



Alternate Wetting and Drying in Rice: Water Savings, Methane Emissions, and Adoption Barriers

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Abstract

Alternate wetting and drying (AWD) replaces the continuous flooding of lowland rice with cycles in which the ponded water is allowed to disappear before the field is irrigated again. It has been promoted for two decades as a way to save irrigation water and, more recently, as one of the few practical means of cutting methane emissions from rice. This narrative review examines the three claims on which that promotion rests. On water, field experiments and meta-analyses agree that the mild or "safe" form of AWD reduces irrigation input without a yield penalty, but much of the saving is reduced seepage and percolation, which may or may not be a saving at the scale of an irrigation system or aquifer. On methane, the reduction is well supported and mechanistically understood, although it is partly offset by higher nitrous oxide emissions where drying coincides with available nitrogen. On adoption, the record is weaker than the agronomy would predict. The reasons lie less in the practice than in its setting: irrigation fees unrelated to volume, unreliable canal supply, uneven fields, monsoon rainfall and the absence of any payment to farmers for avoided emissions. The review identifies what remains to be established about system-scale water accounting, combined greenhouse gas balances and the institutional conditions under which AWD spreads.

Keywords: *Alternate wetting and drying, Lowland rice, Water productivity, Methane, Nitrous oxide, Technology adoption*

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1. Introduction

Lowland rice is grown in bunded fields that farmers keep flooded for most of the season. The ponded layer suppresses weeds, buffers the crop against irregular supply and makes nutrients such as phosphorus more available, and for these reasons flooding has been the default for as long as irrigated rice has existed. It is also expensive in water. A flooded field loses water continuously by seepage through the bunds and percolation through the plough pan in addition to what the crop transpires, and the total input to a rice field is commonly two to three times that of other irrigated cereals (Bouman and Tuong, 2001; Tuong and Bouman, 2003).

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Flooded soil is also anaerobic, and anaerobic decomposition of organic matter ends in methane. Rice cultivation appears in every global methane budget as one of the larger agricultural sources (Saunois *et al.*, 2020). A practice that interrupts flooding therefore promises two benefits at once, and alternate wetting and drying (AWD) is the best known of them. Under AWD the field is irrigated, the water is left to recede until the soil surface is exposed and the shallow water table has dropped by a set amount, and the field is then irrigated again.

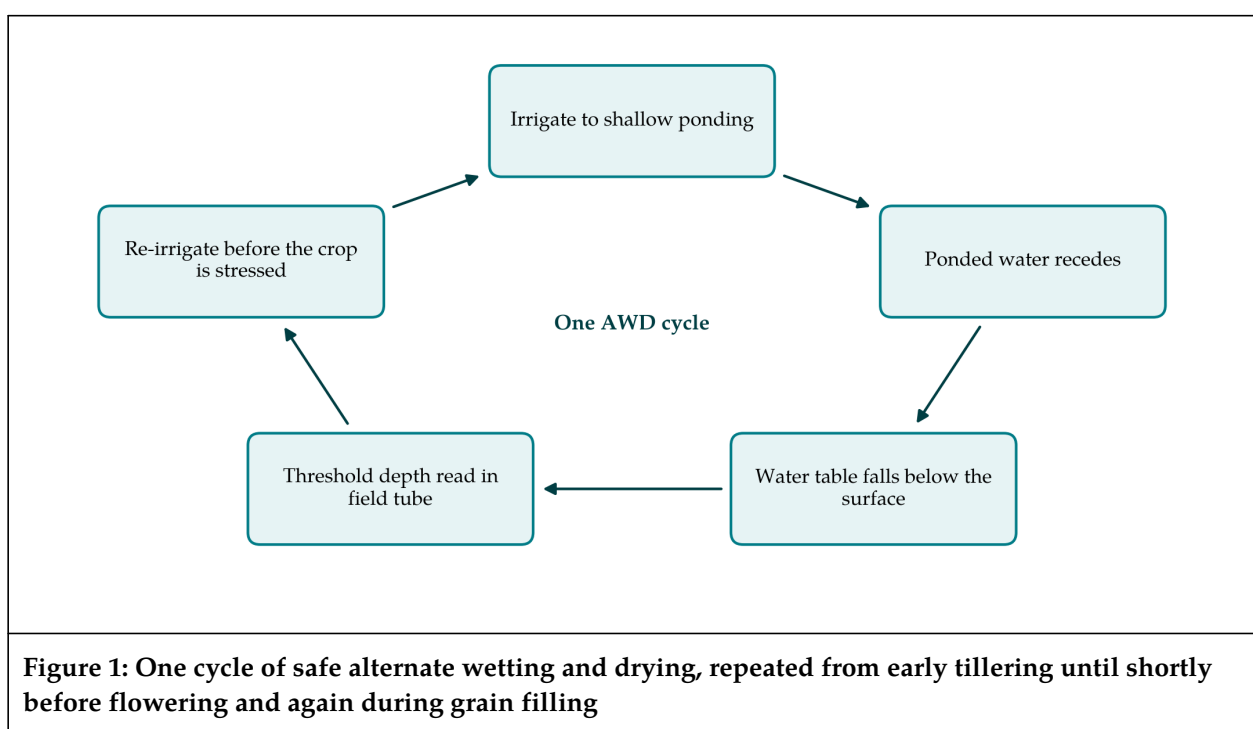
The practice has been taken up in national programmes in several Asian countries and in climate mitigation plans, yet reports from the field describe adoption that is patchy and often temporary (Lampayan *et al.*, 2015). This review considers the evidence behind the two promised benefits and then turns to the question that the agronomic literature tends to leave until last: why a practice that appears to cost the farmer nothing is not more widely used.

