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Alternate Wetting and Drying (AWD) Irrigation Technology Uptake in Rice Paddies of the Mekong Delta, Vietnam: Relationship between Local Conditions and the Practiced Technology

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Abstract

Worldwide increasing water demands have made alternate wetting and drying (AWD) irrigation an attractive water-saving technology for paddy rice farming. With AWD, rice paddies are intermittently irrigated, except during the rooting and flowering stages, reducing water use by 15%-40%. We assessed AWD uptake by comparing the standardized AWD used by official institutions and the practiced AWD used by farmers in An Giang Province, Mekong Delta, Vietnam. We observed that 1) farmers did not use plastic pipes to measure the water level, although these allow assessment of the correct timing for watering and 2) farmers also practiced AWD during the rainy season, despite it originally being developed as a water-saving technology. These modifications indicate that farmers have adapted AWD for use in their local farming conditions. Agrarian certification systems should be used to increase AWD uptake; however, these require standardized procedures. Therefore, this disparity between the standardized and practiced technology should be addressed to improve AWD uptake.

1. Introduction

The 21st century is "the century of water," and various water issues have been emphasized worldwide [Sunada 2008]. With regard to the issue of water availability, the United Nations [UN 2012] reported that "11% of the global population, i.e., approximately 783 million people, remains without access to an improved source of drinking water." Moreover, there is increasing competition for water resources between domestic, industrial, and agricultural sectors.

Water availability is a particularly serious issue in Asia as the primary Asian foodstuff is paddy rice. Irrigated paddy fields are traditionally flooded from transplanting (or sowing) to harvest, which results in water loss through evapotranspiration and percolation. The International Rice Research

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Institute (IRRI) has found that paddy rice only needs to be flooded during the rooting and flowering stages [Van der Hoek *et al.* 2001]. Consequently, IRRI developed the alternate wetting and drying (AWD) procedure, whereby paddy fields are only intermittently irrigated except during these critical stages. AWD procedure ("safe-AWD") follows strict standards, whereby paddy fields are watered up to 5 cm and then re-watered when the water level naturally declines to 15 cm below the soil surface, reducing total water usage by 15%-40% compared with continuous flooding, with no major negative impact on yield [Humphreys *et al.* 2010].

IRRI assumed that AWD would be well-received by Asian countries because of its reduction capacity of irrigation cost; however, it is still not very popular. In Bangladesh, AWD demonstrations by IRRI did not lead to its subsequent spread because of insufficient extension workers to transfer the technology to farmers and disparity between the AWD logic and local farmers' perception regarding paddy rice farming [Kurschner *et al.* 2010]. In the Philippines, AWD was adopted in paddy areas where farmers were using power pumps; however, it was not adopted in areas where gravity irrigation was utilized as this system included a fixed irrigation fee for each season and did not benefit the AWD adopting farmers [Lampayan *et al.* 2009]. In China, it was decided that AWD would not to be adopted in paddy areas that had no stable water sources [Moya *et al.* 2004]. However, AWD has spread more extensively in An Giang Province in the Mekong Delta, Vietnam (Figure 1).

Vietnam is one of the major rice producers of the world, and the Mekong Delta accounts for more than half of Vietnam's production [MAFFJ 2011]. The total rice production in the Mekong Delta has been steadily increasing for several decades through the introduction of new rice varieties, chemical fertilizers, and power pump irrigation. However, farmers' incomes have not matched this increase for two major reasons: relatively poor quality rice grain which has a lower selling price for export and high production costs as chemical fertilizers or irrigation are used [UNEP 2005]. AWD is expected to reduce irrigation costs and thus increase farmers' incomes [Truong Thi Ngoc Chi *et al.* 2013], and this has been supported by cost-benefit analyses of households that have and have not adopted AWD in An Giang Province [Diangkinay-Quicho 2013; Lampayan *et al.* 2015]. However, to date, no detailed studies have investigated AWD uptake by farmers.

According to previous studies [Kurschner *et al.* 2010; Lampayan *et al.* 2009; Moya *et al.* 2004], widespread AWD uptake has been constrained by a combination of local agricultural conditions including infrastructure, prevalent political institutions, and farmers' perceptions. Therefore, we investigated AWD adoption and practice in the An Giang Province and subsequently examined how AWD had integrated into the local agrarian system.

