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Compatibility of Alternate Wetting and Drying Irrigation with Local Agriculture in An Giang Province, Mekong Delta, Vietnam

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Abstract In response to the tightening supplies and growing demands for water on a global scale, the International Rice Research Institute has attempted to diffuse a water-saving technology called alternate wetting and drying irrigation (AWD) for rice farming in Asian countries. This study assessed the compatibility of AWD with local agriculture, based on field surveys in An Giang Province (AG), which is located in the Mekong Delta of Vietnam. Interviews with the local government staff that is responsible for AWD diffusion in AG indicated that farmers who used AWD realized not only water-saving effects, but also improvements in rice yield and growth. For instance, rice farming in the Mekong Delta has always suffered from culm lodging due to the flood plain location; however, farmers realized decline of culm lodging through AWD, and hence these additional benefits will help to further diffuse AWD. Moreover, these interviews illuminate that AWD can be used in certain natural, agro-engineering, and social settings, because it's an irrigation technology that requires precise water level control. For instance, higher-lying paddy fields tend to dry up earlier due to higher levels of percolation and seepage, while lower-lying fields are difficult to drain; therefore, mid-lying fields are best suited to AWD. This study highlights the importance of compatibility between AWD and the local agriculture in the diffusion process based on qualitative surveys, which should be quantitatively verified with statistical data and satellite images on a wider scale.
Key words: Compatibility, Diffusion of innovation, Irrigation technology, Rice farming, Vietnam

Introduction

Under pressing water demands on a global scale, the agrarian sector is required to make efforts toward water-saving. In particular, irrigated paddies are flooded from transplanting (or seeding) to harvest, which results in substantial water use through evapo-transpiration and percolation. Therefore, the establishment of water-saving rice farming is an urgent issue.

The International Rice Research Institute (IRRI) has developed water-saving irrigation technology called alternate wetting and drying (AWD), through which farmers restrict flooded periods in their paddies except during the water-required stages of rooting and flowering (Bouman *et al*., 2007). If farmers were to conduct a strict AWD procedure, called safe AWD, in which paddy fields are watered up to 5 cm and then re-watered when the water level naturally declines to 10-15 cm below the soil surface, the total water usage could be reduced by 13-38%, compared with continuous flooding, without negative impact on yield (Lampayan *et al*., 2015).

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Although the IRRI has attempted to diffuse AWD in Asian countries (e.g., Lampayan *et al*., 2009; Kurschner *et al*., 2010), those results are not necessarily robust. For instance, in Bangladesh, voluntary diffusion was restricted by unstable water supply, insufficient extension experts to transfer the technology, and a disparity between the AWD logic and local farmers' perceptions about rice farming (Kurschner *et al*., 2010). Despite such negative trends of AWD diffusion, An Giang Province (AG), [1)] located in the Mekong Delta of Vietnam is a successful case in which the provincial adoption ratio reached 53% by area in the dry season of 2015 (SDPPAG, 2015). Understanding the adoption process of innovations can help to predict their adoption patterns and to know how to encourage their adoption (Oster and Thornton, 2012). Thus, we reported farmer's AWD adoption process in a previous paper (Yamaguchi *et al*., 2016); however, it was based on a small number of household practices from a commune, and thus, we could not generalize about AWD diffusion of AG. Hence, this study aims to analyze the AWD adoption process of AG on a wider scale.

In the theory of "Diffusion of Innovations," five important factors were cited in considering whether an innovation should be adopted: "*relative advantage* is the degree to which an innovation is perceived as better than the idea it supersedes... *compatibility* is the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters... *complexity* is the degree to which an innovation is perceived as difficult to understand and use... *trialability* is the degree to which an innovation may be experimented with on a limited basis... *observability* is the degree to which the results of an innovation are visible to others" (Rogers, 2003). Regarding AWD diffusion in AG, Diangkinay-Quicho (2013) compared rice production costs between AWD adopters and non-adopters, and discussed the relative advantage of AWD in an economy. Lampayan *et al*., (2015) mentioned that AWD had been well embedded in local agrarian policies in AG, and emphasized that government guidance would improve complexity, trialability, and observability of AWD. However, those studies lacked the perspective of compatibility between AWD and local agrarian situations, and thus, did not sufficiently explain the reason why AG's farmers have accepted AWD more steadily than other sites.