2. Approach of the Review

This is a narrative review of the published literature, organised around three themes: water, greenhouse gases and adoption. It relies on field experiments from the main rice-growing regions, on the meta-analyses that have pooled them, on the guidance documents of the International Rice Research Institute and the Intergovernmental Panel on Climate Change, and on socio-economic studies of adoption in South and Southeast Asia. The selection is not exhaustive and no systematic search was carried out. Where sources disagree, the disagreement is reported and an explanation is offered where the literature supports one.

3. The Practice and Its Variants

AWD is a family of practices that differ in how dry the soil is allowed to become. The form recommended for extension is "safe AWD", defined by a simple field measurement. A perforated tube is sunk into the soil so that the farmer can see the depth of the water table inside it. Irrigation is applied when the water level has fallen to about 15 cm below the soil surface, the field is reflooded to a shallow depth of around 5 cm, and ponding is maintained from about a week before to a week after flowering, when the crop is most sensitive to water deficit (Bouman *et al.*, 2007; Richards and Sander, 2014). Figure 1 shows one cycle. At the 15 cm threshold the roots of the rice plant still reach saturated soil, which is why the practice is described as safe.



Researchers have also tested more severe regimes in which irrigation is delayed until the soil water potential in the root zone falls well below saturation. These variants save more water and, as discussed below, are the ones in which yield losses appear. The distinction matters because studies that report "AWD" without stating the threshold cannot be compared, a problem noted in every synthesis of the literature (Carrijo et al., 2017).

4. Water Savings

Field experiments consistently show lower irrigation input under AWD than under continuous flooding. The size of the reduction varies widely with soil and hydrology. On heavy soils with a shallow groundwater table the saving is small, because little water was being lost by percolation in the first place; in the experiments of Belder et al. (2004) at such sites in China and the Philippines, the ponded water disappeared but the soil stayed close to saturation and yields were unaffected. On lighter soils with deep groundwater the saving is larger. A meta-analysis of published comparisons concluded that AWD reduced water use substantially overall and that mild AWD did so without a significant yield change (Carrijo et al., 2017).

What is saved needs closer inspection. Evapotranspiration changes little under safe AWD, since the canopy still transpires at the potential rate and the soil surface is wet for much of the time. The reduction comes mainly from seepage and percolation, which fall when there is no standing head of water. At the scale of the field these are losses. At the scale of an irrigation system they are often not, since percolated water recharges an aquifer from which other farmers pump, and seepage reaches drains that are reused downstream (Bouman and Tuong, 2001; Tuong and Bouman, 2003). AWD certainly saves pumping energy and canal deliveries for the farmer who practises it. Whether it releases water for other uses depends on where the "lost" water was going, and few studies have followed it.

Two further qualifications apply. Much of the water used by a transplanted rice crop goes into land preparation, when the field is soaked and puddled before planting, and AWD does nothing to reduce that share. The comparison also depends on how the flooded field was managed. A plot kept carefully at a shallow depth loses less water than a field held deep as insurance against an unreliable supply, so the saving to be expected in practice depends on the depth of water that farmers habitually keep (Bouman et al., 2007).