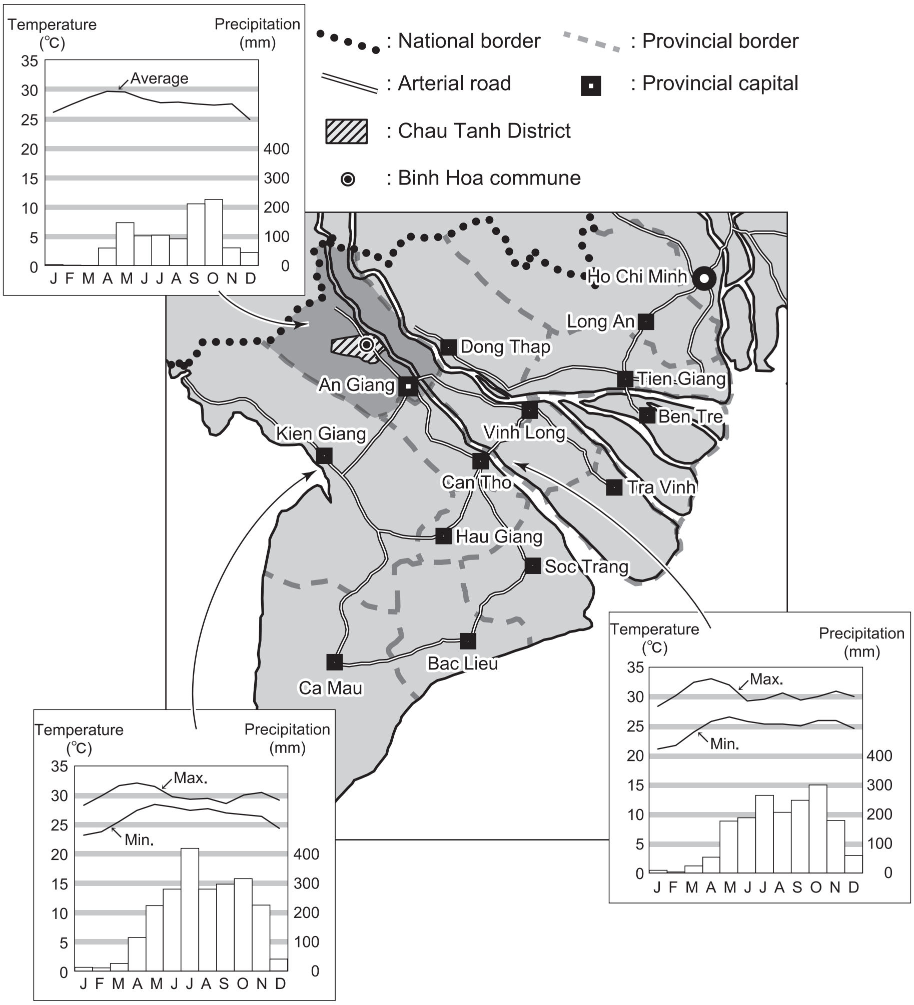

Fig. 1. Location of the Study Site and Climate in the Mekong Delta

Sources: An Giang Province data were taken from Thieu Vinh An [2014]. The precipitation data for Kien Giang and Can Tho were taken from Quy Toan Do and Christiansen [2010], and the temperature data were taken from Raspisaniye Pogodi Ltd. [2015].

2. Methodology

We undertook two separate field investigations in May and September 2014.

In the first investigation, general agrarian information on AWD, including uptake level and current plans, were obtained from the Department of Agriculture and Rural Development in An Giang Province and Sub-department of Plant Protection in An Giang Province (SDPPA). The general landscape around An Giang Province was surveyed. Based on this information, we decided to focus

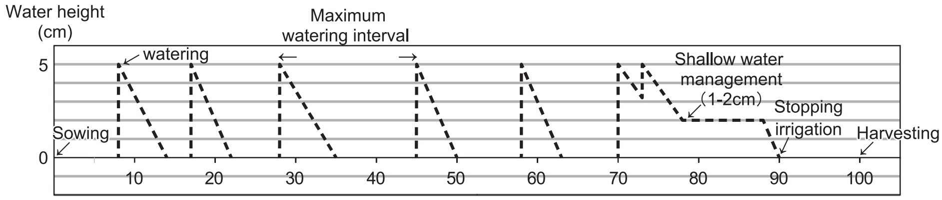

Fig. 2. Paddy Water Management during the Dry Season (taken from household A)
Water depth below the soil surface was unclear because farmers did not use a pani-pipe.
Source: Field investigation in 2014.

the second investigation on the rural commune of Binh Hoa in Chau Tanh District.

In the second investigation, we conducted structured interviews with 21 households, which were selected by the People's Committee of the rural commune.[1] The prepared questionnaire included the sections of agricultural outline, adoption and AWD practice, paddy field water management, and irrigation pump use. We also confirmed daily water level changes and the timing of watering during the dry cropping season (from winter 2013 to spring 2014) (Figure 2).[2] Although the interviewees did not record this information, they carefully observed their paddy fields almost every day and remembered when they watered them and how many days after irrigation the floodwaters disappeared.

During the first investigation, we noticed that the AWD procedures practiced by farmers were different from IRRI's standardized procedure. Therefore, we focused on these differences and adopted the concept of "reinvention," which is defined as "the degree to which an innovation is changed or modified by a user in the process of its adoption and implementation" [Rogers 2007: 103]. For an innovation to be adopted and continuously implemented, it must match the user's requirements. Agrarian technologies are particularly dependent on the surrounding conditions, including the natural environment, infrastructure, or farmers' skills [Suzuki 1998] and, therefore, any agrarian innovation also needs to fit these. We considered reinvention as transformation of the original innovation into a desired form by the locals, allowing the innovation to take root in the local area.

We analyzed the differences between the standardized AWD, as outlined in the guide book published by SDPPA [2011] (Figure 3), and the practiced AWD at the site. The guide book explains the agrarian policy of "one must and five reduction (1M5R)," whereby "one must" requires farmers

1) We could not obtain details around the process of household selection for political reasons. Thus, we attempted to validate the data from these households by comparing them with existing studies. We also present median values and ranges to reduce the likelihood of sampling bias.
2) Where households possessed multiple paddy plots, we requested that they focused their responses on the largest plot.

Fig. 3. The Guide Book of the "One Must and Five Reduction" Policy, published by SDPPA [2011]

to use certificated seeds rather than autogenous seeds and "five reduction" is recommended to reduce the sowed seed number and the amounts of agrichemicals, fertilizers, irrigation water, and post-harvest loss. This policy aims to increase rice farmers' incomes by eliminating inefficiencies in rice farming [Truong Thi Ngoc Chi *et al.* 2013]. The guide also explains how to implement AWD, which has been officially adopted as a water-saving technology since 2009.

In the following sections, we first explain the landscape and paddy rice farming practices at the study site, and then provide an overview of the AWD uptake situation in An Giang Province. We then provide some real-life examples of AWD adoption and water management based on the Binh Hoa commune case study. Finally, in the discussion, we examine the differences between the standardized and practiced AWD.