Therefore, we firstly assess compatibility between AWD and local farmers' demands on a district scale based on interview surveys. Rogers (2003) mentioned that "[p]eople who use an innovation shape it by giving it meaning as they learn by using the new idea." Similarly, although AWD was originally developed as a water-saving technology, farmers might experience benefits in addition to water-savings. An experimental field study in AG found that AWD improved rice yield compared with the continuous flooding irrigation (Ha *et al*. 2014); therefore, it is necessary to examine not only direct but also indirect effects of AWD to evaluate the technology from the farmers' point of view.

In addition, we assess compatible agrarian settings with AWD adoption in AG based on interview surveys. Atwell *et al*., (2009) mentioned that it must be compatible with existing production situations, such as local practices and technologies, in the introduction of new agrarian technologies. Although AG shows better results in AWD diffusion, there are disparities in the adoption ratio by communes (Fig. 3). The gaps in the AWD adoption ratio in AG should be related to the difference of agricultural settings in each commune; however, it is unclear what agricultural settings are necessary in the case of AG.

Study site and survey methodology

Rice farming in AG

AG is located at the flood plain of the Mekong Delta (Fig. 1). The monthly average temperature generally exceeds 25 °C throughout the year; the annual climate is clearly divided into wet and dry seasons (Fig. 2). Before the 1950s, rice farming was restricted by inundation in the wet season and poor irrigation in the dry season; therefore, floating rice farming during the wet season was dominant (Otsuka, 2014).

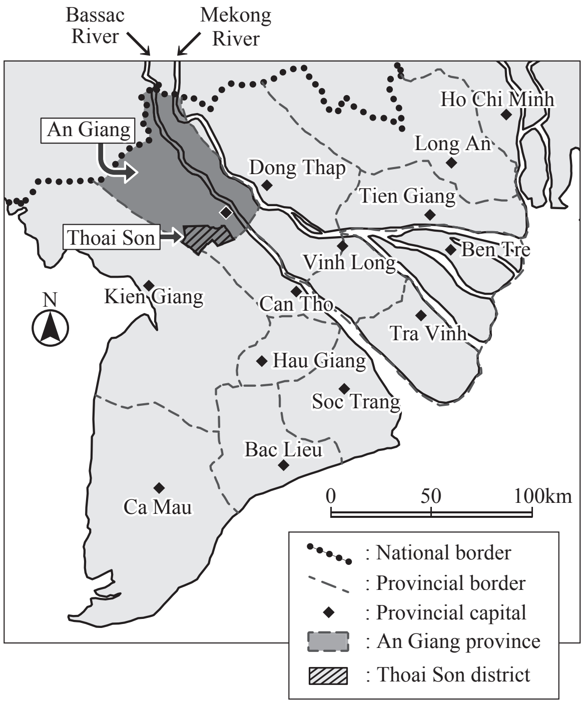

Fig. 1. Location of study site in the Mekong Delta.

Double rice cropping became possible by introducing fast-growing rice cultivars, irrigation pumps, and semi-dike systems from the end of the 1960s (Otsuka, 2014). The semi-dike system denotes the paddy area enclosed by the embankment, which can protect paddy fields from inundation except in the peak of the wet season (September-November). The adoption ratio of double-cropping in AG exceeded 90% by area at the beginning of the 1990s (Otsuka, 2014).

At the end of the 1990s, construction of full-dike systems started. The full-dike system comprises higher embankment than the semi-dike system and fixed drainage pumps in addition to irrigation pumps, which can protect paddy fields from inundation in all seasons, thereby making triple-cropping possible. The ratio of triple-cropping reached 68.5% by area in AG in 2013 (SOAG, 2014).

Dry-season farming generally runs from the end of December to the middle of April in AG, and thus, this season is called *lúa đông xuân* (winter-spring rice) in Vietnamese (Fig. 2). The 1st wet-season farming period (*lúa hè thu*: summer-autumn rice) occurs from May to August when precipitation and inundation are not

