Title of dissertation				
Exploring water management strategies in paddy rice for enhanced productivity and reduced greenhouse gas emissions				
RONPAKU Fellow				
Name	**Kristine Samoy Pascual**			
Position	Senior Science Research Specialist		ID No.	R12006
Department	Central Experiment Station			
Institution	Philippine Rice Research Institute		Nationality	Filipino
Japanese Advisor				
Name	Masaru Mizoguchi			
Position	Professor	Institution	University of Tokyo	

Irrigated lowland rice, which provides 75% of the world's rice production, continually faces challenges related to water scarcity and the impacts of climate change while also being a significant contributor to greenhouse gas (GHG) emissions. Although several water-saving techniques for rice were developed to address these challenges, there is still a need to elucidate their effectiveness in improving water and rice productivity and reducing GHG emissions, considering the diverse agronomic practices and hydrological environment where the rice grows. This study consists of four independent studies with mutually related objectives of enhancing water and rice productivity, profitability and reducing GHG emissions in rice.

1. Is alternate wetting and drying irrigation technique enough to reduce methane emissions from a tropical rice paddy?
A combination of a pre-season wet soil condition and rice straw incorporation just before transplanting, typical for a tropical rice double cropping, can induce a flash of methane (CH_4) emission shortly after the transplanting. The conventional practice of AWD irrigation technique that typically starts 21 days after transplanting (DAT) can hardly reduce this emission because the soil becomes methanogenic before the onset of AWD treatment. Field experiments were conducted in Muñoz, Nueva Ecija, Philippines, during the 2014-2017 dry rice seasons to examine the effects of the timing of rice straw/stubble incorporation on the efficacy of AWD in reducing the CH_4 emission. Two treatments of the timing of stubble incorporation were stubbles incorporated during the start of wet land preparation and during the dry fallow tillage. For water management, we compared two treatments: continuous flooding (CF) and AWD with a –15 cm threshold level for irrigation. The AWD under stubbles incorporated during the dry fallow tillage was implemented earlier at 10 DAT. We observed a significant interaction ($p < 0.01$) between the effects of AWD and straw management on CH_4 emissions; the seasonal total CH_4 emission was reduced by AWD compared with CF by 73%under stubbles incorporated during the dry fallow tillage, while the reduction was < 20% under stubbles incorporated during wetland preparation. The AWD significantly ($p < 0.05$) increased the nitrous oxide (N_2O) emissions by 47 and 48% relative to CF under stubbles incorporated during wetland and dry fallow tillage, respectively. The global warming potential (GWP, $CH_4 + N_2O$) and yield-scaled GWP were still substantially lower by 62% and 59%, respectively, in AWD than in CF under stubbles incorporated during the dry fallow tillage, but the reduction was not realized under stubbles incorporated during wetland preparation due to the relatively smaller CH_4 reduction and increased N_2O emission.

2. Rice husk ash and water management affect the GHG emission and water productivity in rice

The combination of AWD and varying rice husk ash (RHA) rates (10, 20, and 30 t ha-1) were evaluated in clay soil in Muñoz, Nueva Ecija, Philippines to determine their effect on yield, water productivity, and GHG emissions in paddy rice for four cropping seasons (CS). We compared these treatments with continuous flooding and no RHA as controls. RHA decreased N_2O emissions by 8–22%, in the order of RHA30 > RHA20 > RHA10 relative to the control. AWD had a marginal effect ($P < 0.10$) on CH4 emissions, with an 11% reduction. A significant interaction ($p < 0.05$) among water, RHA, and CS on N_2O emissions was associated with rice stubble management in the first CS before wetland preparation. Under AWD, the highest RHA rate increased N_2O emissions by 215% compared to the control, while CF showed reversed effects with a 77% reduction. However, the global warming potential was still significantly lower ($p < 0.05$) by up to 15–fold compared to other CS in all RHA rates. Although yield did not differ among treatments, AWD saved 39% water, and water productivity increased by 0.56 kg m–3 relative to CF. Our results showed that the primary RHA effects mitigated N_2O emissions while AWD had only marginal effects on CH_4 emissions while maintaining yield. The low total GWP suggests that the mitigation potential of RHA and water management's combined effects is associated with properly managing rice stubbles first.