3. Landscape and Agricultural Practices at the Study Site

In 2008, the total rice production of the Mekong Delta exceeded 20 million tons (husked rice). An Giang and Kien Giang Province are particularly important for rice production [MAFFJ 2011],

Table 1. Basic Information on the Study Site

	Population	Number of households	Total area (ha)	Paddy area (ha)
An Giang Province	2,142,709[a]	524,759[a]	353,676[b]	192,594[c]
Chau Tanh District	169,723[a]	—	35,507[b]	27,686[c]
Binh Hoa commune	19,568[b]	4,080[b]	2,228[b]	1,926[d]

Sources: a: conditions in 2009 [CPHCSC 2010], b: conditions in 1999 [MICV 2010], c: conditions in 2007 [Nguyen Lam Dao *et al.* 2009], d: conditions in 2007 (estimate based on a 1/50,000 map).

with An Giang Province contributing 17% of the total rice production. Compared with other rice producing areas in Vietnam, rice farming in the Mekong Delta occurs in relatively larger fields and is primarily linked to export [Young *et al.* 2002].

The Mekong Delta is approximately 40,000 km^2 in area and is located between 8°34' and 10°55' N. The monthly average air temperature rarely drops below 25°C (Figure 1); paddy rice can be cultivated year round if water conditions are appropriate. The western part of the Mekong Delta has an annual precipitation of >2,000 mm due to the monsoon effect from the southwest. However, annual precipitation decreases inland and is approximately 1,300 mm in An Giang Province. Most of the precipitation tends to occur during the rainy season of June-November (monthly precipitation, 200-300 mm), with much lower levels during the dry season of December-March.

The Mekong River splits into the Hau Giang and Tien Giang Rivers at the Vietnam-Cambodia border. Kaida [1975] categorized An Giang Province as the floodplain of the Hau Giang River, with paddy fields accounting for approximately 60% of all provincial land. There are small differences in the landscape between the 11 districts within the Province, with eastern districts, such as Phu Tanh and Chu Phu, being prone to flooding and western districts, such as Tinh Bien and Tri Ton, having several small hills. The Chau Tanh District is also located in the middle of the floodplain, with paddy fields occupying approximately 80% of the area (Table 1).

Rice production in An Giang Province used to be based on the single-cropping of floating rice varieties. However, with the introduction of improved fast-growing and high-yielding rice varieties at the end of the 1960s, farmers could double their crop production, except during the peak flooding periods from September to November. At the beginning of the 1990s, these improved varieties prevailed across most of the Province [Otsuka 2014]. At the end of the 1990s, the local government began to construct the full-dike systems that enclose some settlements and fields [Tran Van Hieu 2010]. These systems use huge pumps to drain excess water during the rainy season, enabling farmers to triple crop. Our case study site, the Binh Hoa commune, has been enclosed by a full-dike since 2010.

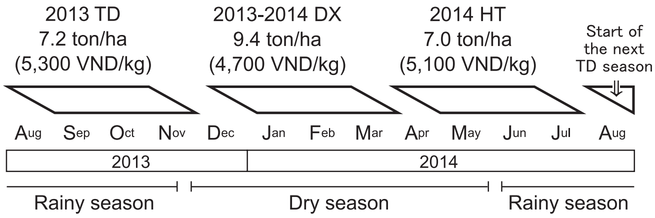

Fig. 4. Agricultural Calendars for Paddy Rice and Their Associated Yield

Yield amounts are median wet weights of husked rice before drying across the surveyed households (n=21).
Numbers shown in parentheses denote the selling price to middlemen; VND=Vietnamese dong.
Source: Field investigation in 2014.

The rice cropping seasons in An Giang Province are separated into *hè thu* (HT; summer-autumn), *thu dông* (TD; autumn-winter), and *dông xuân* (DX; winter-spring) (Figure 4). During HT, farmers seed at the end of the dry season and harvest before the middle of the rainy season; during TD, farming is conducted during the heaviest rainy season of the year; and during DX, farming is almost the same as dry cropping. Based on the interview results, HT, TD, and DX harvest yields approximately 7.0, 7.2, and 9.4 ton/ha, respectively (Figure 4).[3] It is difficult to directly compare these harvest amounts because farmers sometimes use different varieties depending on the cropping season. However, farmers generally consider that DX season yields the best harvest of the year, with production tending to decline during HT and TD rainy seasons.

4. AWD Uptake in An Giang Province

IRRI initiated the AWD introduction project in Vietnam in 2003 [Rejesus *et al.* 2013] and An Giang Province at around this time [CTIEI 2011]. Since 2005, AWD has been incorporated into agrarian policies in An Giang Province [Rejesus *et al.* 2013], with SDPPA providing training workshops and field exhibitions; since 2009, the local government has promoted the 1M5R policy, in which AWD was adopted as the primary water-saving technology [Truong Thi Ngoc Chi *et al.* 2013].

As shown in Figure 5, Long Xuyen, which is the central township in the Province, had the highest level of AWD uptake in 2009 and 2013, largely due to government efforts having been focused on this area since 2005. Uptake level is also currently increasing elsewhere, although there are still large differences between districts, with levels of use ranging from 28% in Tinh Bien to 79% in Phu Tan. Chau Tanh fell between these levels, and the uptake level in the Binh Hoa commune was 58% in 2013.

3) Most farmers in An Giang Province sold their rice immediately after harvest. Therefore, the weights shown here denote wet weight of husked rice before drying, which would include 20%-30% water.