5. Yield Effects

The meta-analysis by Carrijo et al. (2017) distinguished mild from severe AWD and found that yields under the mild form did not differ from those under continuous flooding, whereas severe drying reduced yield markedly. Soil properties modified the response, with losses more likely on soils of low organic carbon and high pH. Individual studies range more widely. Some report yield gains under moderate AWD, attributed to deeper rooting, fewer unproductive tillers and better grain filling (Yang et al., 2017), while trials with poor water control report losses. In direct-seeded systems in California, drying cycles were introduced without loss of yield (LaHue et al., 2016). The practical reading is that safe AWD is yield-neutral where the farmer can reflood on time, and that the risk lies in not being able to.

6. Methane and Other Greenhouse Gases

Methane in a rice field is produced by methanogenic archaea in reduced soil, consumed in part by methane-oxidising bacteria in the thin oxic zones at the soil surface and around roots, and carried to the atmosphere chiefly through the aerenchyma of the rice plant (Le Mer and Roger, 2001; Conrad, 2007). Drying the field admits oxygen, raises the redox potential, halts methanogenesis and regenerates oxidised iron and sulphate that suppress methane production for a time after reflooding. The effect of drainage on emissions was shown by continuous field measurement in Japan in the 1990s (Yagi et al., 1996) and has since been confirmed across Asia, where water regime and organic amendments emerge as the dominant controls on emission (Wassmann et al., 2000; Yan et al., 2005).

National greenhouse gas inventories reflect this. The IPCC method scales a baseline emission factor for

continuously flooded rice by a factor for water regime, and the factors for single and multiple drainage are well below one (IPCC, 2006; IPCC, 2019). A global meta-analysis of water management found that non-continuous flooding roughly halved methane emissions relative to continuous flooding (Jiang et al., 2019).

The qualification is nitrous oxide. Alternating aerobic and anaerobic conditions favour nitrification followed by denitrification, and nitrous oxide emissions rise under AWD, particularly when drying follows a nitrogen application (Lagomarsino et al., 2016). Most syntheses conclude that the increase offsets only a small part of the methane reduction when the two gases are combined on a global-warming-potential basis (Jiang et al., 2019; Linquist et al., 2015). Measurements on intermittently flooded farms in India, however, recorded nitrous oxide fluxes far above those assumed in inventories, and the authors argued that water management must be judged on both gases together (Kritee et al., 2018). The matter is not settled, and it argues for mild drying and careful timing of nitrogen in place of the assumption that drier is better.

Drying also changes the chemistry of trace elements. Aerobic periods reduce the mobility of arsenic and lower its concentration in grain (Linquist et al., 2015), a benefit where groundwater carries arsenic. Cadmium behaves in the opposite way and becomes more available as the soil oxidises, so that on cadmium-affected soils AWD may trade one contaminant for another.

7. Barriers to Adoption

If safe AWD maintains yield, saves water and reduces emissions, slow adoption needs explaining. The socio-economic literature points to the conditions under which farmers irrigate more than to the practice. Table 1 groups the barriers most often reported.

Table 1: Barriers to the adoption of alternate wetting and drying reported in the literature		
Barrier	How it operates	Representative sources
Incentives	Water is paid for by area or season, and avoided methane earns the farmer nothing	Lampayan et al., 2015; Pearson et al., 2018
Supply reliability	A farmer unsure of the next canal turn keeps the field flooded as insurance	Rejesus et al., 2011
Field conditions	Uneven land dries in patches; field-to-field flow prevents individual control	Bouman et al., 2007
Climate	Wet-season rain refloods fields and prevents drying	Nelson et al., 2015; Sander et al., 2017
Weeds, labour and perceived risk	Exposed soil favours weeds and adds monitoring; cracks are read as crop damage	Lampayan et al., 2015; Pearson et al., 2018

7.1. Incentives and control over water

The clearest result concerns incentives. In the shallow tube-well schemes of Bangladesh, farmers commonly pay the pump owner a fixed fee per unit area or a share of the crop. Under either arrangement the water saved by AWD benefits the pump owner through lower fuel costs and not the farmer who does the work (Pearson et al., 2018). In gravity canal systems charged by area the same logic holds. Where farmers pump their own water and pay for fuel, AWD reduces a visible cost, and it is in such settings that adoption has been most durable (Lampayan et al., 2015).

Control is the second condition. AWD presumes that water can be delivered when the threshold is reached. In a canal system run on rotation, a farmer who lets the field dry risks finding that the next turn comes late. In the Philippines AWD was introduced in a system where the irrigation agency imposed the rotation itself, so that drying periods were decided at the level of the lateral and not by the individual; an evaluation there found reduced irrigation time without loss of yield or profit (Rejesus et al., 2011). The

lesson is that AWD may be better treated as a rule of system operation than as a choice left to each field.

