuel used, so there is an economic incentive to pump more efficiently (Palis et al. 2004). In An Giang Province, Vietnam, the presence of full dike systems was instrumental to 52% of the adoption of

AWD (Yamaguchi et al. 2019). On the other hand, the introduction of AWD in large gravity-based systems has been difficult. Particularly, in the Philippines, where there is a dwindling quality of irrigation infrastructure, the ability to exclude users and enforce compliance mechanisms and price water per volume is very difficult in such systems (Enriquez et al. 2021).

- **Economic incentives and risk-averseness.** AWD is not just a knowledge-intensive innovation, but it can also discourage farmers from testing the approach when they see cracking of soils as the water recedes below the surface, even though this can be managed safely and does not affect the yield. This is because farmers are largely risk-averse and maintain the idea that flooded conditions mean that there will be higher rice yield and seeing cracks in the soil could mean poor yield performance (Palis et al. 2004). Given these perceptual barriers, it does not help that AWD often does not bring farmers economic incentives either through better yield or incomes (Bouman et al. 2007). In the Philippines, pump-based irrigation has been successful because farmers pay for the fuel used to irrigate their farms, and by using AWD, farmers benefit from cost-savings, which is not possible in large canal-based irrigations where there is no water pricing regulation as irrigation fees are subsidized by the government (Enriquez et al. 2021; Palis et al. 2004).

- **Trade-off on pest, disease, soil organic content (SOC), and weed management.** Albeit AWD can curb the occurrence of non-aquatic weeds, rice blast, bacterial leaf blight, and root-knot nematode, it can, on the other hand, provide conducive conditions for pathogen survival and transfer between rotation of related aerobic crops, which may require additional knowledge on integrated pest management (Allen & Sander 2019). Conversion of flooded to aerobic soil conditions can reduce SOC quantity and limit its carbon storage functions (ibid). These issues can be addressed with specific and targeted crop management responses, but they may increase the requirement for knowledge-intensive farm management to avoid this trade-off.

- **Integrated water governance.** In many developing countries, water resources, including irrigation, and water-related management institutions are often fragmented, uncoordinated, and have weak capacity. This could be forest agencies and water resource boards that govern ecosystems located upstream and river basins, to water utilities that compete for water with other sectors like agriculture. Poor integrated ecosystems approach to managing land, water, and forest ecosystems could lead to technical and environmental constraints for irrigation systems, particularly the large ones. For example, forest degradation and deforestation can increase siltation and excessive siltation of dams and canals can reduce the capacity of irrigation canals to deliver larger volumes of irrigation (Clemente et al. 2020). Weak enforcement capacity perpetuates illegal access and locking of access gates to water, illegal settlers and pumping/dumping of garbage, and poor canal maintenance. This can discourage cooperation among farmers to adopt AWD, which ultimately hampers the collective adoption of intermittent irrigation whereby farmers may become disincentivized by seeing that other people around them take advantage of the current situation or are not doing anything about the governance and management issues (Enriquez et al. 2021). Behavioral studies show that strengthening social norms and enforcement mechanisms through social disapproval can improve cooperation within irrigation schemes (Tsusaka et al. 2013).

4: Entry-points for accelerating scaling of intermittent irrigation in Asia

Proper design of irrigation schemes, irrigation governance, and coordination among farmers, extension officers, irrigation authorities, and local governments can translate to benefits and enable the large-scale adoption of AWD. Additional incentives like carbon credits could support large-scale implementation. Below are several measures which have been found successful in supporting the adoption of AWD and other intermittent irrigation methods[13].