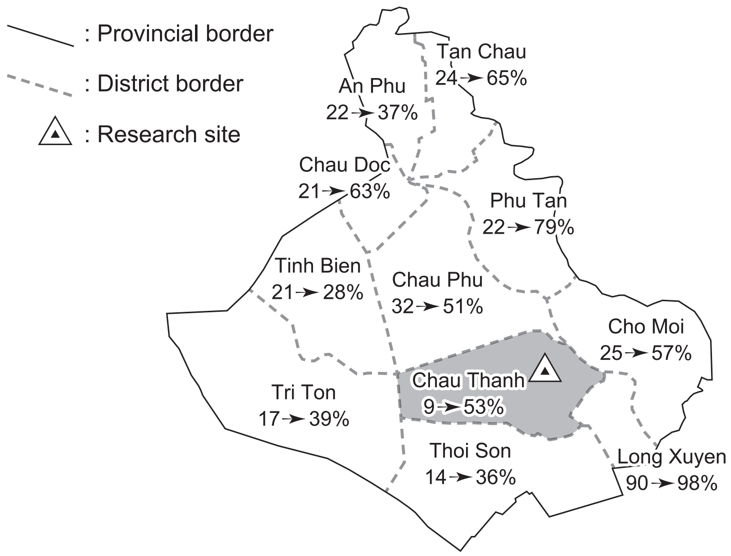

Fig. 5. Rates of AWD Technology Uptake by Districts in An Giang Province in 2009 and 2013
Numbers denote the changes in AWD uptake rates by the area in each district during dry season farming.
Source: Interview survey on the Sub-Department of Plant Protection in An Giang (SDPPA) in 2014.

As mentioned in section 2, the guide book of the 1M5R policy [SDPPA 2011] explains the standardized procedure of AWD-namely, that farmers should water their paddy fields at a shallow height of approximately 5 cm and wait for water to decrease to 15 cm below the soil surface before re-watering. This strict schedule of water management for paddy rice farming is described as follows.

It needs to moisten the inner paddy soil just after sowing but to avoid flooded irrigation for first 7 days. Fertilization should be conducted at 7-10 days after sowing (DAS), the paddy should be flooded to a depth of 1-3 cm at this period. Water height should be maintained 3-5 cm during 10-20 DAS because flooded irrigation is necessary for rice growth during this period and it also controls weeds. The second fertilization should be conducted 18-22 DAS. Rice is in vegetative growth during 25-40 DAS, about 60% soil moisture is sufficient for prosperous growth, thus, AWD should be conducted during 25-40 DAS. Additionally, rice is prone to sheath blight disease during this period, shortening of the flooded conditions by AWD restricts spread of the pathogenic fungus (Rhizoctonia solani). Third fertilization should be conducted during 40-45 DAS, water depth should be maintained at 1-3 cm for this period. Nothing significant is noted during 45-60 DAS. The period of 60-75 DAS corresponds to the flowering stage; rice requires large volumes of water, thus, water depth should be continuously

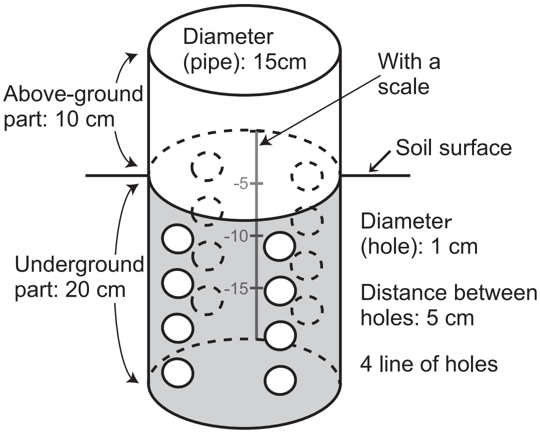

Fig. 6. Sketch of an Installed "Pani-pipe"
Source: Illustrated by the authors based on the explanation in SDPPA [2011].

> *kept at 5 cm. Farmers should drain the water from the paddy fields 10-15 days before harvest. Draining the water before harvesting promotes rice ripening and facilitates the machine harvesting operation.* [SDPPA 2011]

The guide also recommends the installation of a plastic "pani-pipe" in the paddy fields to confirm the water depth below the soil surface using the many holes and scale marks (Figure 6).

The standard AWD procedure outlined by SDPPA is almost identical to IRRI's safe-AWD procedure, although SDPPA provides a stricter schedule that also includes fertilizer application. In the discussion, we compare this standardized and practiced AWD on site to investigate the reinvention of this procedure.

5. Results

5.1 *Paddy Rice Farming*

Table 2 provides basic information about the surveyed households and their heads. None of the household heads were engaged in off-farm work, as agrarian activity was their primary income source. Across the 21 households surveyed, the median area planted with rice was 1.2 ha, with 12 households cultivating 1-2 ha. Similarly, the World Bank [2013] reported that Mekong Delta households owned a mean 1.5 ha paddy rice area and Truong Thi Ngoc Chi *et al.* [2013] reported a mean 1.64 ha per household paddy field area, based on an extensive survey of 471 households in An Giang Province. Each household generally possessed one paddy field plot but some possessed several.

Table 2. Basic Information about the Survey Respondents and Their Households

n=21	Age of informants	Standard of education*	Property of paddy fields (ha)	Number of paddy plots	Paddy area by plot (ha)	Distance from homestead to fields (km)	Number of motorbikes	Frequency of field visiting**
Median value [range]	48 [31-75]	Second. S. [Prim. S.- High S.]	1.2 [0.2-6.7]	1 [1-5]	1.0 [0.2-4.5]	1.7 [0-11.8]	2 [1-5]	1 [1-3]

* In the Vietnamese education system, people progress from 5 years of primary school ("Prim. S.") to 4 years of secondary school ("Second. S.") and 3 years of high school ("High S.")
** Frequency indicates the interval between paddy field visits by farmers.
Source: Field investigation in 2014.