7.2. Climate and field conditions

The practice also has physical limits. In the wet season, rainfall may exceed losses for weeks at a time, and fields cannot be dried however willing the farmer. Mapping of climatic suitability for the Philippines showed that the area where AWD is feasible in the wet season is far smaller than in the dry season (Nelson et al., 2015; Sander et al., 2017). Estimates of national mitigation potential that apply a single reduction factor to all irrigated rice overstate what can be achieved.

Field layout matters as much as climate. In many Asian systems water passes from plot to plot across the bunds, so that a farmer in the middle of a block can neither hold water back nor dry the field independently of the neighbours. Drying is also uneven on poorly levelled land, where high spots crack and invite weeds while low spots stay wet. Extension guidance therefore treats sound bunds, a reasonably level surface and control over the inlet as preconditions for the practice (Bouman et al., 2007). Land consolidation and laser levelling can supply them, at a cost.

8. Gaps and Future Work

Four gaps deserve priority. The first is water accounting above the field. Claims of water saved should be tested with basin or command-area balances that distinguish reductions in consumptive use from reductions in recoverable flows. The second is the combined greenhouse gas balance under farmers' conditions. Most flux data come from research stations with good water control, and measurements on working farms, including nitrous oxide at high temporal resolution, remain scarce. The third is institutional. Comparative studies are needed of the arrangements under which AWD has persisted, such as volumetric charging, prepaid pump cards, scheduled rotations and aggregated carbon projects, so that programmes can be designed around the constraint that binds in each place. Long-term effects on soil organic matter under repeated drying also await study.

The fourth gap is verification. Carbon projects and national inventories need evidence that fields were in fact dried, and neither farmer diaries nor occasional visits provide it at scale. Satellite detection of surface water and low-cost water-level sensors have been proposed for the purpose, but their reliability beneath a closed rice canopy and their cost per farm are not yet well documented.

9. Conclusions

Safe AWD is among the better-evidenced practices in irrigated agriculture. It lowers irrigation input at the field, keeps yield where water can be reapplied on time, and reduces methane emissions by a margin large enough to survive the nitrous oxide penalty in most assessments. The same body of evidence shows that field-level water savings should not be equated with basin-level savings, and that the practice spreads only where farmers gain from saving water and can rely on getting it back. Efforts to scale AWD are therefore as much a matter of irrigation pricing, scheduling and field infrastructure as of agronomic extension.

Conflict of interest

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References

- Belder, P., Bouman, B.A.M., Cabangon, R., Guoan, L., Quilang, E.J.P., Yuanhua, L., Spiertz, J.H.J. and Tuong, T.P. (2004). [Effect of water-saving irrigation on rice yield and water use in typical lowland conditions in Asia](#). *Agricultural Water Management*, 65(3): 193-210.