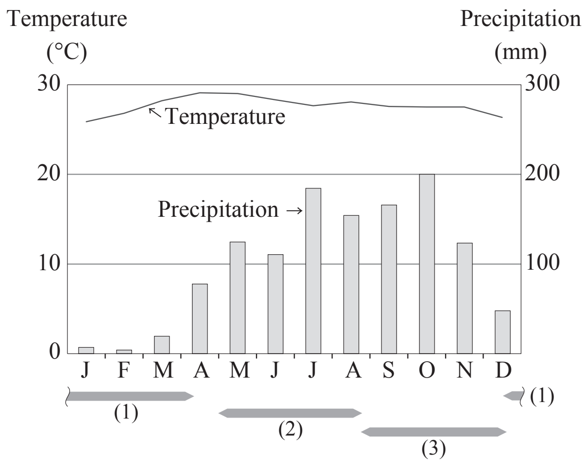

Fig. 2. Relation between annual climate and rice farming calendar in An Giang province.
Temperature and precipitation denote the average situation from 2009 to 2013.
(1): The rice farming at the dry season. (2): The 1st rice faming at the wet season. (3): The 2nd rice faming at the wet season.
[Source] The climate data is based on SOAG (2014). The farming calendar is based on the first survey in May 2015.

serious problems. The amount of precipitation increases and the water level of the Mekong River rises from September to the beginning of December, and the 2nd wet-season farming period (*lúa thu đông*: autumn-winter rice) occurs during this period. Among the three cropping seasons, the dry-season yield is highest (Table 1). Although triple-cropping has become popular in AG, this study mainly focuses on dry-season farming, because AWD was introduced as a water-saving technology.

Rice production in AG has been increasing by the introduction of triple-cropping; however, farmers' incomes have not increased adequately due to increased production costs (Truong *et al.*, 2013). Thus, in 2005, the local government officially introduced AWD with the cooperation of the IRRI in order to reduce pump irrigation costs. Since 2009, AWD has been regarded as the official water-saving technology in the 'One Must Do, Five Reductions' (1M5R) agrarian campaign, [2)] which helped AWD diffusion in AG (Lampayan *et al.*, 2015).

Field survey procedure

There are 11 districts among the AG. We focused on Thoai Son (TS) district, which is located in the southern part of AG (Fig. 1). TS has the second largest paddy area among the 11 districts; the area ratio of triple-cropping paddies has exceeded 90% (Table 1). However, the area ratio of AWD adoption in TS is lower than the average value of AG. Moreover, the communal AWD adoption ratio widely fluctuates in TS (Fig. 3).

The Sub-Department of Plant Protection in An Giang (SDPPAG) mainly administrates agrarian matters in AG. There are three levels of SDPPAG offices, namely, provincial, district, and communal. Communal SDPPAG staff live in the communes where they are in charge, and thus familiar with the agrarian conditions of their own commune. Those communal staff gathers agrarian statistical data and introduce new technologies for farmers in each commune. While 11 district offices administer the communal offices, a provincial office integrates all the SDPPAG offices in AG.

In May 2015, we first conducted unstructured-interviews with TS district office staff and communal staff from three selected communes (Dinh Thanh, Vinh Khanh, and Vinh Phu) in TS to obtain basic information of rice farming, such as agrarian calendar, fertilizing, and water management, including AWD in TS and selected communes. Based on the first survey, we conducted semi-structured-interviews with communal staff from all 17 communes in TS in September 2015 (second survey). We asked about the benefits of and restrictions to AWD for farmers using open-ended questions. We categorized their answers on benefits and restriction factors according to their meaning using after-coding analysis. Then we analyzed the compatibility between AWD and farmers' demands and the compatible agrarian settings with AWD adoption by local farmers.

It should be noted that because our interviewees

Table 1. Basic information of rice farming and AWD in An Giang province and Thoai Son district.

	Number of communes[a]	Paddy area (ha)[b]	Number of rice farmers (HH)[b]	Paddy area / rice farmers (ha/HH)[b]	Rice yield (t ha^{-1})[a]			Ratio of triple cropping (%)[a]	AWD adoption by area (%)[b]
					Dry	1st wet	2nd wet		
An Giang province	156	237,898	227,464	1.0	7.4	5.6	5.8	68.5	52.4
Thoai Son district	17	38,438	26,599	1.4	7.7	5.8	5.9	91.8	44.4

a: The values denote the situation of 2013. b: The values denote the situation in the dry season of 2015.
HH: Household.
Dry: The rice farming at the dry season. 1st wet: The 1st rice farming at the wet season. 2nd wet: the 2nd rice farming at the wet season.
[Source]
a: SOAG (2014). b: SDPPAG (2015).