The paddy fields were not always adjacent to their homesteads, with some households needing to move some distance for management. Because all households surveyed possessed motorbikes, the distance between their homesteads and paddy fields was not a major issue; most households checked the conditions of their paddy fields every day.

All paddy plots of the households surveyed were connected with primary or secondary water channels for irrigation and drainage. Although some households undertook plot-to-plot irrigation in the past, few fields now depend on this as the local government set up branching water channels at the farmers request.

Most of the farmers surveyed plow and flood their fields during the inter-cropping periods and then sow the next season's crops once the land has drained. All households surveyed used certified rice seed supplied by private companies or public institutions. One major variety planted in 2013 was jasmine rice, which has a special flavor and is mainly exported to the Middle East; the improved varieties OM4281, OM5451, and OM6976 were also cultivated.[4] Until recently, farmers used to sow by hand-broadcasting and conducted complementary planting; however, following 1M5R rice seed saving policy implementation, most farmers have now switched to using a drum seeder, with only three of the surveyed households continuing to hand-broadcast seed.

5.2 *AWD Adoption and Practice*

Table 3 shows AWD adoption and practice among the surveyed households. AWD was first adopted by some households in 2004, with maximum uptake in 2007. By 2010, all households were practicing AWD. Households chose to use AWD based on information from two sources: the workshops provided by IRRI and SDPPA, and observations and daily conversations with neighbors. Only one

4) The respondents identified the flavored rice as jasmin but did not have detailed information about the variety. The OM series, e.g., OM4281 and OM5451, are domestic varieties that were developed from the IR rice varieties to suit local Vietnamese conditions.

Table 3. Year in Which AWD Was First Implemented and Information Sources Used by Surveyed Households

Information sources in adoption	Adoption year				
	2004	2007	2008	2010	Total
Only from workshops	0	1	0	0	1
Only from neighbors	3	2	1	0	6
Both workshops & neighbors	3	7	2	2	14
Total	6	10	3	2	21

Source: Field investigation in 2014.

Table 4. Reasons Why Surveyed Households Practiced AWD

Reasons for adoption					
Improved yield	Government instruction	Viet GAP	Large scale paddy field	Request by middlemen	As neighbor doing
4	3	0	2	1	4

We asked informants to respond using five answers: 0. don't know; 1. not important; 2. less important; 3. important; and 4. very important. Each number is the median value for 21 households.
Source: Field investigation in 2014.

household adopted AWD based solely on the workshops, with 14 households using a combination of information from the workshops and neighbors, and six households using only information from neighbors.

We asked the household heads to evaluate the importance of several interrelated factors in their AWD practice (Table 4). Most household heads emphasized "increasing productivity" as a primary reason for uptake, with nearly all stating that AWD increased their rice yield during both the dry and rainy seasons. The level of increase differed between households, reaching a maximum level of 30% for one household. The household heads also mentioned that it was important to synchronize harvest timing with neighboring households. Harvesting was generally conducted using a combine harvester to reduce post-harvest losses, and drying was then performed by middlemen, who generally moved from one area to another during the harvest periods. Therefore, if one particular household harvested at a different time from neighboring households, they had to hold onto their harvested grain until the next visit, during which time the rice would dry out, resulting in a lower rice weight and thus lower profits (because the selling price is the same regardless of drying condition).

Good Agricultural Practice (GAP) is a certification system that adds value to agrarian products [Nakajima 2010]. Vietnam introduced a domestic version of GAP ("Viet GAP"), which has more relaxed rules than the international version. In the Mekong Delta, rice farming households with Viet GAP certification appeared from approximately 2010 [Tran Quoc Nhan *et al.* 2013]; however,

Table 5. Advantages of AWD According to the Surveyed Households

Merits	Number of responses
Saving pump cost	15
Saving fertilizer	8
Sharing experience	7
Synchronized calendar	5
Good relation among farmers	5
Saving agrochemicals	4
Saving seed	4
Advantage of selling price	4
Facilitation of harvesting	1
Good relation between farmers and the government	1

Source: Field investigation in 2014.

the surveyed households had a relatively low awareness of Viet GAP, and none of the households practiced AWD to obtain this. The "large-scale paddy field"[5] policy, in which rice farmers form an association that contracts with companies to boost their influence, has also been implemented in the Mekong Delta [Tran Quoc Nhan *et al.* 2013], but household heads seldom mentioned a relationship between AWD and this policy.

We also asked an open question about AWD advantages (Table 5). In response, 15, 8, and 4 household heads mentioned water-saving benefits, reduced fertilizer use, and reduced seed requirement, respectively. We did not obtain any detailed data on fertilizer and seed used, but no previous studies have reported a direct link between AWD and reduced levels of these factors. Therefore, it is possible that those household heads were considering their overall impression of the 1M5R policy when answering because farmers took a class on this under the government's guidelines. Four household heads also mentioned a reduced requirement for agrochemicals as AWD merit, which is also noted in SDPPA's guide book. Seven household heads considered the shared experience as an AWD merit, which may have been generated through the exchange of AWD information—the answer "Good relations among farmers" would also have a similar meaning.

We also asked about the disadvantages of AWD. However, only two household heads specified any disadvantages, with reference to the water arrangement issue.