3. On-farm participatory field trials of AWD and resource-use efficient technologies bundling in rice

On-farm participatory field trials were conducted in Muñoz, Nueva Ecija, Philippines over two dry seasons to assess the cost-effectiveness and grain yields of AWD with bundled resource-use technologies for rice. The trials evaluated whether bundling could enhance yields, reduce production costs, and improve gross margin under farmers' field conditions. Technology combinations were grouped as treatments (T) to reflect increasing bundling levels: T1 (farmers' practice (FP) with continuous flooding or CF), T2 (CF with mechanical transplanting, site-specific nutrient management (SSNM), and pre-emergence herbicide or PH), T3 (T2 with laser land leveling or LLL), T4 (FP with AWD), T5 (AWD, mechanical transplanting, SSNM, and PH), and T6 (T5 with LLL). Bundles involving LLL (T3) significantly increased the unit cost of production ($P < 0.05$) but did not result in proportional yield or gross margin increases. The outcome was likely attributed to exposure to less fertile soil after cut-and-fill operations and the high rental fee of LLL. However, the AWD in T6 with LLL mitigated these effects, resulting in no significant impact on yield. T5 balanced production costs and yield, offering a more economically viable approach than T3. The variability in yields and gross margins across treatments suggests that the expected benefits of higher yields and reduced costs from bundling technologies were inconsistent, with some treatments showing no advantages over farmers' practices. The bundles combining AWD, SSNM, mechanical transplanting, and pre-emergence herbicide offered a balanced approach to cost efficiency and productivity.

4. Determinants in the adoption of AWD in a gravity surface irrigation system in the Philippines

The AWD is a well-known low-cost water-saving and climate change adaptation and mitigation technique for irrigated rice. However, its adoption rate has been low despite the decade of dissemination in Asia, especially in the Philippines. This study empirically explored factors shaping AWD adoption in a gravity surface irrigation system using cross-sectional farm-level survey data. We used regression-based approaches to examine the factors influencing farmers' adoption of AWD and its impact on yield. Results showed that most AWD adopters were farmers who practiced enforced rotational irrigation scheduling within their irrigators' association (IA). With the current irrigation management system, the probability of AWD implementation increases when farmers do not interfere with the irrigation schedule (otherwise, they opt to go with flooding). Interestingly, the awareness factor did not play a significant role in the farmers' adoption due to the RI setup. Perceptions of water management as an effective weed control method were found to have a positive association with the likelihood of AWD adoption. Furthermore, the grain yields of AWD adopters showed no significant difference compared to those of non-adopters. Thus, given the rotational irrigation scheduling already in place within the

study site, we recommend fine-tuning this setup following the recommended safe AWD at the IA scale.

General discussion, conclusions, and recommendations

This study demonstrated that the effectiveness of water-saving techniques, such as AWD, in reducing GHG emissions is influenced by the timing and method of biomass residue management, as well as the quantity, quality, and source of biomass. Incorporating stubbles during the dry fallow period was more effective in reducing CH_4 emissions than during wet land preparation complemented with a site-specific modification of AWD (i.e. implemented earlier at 10 days after transplanting), while rice husk ash primarily reduced nitrous oxide (N_2O) emissions in increasing application rates but with limited impact on CH_4 emissions. Water productivity improved mainly due to reduced water use under AWD without significantly affecting grain yields. Moreover, integrating AWD with other resource-use technologies like site-specific nutrient management, mechanical transplanting, and pre-emergence herbicide application provided a balanced approach to cost efficiency and gross margins compared with other packages of technologies with laser land leveling. At the farmers' level under a large-scale irrigation system, the study identified four key factors significantly associated with AWD adoption: irrigation flexibility, awareness, field water depth, and perceptions of water management as weed control, each with varying levels of influence. To scale out the AWD, the study recommends aligning existing irrigation schedules with the principles of safe AWD and developing support mechanisms that connect carbon credit incentives to increase adoption.

Photos

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