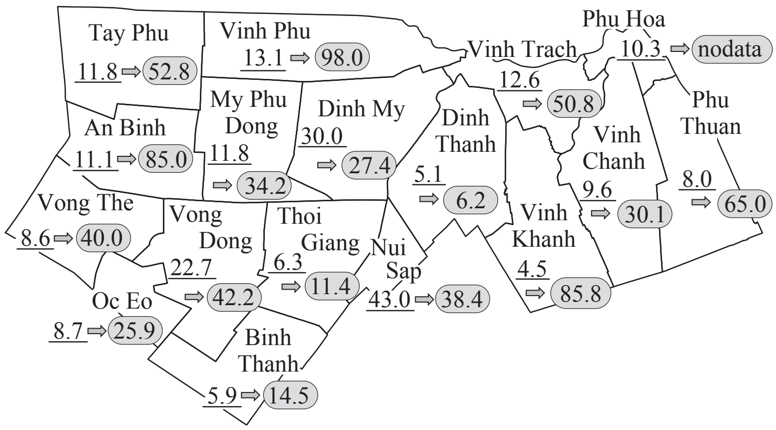

Fig. 3. Transition of AWD adoption ratio from 2010 to 2015 in Thoai Son district.
The numbers denote the communal AWD adoption ratio (%, by area) of the dry season farming. Underlined numbers are values in 2010, circled numbers are values in 2015.
[Source] SDPPAG (2015).

were local government officials their answers might be politically biased. To minimize any bias, we conducted group interviews wherein a few farmers were also in attendance. Additionally, we compared the SDPPAG staff answers to this survey with the views of local farmers collected in our previous studies (Yamaguchi *et al.*, 2016; Yokoyama *et al.*, 2016), and verified that the evaluations of AWD by both parties were in agreement.

Results and discussion

Water management and AWD practice (by the first survey)

There are 104 full-dike systems and 11 semi-dike systems in TS. The median area is 290 ha for the full-dike system and 58 ha for the semi-dike system. Each full-dike system is equipped with 1-10 fixed large-capacity pumps, which drain water from within the embankment during the 2nd wet season farming. Drainage pumps are not operated during the 1st wet season farming because the flood level is not serious, and thus, it can be protected only with embankment.

Among the 104 full-dike systems, most drainage pumps are managed by personal farmers or farmers' groups who installed them using their own finances, and those investors decide the amount of contribution of each farmer for drainage costs. There are four cases of the full-dike system in which drainage pumps are collectively managed by farmers via consensus. In both cases, farmers pay drainage pump costs of 75-100 US dollars (USD)/ha for 2nd wet season farming.

Dry-season farming is generally irrigated plot-wise individually using small-capacity pumps, and the irrigation cost varies according to ownership pattern: farmers that own pumps spend approximately 10 USD/ha/season on fuel costs, while farmers that borrow pumps bear additional rental fees. [3] The first survey also revealed that, in a small number of full-dike systems, farmers depend mostly on large-capacity pumps, even for irrigation, and each farmer pays approximately 50 USD/ha/season in this case.

Rice farming in TS has changed during the last decade owing to the implementation of the 1M5R campaign (SDPPAG, 2015). TS farmers generally utilize the cultivars improved by the IRRI or domestic research institutes. Farmers purchase rice seeds at agrarian stores or from neighboring farmers who are certified by the local government. Although the hand-broadcasting method has been adopted in TS, many farmers have begun to use drum seeders, as recommended by the 1M5R manual, to reduce the amount of sowing seeds required. Regarding fertilizer and pesticide, the 1M5R manual precisely indicates the proper timing and amount of application, and commune staff stated that most farmers largely followed the procedures. It takes approximately 100 days from sowing to harvesting. Although the manual recommends using combine harvesters to reduce post-harvest loss and harvest cost, there are only a few privately owned combine harvesters currently. Thus, farmers ask agrarian companies or wealthy farmers with combine harvesters to harvest their fields for a charge.

The 1M5R manual provides the detailed procedure for AWD, summarized as follows. [4] (1) Farmers should restrict flooding fields except during the rooting stage (10-20 days after seeding, DAS) and flowering stage (60-75 DAS). (2) The water level should be kept below 5 cm even during flooding periods. (3) When the water level