5.3 *Water Management Practices during the Dry Season (DX)*

There were clear differences in water management practices between the dry and rainy seasons in

5) "Large scale paddy field" is an agrarian policy of the Vietnamese Government that aims to strengthen farmers' bargaining power through collaboration between small farmers. Farmers need to use the same rice varieties and farming technologies so that their crops are of equal quality.

the Binh Hoa commune. During the dry season, water levels in both the paddy fields and irrigation channels naturally decline; therefore, farmers add water to their fields using power pumps. Conversely, during the rainy season, when there is a large amount of precipitation, farmers need to drain water from their paddy fields using the huge pumps of the full-dike system.

We prepared pattern diagrams showing the actual water management practices performed during the dry season by 15 of the households surveyed (e.g., Figure 2); six of the original households surveyed were excluded due to ambiguous answers.

Contrary to the SDPPA's guidelines, none of the households continued to use pani-pipes to measure water levels after the initial implementation of AWD. Some households used these during the first few cropping season, but then stopped because of the additional labor requirement. The households instead used their own criteria to determine the timing of watering. Consequently, no data on water depth below the soil surface is shown in these diagrams, but the number of days taken for water to disappear from the soil surface after watering was determined.

The general water management practices are presented in Table 6. All household heads gave a maximum water height of 5 cm. Almost all households also performed the first flooding at 7-10 days after sowing (DAS). Harvesting was generally conducted at approximately 100 DAS, but most households stopped irrigation 10-15 days before harvest to dry up their fields.

At 26-40 DAS, SDPPA recommends practicing AWD, and the fields at the study site were not flooded for approximately 10 days (66%) during this period. At 46-60 DAS, SDPPA does not provide any particular instructions, and the fields were not flooded for approximately 9 days (60%). By contrast, at 11-20 DAS, SDPPA recommends continuous flooding, but the fields were not flooded for 5 days (50%). At 61-75 DAS (the flowering stage), SDPPA also recommends continuous flooding, but the fields were not flooded for approximately 5 days (33%). After 75 DAS, most farmers transitioned to very shallow water management, where the water height was maintained at 1-2 cm.

The AWD instructions provided by IRRI and SDPPA note that farmers should continuously flood their paddy fields during the flowering stage. At the study site, the ratio of non-flooded days was significantly lower during the flowering stage (61-75 DAS) than during the recommended period for AWD (26-40 DAS) (Mann-Whitney U test, $p<0.05$), which suggests that the surveyed households did try to keep their fields permanently flooded at this time.

If the water supply is stopped, water height naturally decreases because of evapotranspiration and percolation, the degree of which is referred to as the water requirement rate. Several household heads stated that floodwaters would disappear 3-4 days after irrigation at the beginning of the cropping season, and 5-7 days after irrigation in the middle of the cropping season. Thus, based on the

Table 6. Water Management in Paddy Fields during the Dry Season (DX)

n=15	First flooded day*	Stopping irrigation day*	Day of harvesting*	Number of times of watering	Maximum interval days of watering	Water requirement rate (mm/day)	Non flooded days during the season**	Non flooded days			
								during 11-20*	during 26-40*	during 46-60*	during 61-75*
Median value [range]	7 [5-8]	90 [80-110]	100 [100-120]	8 [6-10]	16 [10-20]	12 [7-8]	30 [14-49]	5 [0-8]	10 [5-13]	9 [0-15]	5 [0-10]

* Days after sowing.
** Non-flooded days were calculated from the day of first flooding after the rooting stage to the cessation of irrigation before harvest.
Source: Field investigation in 2014.

Table 7. Irrigation Costs of Pump-owner and Pump-hiring Households during the Dry Season (DX)

Pump owner HHs: 13 Pump hiring HHs: 8	Number of pumps by HH (n=13)	Fuel fee of pump owner HHs (n=10, VND/ha/season)	Pump hiring costs including fuel fee (n=8, VND/hour)	Number of times of watering*	
				Pump owner HHs (n=10)	Pump hiring HHs (n=5)
Median value [range]	1 [1-3]	200,000 [150,000-300,000]	40,000 [24,000-40,000]	8.5 [7-10]	7 [6-8]

HH="household"
We interviewed the heads of 21 households, but some were unable to provide detailed answers. Thus, we provide the number of households that responded for each item.
* Mann-Whitney U test, $p<0.05$.
Source: Field investigation in 2014.

patterns of use, we estimated a median water requirement rate of 12 mm/day for each household's paddy field. This value does not include precipitation, but since monthly precipitation is <30 mm during the dry season, water supplied by rainfall would not be very significant.

The maximum interval between two watering events across the households was 20 days (median, 16 days). Households watered their paddy fields to reach a level of 5 cm a median of eight times during the dry season, except during the very shallow water management period.

5.4 *Power Pump Use*

During the dry season, farmers at the study site used personal power pumps to irrigate their fields because the water level in the irrigation channels was lower than that in the soil surface of the paddy fields. Table 7 shows the use of power pumps among the surveyed households.

Power pumps were owned by 13 surveyed households and were hired by the other eight households during DX and start of HT seasons. Pump owners seldom remembered the actual price of their pumps, but we received purchase prices of 4.5 million VND[6)] in 2009 and 5.0 million VND in 2004. Although the capacity of the pumps varied, they were generally able to irrigate a 1-ha paddy field to up to 5 cm in 3 h, at a fuel cost of 10,000-12,000 VND/ha. The pump-owner households generally watered their fields 8.5 times during the dry season, at a median cost of 200,000 VND/ha.

Only two pump-hiring household heads knew the total hire costs during the dry season: one household watered a 0.5-ha field six times during the season and paid 500,000 VND and the other watered a 0.45-ha field six times and paid 400,000 VND. However, all pump-hiring households were able to provide hourly rates, which were a median of 40,000 VND/h including fuel costs. Therefore, based on this pump hire cost, the number of times the fields were watered (median, seven times), and the average pump ability (3 h to irrigate a 1-ha field), we estimated that the total irrigation cost for pump-hiring households was 840,000 VND/ha during the dry season.