a. **Expanding the climate suitability analysis for AWD for the entire Asian region and innovating on ways to measure AWD adoption.**
   Generating a region-wide suitability assessment and defining current adoption rates for AWD will provide the baseline and potentials for climate mitigation opportunities and scaling the adoption of AWD. This is an important foundational step for generating a regional picture of intermittent irrigation. To date, only the Philippines and Thailand have published suitability analyses. As discussed in Section 3.1, inconsistencies in the methodology and scope of adoption studies, including the cost for field-based data collection, make it difficult to have a comparable and more frequent estimation of AWD adoption. There is a large potential for the use of remote sensing to make measurement of AWD adoption cheaper and comparable across countries. The first attempt to this was the study of Lovelle (2019) which used European Space Agency Sentinel-1a and 1b radar data together with in-situ moisture readings. Progress in this area would also benefit carbon credit schemes for AWD which could make the transaction costs for the monitoring, reporting, and verification (MRV) of CERs significantly cheaper. This could in-turn improve the profitability and viability of carbon credit projects for farmers.

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[13] Since MD and MiDi have little or no experience for adoption in the farmer's fields, the discussion is done here, based on the experience for adoption of AWD. These entry points can generally apply to other intermittent irrigation methods.

b. **Adopting effective pricing arrangements.** The large-scale implementation of AWD in the Philippines by the NIA, IRRI, and the Philippine Rice Research Institute (PhilRice), showed that farmers' incentives to adopt AWD varied with irrigation schemes. Gravity-driven canal irrigation schemes and area-based flat-rates for irrigation water are a disincentive for AWD because there are currently no economic benefits to be gained. Farmers in these systems have fewer incentives to adopt AWD and drain the fields completely than farmers who relied on fuel-operated irrigation pumps. This is because farmers in this system pay for the amount of fuel used for pumping irrigation water, and can thus save money by irrigating for shorter periods or less frequently. Volumetric water-pricing systems contribute slightly more as public goods, providing an incentive toward reducing water consumption. However, incentives to pump less water are eradicated if electricity is highly subsidized. Private pump owners may be unwilling to negotiate on payment structure (i.e., change from fixed rate to cost based on actual usage).

c. **Managing irrigation systems.** In the case of flat-rates, irrigation authorities play a key role in tailoring water supply to the actual demand following the AWD scheme. For instance, in Bohol Island in Central Philippines in 2006, irrigation water was assigned to each farmer for 3 days and then none for the next 10-12 days. They introduced an up-and-downstream water rotation where downstream water users received water first. Consequently, downstream areas had a more reliable water supply and the area under AWD could be expanded. In some areas, cropping intensity increased by 40% to up to 160%.

d. **Ensuring collaboration among multiple stakeholders**. Lampayan et al. (2015) suggest that it is important to promote AWD through a multi-stakeholder grouping, which was particularly effective in the Philippines and to some extent in Bangladesh. Strong central and local government support for AWD as part of a national policy was important in Vietnam. Engagement with partners in local government, private sector, and nongovernment organizations (NGOs) who can facilitate the promotion and training of AWD is also important, as are well-organized farmer cooperatives to facilitate training and support mechanisms.

e. **Considering different scales within irrigation service area.**

   (i) Reconciling interest. Programs must take the interests of specific interest groups into account. Particularly, downstream farmers may benefit more from AWD than upstream farmers. Divergent interests may be a challenge and could be addressed by (a) mobilizing groups with vested interest to express their needs in relevant forums; (b) forging alliances with local politicians; (c) stressing links with poverty alleviation programs (e.g., conditional cash transfer programs); and (d) raising awareness about the challenges faced by tail-end users to the broader public.

   (ii) Assessing "true water savings". This concept considers higher scales in water management. Irrigation water "lost" in an upstream field may still benefit downstream users. If efficiency is increased and "lost" irrigation water is reduced upstream, downstream users may experience reduced water supply. Thus, planning, improving, and managing irrigation systems need to happen beyond the field level implementation of AWD and to consider different scales in the basin/irrigation service area.