- Bouman, B.A.M. and Tuong, T.P. (2001). [Field water management to save water and increase its productivity in irrigated lowland rice](#). *Agricultural Water Management*, 49(1): 11-30.
[https://doi.org/10.1016/S0378-3774\(00\)00128-1](https://doi.org/10.1016/S0378-3774(00)00128-1)
- Bouman, B.A.M., Lampayan, R.M. and Tuong, T.P. (2007). [Water Management in Irrigated Rice: Coping with Water Scarcity](#). International Rice Research Institute, Los Baños.
- Carrijo, D.R., Lundy, M.E. and Linquist, B.A. (2017). [Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis](#). *Field Crops Research*, 203: 173-180.
<https://doi.org/10.1016/j.fcr.2016.12.002>
- Conrad, R. (2007). [Microbial ecology of methanogens and methanotrophs](#). *Advances in Agronomy*, 96: 1-63.
- IPCC (2006). [2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use](#). Institute for Global Environmental Strategies, Hayama.
- IPCC (2019). [2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use](#). Intergovernmental Panel on Climate Change, Geneva.
- Jiang, Y., Carrijo, D., Huang, S., Chen, J., Balaine, N., Zhang, W., van Groenigen, K.J. and Linquist, B. (2019). [Water management to mitigate the global warming potential of rice systems: A global meta-analysis](#). *Field Crops Research*, 234: 47-54.
- Kritee, K., Nair, D., Zavala-Araiza, D., Proville, J., Rudek, J., Adhya, T.K. et al. (2018). [High nitrous oxide fluxes from rice indicate the need to manage water for both long- and short-term climate impacts](#). *Proceedings of the National Academy of Sciences*, 115(39): 9720-9725.
- Lagomarsino, A., Agnelli, A.E., Linquist, B., Adviento-Borbe, M.A., Agnelli, A., Gavina, G., Ravaglia, S. and Ferrara, R.M. (2016). [Alternate wetting and drying of rice reduced CH₄ emissions but triggered N₂O peaks in a clayey soil of central Italy](#). *Pedosphere*, 26(4): 533-548.
- LaHue, G.T., Chaney, R.L., Adviento-Borbe, M.A. and Linquist, B.A. (2016). [Alternate wetting and drying in high yielding direct-seeded rice systems accomplishes multiple environmental and agronomic objectives](#). *Agriculture, Ecosystems & Environment*, 229: 30-39.
- Lampayan, R.M., Rejesus, R.M., Singleton, G.R. and Bouman, B.A.M. (2015). [Adoption and economics of alternate wetting and drying water management for irrigated lowland rice](#). *Field Crops Research*, 170: 95-108. <https://doi.org/10.1016/j.fcr.2014.10.013>
- Le Mer, J. and Roger, P. (2001). [Production, oxidation, emission and consumption of methane by soils: A review](#). *European Journal of Soil Biology*, 37(1): 25-50.
- Linquist, B.A., Anders, M.M., Adviento-Borbe, M.A.A., Chaney, R.L., Nalley, L.L., da Rosa, E.F.F. and van Kessel, C. (2015). [Reducing greenhouse gas emissions, water use, and grain arsenic levels in rice systems](#). *Global Change Biology*, 21(1): 407-417.
- Nelson, A., Wassmann, R., Sander, B.O. and Palao, L.K. (2015). [Climate-determined suitability of the water saving technology "alternate wetting and drying" in rice systems: A scalable methodology demonstrated for a province in the Philippines](#). *PLoS ONE*, 10(12): e0145268.
- Pearson, K.A., Millar, G.M., Norton, G.J. and Price, A.H. (2018). [Alternate wetting and drying in Bangladesh: Water-saving farming practice and the socioeconomic barriers to its adoption](#). *Food and Energy Security*, 7(4): e00149.
- Rejesus, R.M., Palis, F.G., Rodriguez, D.G.P., Lampayan, R.M. and Bouman, B.A.M. (2011). [Impact of the alternate wetting and drying \(AWD\) water-saving irrigation technique: Evidence from rice producers in the Philippines](#). *Food Policy*, 36(2): 280-288.
- Richards, M. and Sander, B.O. (2014). [Alternate wetting and drying in irrigated rice](#). Climate-Smart Agriculture Practice Brief. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen.
- Sander, B.O., Wassmann, R., Palao, L.K. and Nelson, A. (2017). [Climate-based suitability assessment for](#)

- alternate wetting and drying water management in the Philippines: A novel approach for mapping methane mitigation potential in rice production. *Carbon Management*, 8(4): 331-342.
- Saunois, M., Stavert, A.R., Poulter, B., Bousquet, P., Canadell, J.G., Jackson, R.B. et al. (2020). The global methane budget 2000-2017. *Earth System Science Data*, 12(3): 1561-1623.
- Tuong, T.P. and Bouman, B.A.M. (2003). *Rice production in water-scarce environments*. In: Kijne, J.W., Barker, R. and Molden, D. (eds), *Water Productivity in Agriculture: Limits and Opportunities for Improvement*. CABI Publishing, Wallingford, 53-67.
- Wassmann, R., Lantin, R.S., Neue, H.U., Buendia, L.V., Corton, T.M. and Lu, Y. (2000). Characterization of methane emissions from rice fields in Asia. III. Mitigation options and future research needs. *Nutrient Cycling in Agroecosystems*, 58: 23-36.
- Yagi, K., Tsuruta, H., Kanda, K. and Minami, K. (1996). Effect of water management on methane emission from a Japanese rice paddy field: Automated methane monitoring. *Global Biogeochemical Cycles*, 10(2): 255-267.
- Yan, X., Yagi, K., Akiyama, H. and Akimoto, H. (2005). Statistical analysis of the major variables controlling methane emission from rice fields. *Global Change Biology*, 11(7): 1131-1141.
- Yang, J., Zhou, Q. and Zhang, J. (2017). Moderate wetting and drying increases rice yield and reduces water use, grain arsenic level, and methane emission. *The Crop Journal*, 5(2): 151-158.