Pump-owner households irrigated their fields significantly more often than pump-hiring households. We estimated that pump-hiring households spent approximately four times as much as pump-owner households, not including the cost of transporting a pump from the owner's household to the field they needed to irrigate, which likely decreased the number of times these households watered their fields.

Although personal pump use peaked during DX season, farmers also used pumps during HT season because it starts at the end of the dry season. However, the rainy season starts in the middle of HT season, and some household heads stated that irrigation costs decreased by approximately

6) VND is the Vietnamese currency unit. 1 JPY was approximately 200 VND at the time of our survey (September, 2014).

30% due to precipitation.

Farmers did not utilize personal pumps during TD season, which was in the middle of the rainy season. Instead, water drainage was conducted using the huge pumps of the full-dike system once per week to reduce the water height in the channels within the dike (Figure 7), following which a water gate at the paddy ridge was opened to naturally drain water from the paddy fields into the channels. These huge pumps were managed by the farmers' group at the site, which was comprised several farmers who invested in the huge pump and its operation. The farmers' group and all farmers that used the full-dike met once per year to negotiate the pump operational fee, but the cost usually remained unchanged regardless of the number of times it was used for draining. Each farmer paid 1,800,000 VND/ha during the 2014 TD season.

All household heads stated that they also implemented AWD during TD season, although at this time it was conducted using drainage. Farmers made several trenches within each paddy field plot (Figure 8). A straight inner trench (30 cm wide, 20 cm deep) extended from the water gate to the opposite paddy ridge, and small winding trenches (20 cm wide, 10 cm deep) crossed the straight trench. When farmers opened the water gate during the huge pump operation, extra water was drained into these trenches, reducing the water depth to approximately 15 cm below the soil surface. The amount of water in their fields then gradually increased due to precipitation, following which the huge pump was operated again. Farmers referred to this repeated up-and-down water management as the AWD of TD season.

Fig. 7. Drain Pump Fixed at the Full-dike
Huge drain pumps were operated during the rainy season to drain excess water from the dike into the primary canal.

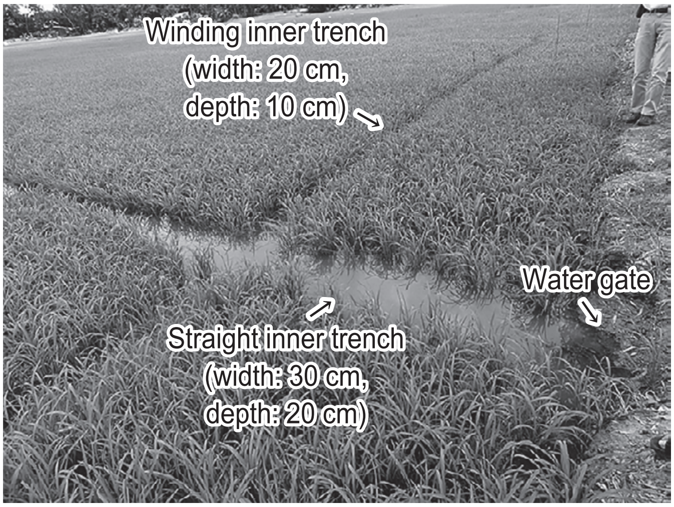

Fig. 8. Inner Trenches of a Paddy Field during the Rainy Season
This paddy field was connected to a secondary canal via the water gate. A straight trench extended to the opposite ridge of the field and a winding trench snaked through the entire field.

6. Discussion

6.1 *Differences between the Standardized and Practiced AWD*

In the previous sections, we described AWD adoption and practice at the Binh Hoa commune as a case study site and found that there are two major differences between the standardized and practiced AWD: the non-use of pani-pipes and practicing AWD during the rainy season.

6.1.1 *Non-use of Pani-pipes*

None of the surveyed households continued to use pani-pipes after the first year of adoption, with all household heads stating that they now decide on the timing of watering using their own observations. Most household members visited their fields every day to check on the plants, soil, and water conditions and were able to provide detailed information about their fields, as shown in Figure 2. However, different households used different cues for watering, including "small cracks on the soil surface" or "no footprint when entering the paddies."

Figure 9 shows the relationship between the size of the paddy field and maximum interval between watering events for the surveyed households. Larger paddy fields were watered at significantly shorter intervals, suggesting that farmers were more concerned about dryness in these fields. Although we did not receive any explanation for this, it is probably related to the fact that it is more difficult to make the surface of larger paddy fields flat and there are often unequal water manage-

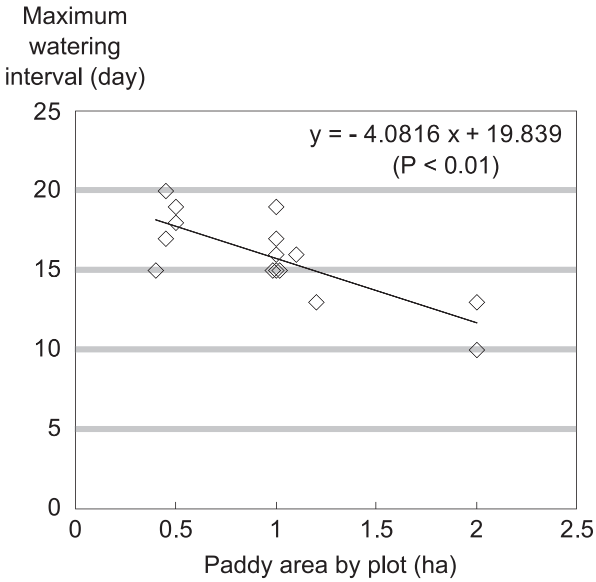

Fig. 9. Relationship between Paddy Field Area and Maximum Watering Interval
Source: Field investigation in 2014.