   (iii) Compensation for eventual losses. This practice is relevant in cases of irrigation water coming from larger irrigation schemes, which is out of the farmers' control. Thus, the engagement of both parties namely, water suppliers and users, is needed to support the adoption of AWD.

f. **Training, introducing "local champions", and ensuring co-ownership.** Farmers' lack of awareness and training can be a barrier to behavior change. Farmers may be worried they will incur yield losses if improperly applying AWD. To achieve scaling of AWD, stakeholders should be well-informed of both the opportunities and challenges to provide adequate training, training materials, compelling communication strategy, demonstration plots, and solid in-country pilot sites. Adoption is often incentivized by local "champions" who show visible examples of the approach. Co-ownership is needed not just from farmers but from irrigation system administrators and managers to implement the technology. For instance, the Climate & Clean Air Coalition (CCAC) Paddy Rice Project has initiated and provided technical inputs to the Bangladesh Focal Area

Forum consisting of several national organizations and NGOs, and has conducted training of trainers on AWD+ practices. The network operates in a region identified in the CCAC suitability maps and has the potential to reach 50,000 farmers. Digital extension and information services are equally helpful. For instance, IRRI has developed a mobile phone-based application called Rice Crop Manager which provides season- and site-specific recommendations for fertilization. Efficient N can reduce N_2O emissions while increasing yields and saving expenses. Additionally, IRRI has developed an on-line GHG calculator (SECTOR)[14] that could be used or adapted for MRV for carbon accreditation.

g. **Rehabilitating and constructing new infrastructure.** Improved and newly built irrigation systems and drainage canals that ensure reliable and efficient water supply/drainage are required. Levelled fields are also important as evenness of fields promotes uniform water management. Therefore, accessibility to laser levelling equipment through government support enables improved water efficiency and AWD adoption.

h. **Combining AWD with other new technologies that can increase yield.** To incentivize the adoption of AWD, it is recommended to combine it with other sustainable management practices that can increase yields and enhance positive environmental effects. AWD should be promoted as an integral part of crop management, which includes recommendations on land preparation and pest management. Good examples are "PalayCheck" of PhilRice in the Philippines, the 1M5R package in southern Vietnam, and the SRP standard also in Vietnam.

i. **Implementing funding mechanisms.** Funds for proper technology transfer, logistics and implementation as well as capacity building and training to ensure the adoption of AWD are needed from local and national government, the private sector, and international donors. Support for large-scale implementation may be provided by NAMAs and future market mechanisms that will replace CDMs[15]. While it may be difficult logistically to incentivize farmers through carbon credits due to high verification costs, carbon credits may be used in larger irrigation system investments, allowing farmers to benefit from these

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[14] https://sector.irri.org/practices

[15] CDM has been agreed to be phased out in the UNFCCC.

improvements. Since a new carbon market mechanism is being discussed at the UNFCCC Conference of the Parties (instead of the CDM) and once a new mechanism is identified, there is a need to examine how adoption of intermittent irrigation will change with regards to introduction of new carbon market schemes.

5: Conclusion

Intermittent irrigation has an important historical link and role in climate adaptation and mitigation in Asia. Low-carbon irrigation practices are crucial not only for food security and the prosperity of farmers but also for mitigating the effects of climate change. Intermittent irrigation techniques like AWD have made a positive impact with tangible benefits to farmers, although within a limited scale and not without its challenges. It is undeniable that the convergence of global drivers, research-for-development, and economics has been increasingly aligned, now more than ever, creating a clear and viable pathway for making intermittent irrigation a positive tipping point needed for the low-carbon and resilient transitions of rice production systems in Asia. Working towards this end requires strategic innovations, good governance, and an enabling policy environment.

Author contribution statement

Conceptualization of the contents, Y. E., V. P. and M. W.; Resources, Y. E., V. P. and M. W.; Writing–original draft, Y. E., V. P., K. N., B. S., B. B. and M. W.; Writing–review and editing, Y. E., V. P., K. N., B. S., B. B. and M. W.; Visualization, Y. E., V. P. and M. W.

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