ment conditions, such as partial drying or wetting, leading to uneven rice growth and grain quality [Yamaji 1992]. Therefore, the surveyed households may water these larger fields more often to avoid partial drying during the dry season. Although IRRI recommends that a water depth of 15 cm below the soil surface is used as a signal for watering under safe-AWD [Humphreys *et al.* 2010], its instructions do not refer to the effects of surface flatness or field size, and it is unclear where farmers should set pani-pipes in large fields with relatively rough surfaces. Thus, in real-life situations, this criterion for watering should be varied according to the paddy field conditions (Figure 9), which may make direct observation of the conditions more reliable than the use of pani-pipes.

6.1.2 *Practicing AWD during the Rainy Season*

At the study site, paddy fields were irrigated during the dry season using personal pumps; therefore, a reduction in their use would reduce costs, leading to direct benefits for farmers, particularly in pump-hiring households. Conversely, it is necessary to drain excess water from the paddy fields during the rainy season; therefore, AWD, which was developed as a water-saving technology, should in theory be useless. However, household heads mentioned that they practiced AWD during the rainy season to improve rice production and grain quality. Although we could not obtain detailed data regarding the effect of AWD on rice production, those surveyed claimed that AWD increased rice production by 10%-30% during both the dry and rainy seasons. A report from An Giang Province indicated that AWD reduces rice lodging, which increases the rice harvest by approximately 10% [Lampayan *et al.* 2015], suggesting that the farmers' impressions of production improvement are relatively accurate.

Lampayan *et al.* [2015] did not explain why AWD reduced rice lodging in An Giang Province, but we can deduce possible reasons based on "*Nakaboshi*." *Nakaboshi* is a traditional Japanese irrigation technique where farmers drain their paddy fields once during the rice farming season and has been used to alleviate the high oxidation potential and to eliminate root rot damage [Kubota 1990]. It has been reported that *Nakaboshi* can also improve rice lodging and increase rice production [Kubota 1990].

A large part of An Giang Province is covered by acid sulfate soils, including Chau Tanh District, where the study site was located [SDPPA 2011]. The Mekong Delta paddy fields are usually continuously flooded during the rainy season in the absence of pump drainage, which leads to more reductive conditions in the soil. Sulfates are naturally reduced to hydrogen sulfide under severe reductive conditions, which causes root rot [Kyuma 1997]. Pinnschmidt *et al.* [1995] reported that rice production in the Mekong Delta has been heavily impacted by root rot; therefore, the implementation of AWD may help to prevent these regional issues.

6.2 *Reinvention of AWD and Local Agriculture*

As shown in Table 3, only one household decided to adopt AWD solely based on the information provided in the workshops of IRRI and SDPPA. Most household heads emphasized the importance of information from both the workshops and neighbors and also mentioned that the adoption of AWD promoted an exchange of agrarian information between farmers (Table 5). This suggests that farmers are seeking appropriate operational forms of agrarian technologies that apply to the local conditions. Rogers [2007: 113] mentioned that "people who use an innovation shape it by giving it meaning as they learn by using the new idea," which leads to reinvention. AWD would also be reshaped through daily practicing and the exchange of information between farmers.

In regions where AWD uptake technology has been limited, IRRI has focused on disseminating the advantages of AWD, e.g., a decrease in methane emissions from paddy fields, and has attempted to spread the technology using the Clean Development Mechanism [Siopongco *et al.* 2013],[7)] and AWD has also been included in the standard Viet GAP technology [Rejesus *et al.* 2013]. Although

7) The Clean Development Mechanism (CDM) is a flexible process for reducing greenhouse gas (GHG) emissions, as defined in the Kyoto Protocol. Through the CDM, countries that are obliged to reduce GHG emissions under the Kyoto Protocol provide funds and technologies to emission reduction projects in countries without Kyoto obligations. The obliged countries obtain emission credits and the countries without obligations attain sustainable development.

these certification systems are valuable for spreading such pro-environmental technologies, they also require following a standardized procedure. However, agrarian technologies are usually dependent on local conditions [Suzuki 1998] and are prone to modification according to the natural and social surroundings. Our case study highlights this disparity between the standardized AWD procedure and the practiced agrarian technologies.

7. Conclusion

Although the number of households interviewed here was insufficient to fully understand AWD adoption and implement across An Giang Province, we gained a good understanding of farmers' recognition of AWD. We identified two differences between the standardized and practiced AWD: the non-use of pani-pipes and the application of AWD during the rainy season. The first difference reflected the farmers' adjustment of the AWD technology to suit their own conditions, such as paddy plot size, whereas the second reflected the soil characteristics and water conditions in the floodplain of the Mekong Delta. Thus, these reinventions allowed AWD to become a useful technology for local farmers.

The implementation of AWD in An Giang Province has been closely linked to dike conditions and the dike pumping system. However, these varied within the Province, for example, the huge pumps of the dike system were operated year round in a commune of Chau Phu District, controlling both irrigation and drainage; therefore, most farmers did not have personal pumps. Therefore, it is likely that the practiced form of AWD in this district would differ from that in Binh Hoa commune because of their different water management requirements.

The use of certification systems is a good approach for improving pro-environmental agrarian technology uptake, such as AWD [e.g. Siopongco *et al.* 2013]. However, their strict requirements make it difficult to adapt the technologies to on-site conditions. Therefore, if An Giang Province case was assumed to be a successful model of AWD uptake, further studies are required to assess the different forms of practiced AWD.

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