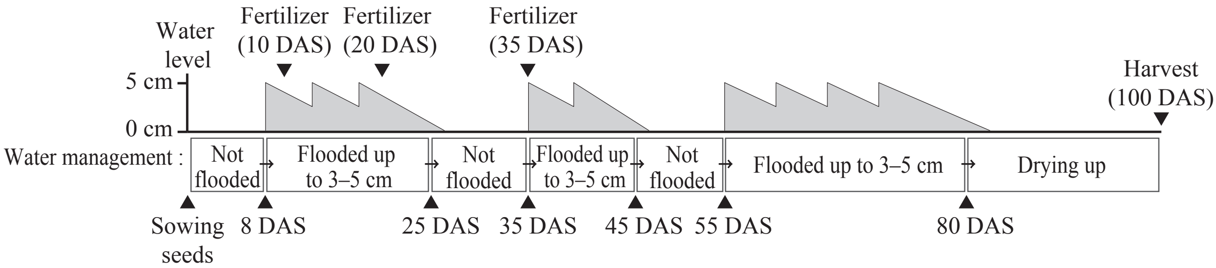

Fig. 4. Typical water management with AWD in Thoai Son disrict.
DAS: Days after seeding.
[Source] First survey in May 2015.

naturally declines to 15 cm below the soil surface, the next watering should be conducted. Finally, (4) farmers should install plastic pipes with many small holes on sidewalls of the paddy plot to track water levels below the soil surface. This procedure is almost the same as that of safe AWD (Lampayan *et al.*, 2015). In addition, the 1M5R manual advises about proper timing of fertilizing; it should be applied under flooded conditions.

Most farmers follow the AWD procedure of the 1M5R manual except that they do not use plastic pipes in dry-season farming. Although the detail of AWD practice varies by commune or household, the followings are typical practices according to the staff in dry-season farming.

Farmers adopting AWD sow seeds on the wet soil surface after soil paddling. Paddies are flooded from 7 DAS, and at the same time, the first fertilizer is applied (Fig. 4). Thereafter, until 20 DAS, paddies are kept in flooded condition with periodic watering. The second fertilizer is applied 20 DAS, when farmers halt periodic watering. In paddy plots that hardly drain naturally, farmers open outlets to drain water effectively. Most farmers do not pay detailed attention to the water level below the soil surface, and thus, they do not use plastic pipes. Farmers guess the proper watering timing based on surface conditions (e.g., they water paddies if the soil surface is slightly cracked, like a bird's footprints). Generally, the period from 20 DAS to 35 DAS is non-flooded. At 35 DAS, paddy plots are flooded for 10 days in order to apply the third fertilizer. Farmers again halt periodic watering at 45 DAS, and the soil surface is exposed to non-irrigated conditions for approximately 10 days. At 55 DAS, farmers resume periodic watering because of the flowering stage, and the flooded condition is kept until 80 DAS, after which farmers begin to dry up their paddies for harvesting.

AWD's benefits for farmers (by the second survey)

We asked 17 communal staff members what benefits farmers reaped by practicing AWD. Although AWD was originally introduced as a water-saving technology, other benefits were also mentioned. Thus, we sorted these additional benefits based on plant physiology and agrarian management.

Benefits of water-saving

Out of 17 staff members, 16 mentioned that AWD decreases irrigation costs (Table 2). [5] According to communal staff, farmers irrigated their paddies 10-12 times in dry-season farming before AWD adoption, whereas 7-9 times after. While the number of watering times reduced, water amount for each irrigation operation increased, and thus, it was difficult to calculate the actual value of irrigation cost reduction. However, we found from our previous household survey that most farmers also realized that AWD saved irrigation costs (Yokoyama *et al.*, 2016), and Truong *et al.* (2013) reported that AWD reduced irrigation costs by 10% in AG.

Benefits of plant physiology

Fourteen communal staff members mentioned "decreasing rice lodging" (Table 2). Previously in the Mekong Delta, wet season farming was dominant, and thus farmers adopted tall rice cultivars that could withstand the inundation (Catling, 1997); however, tall cultivars are prone to culm lodging (Xuan *et al.*, 1981). Although dwarf cultivars introduced during the late 1960s largely alleviated the problem, even these cultivars occasionally suffered from lodging (Lang *et al.*, 2008). Communal staff members also stated that culm lodging continued to be a problem for TS farmers during all seasons. Rice plants became healthier with thick culms after the introduction of AWD, and thus, lodging declined significantly. AG farmers in our previous study (Yokoyama *et al.* 2016) also reported a reduction in culm lodging.

Ten communal staff members mentioned that AWD introduction enhanced rice plant health, which alleviated several diseases and insect damage (Table

Table 2. Benefits of AWD for farmers according to communal SDPPAG staff members.

Items of benefit	Number of answers (/17)
Decreasing irrigation cost	16
Decreasing rice lodging	14
Decreasing harvesting cost	11
Decreasing disease and insect damage	10
Increasing rice yield	7
Increasing selling price	5
Promoting root spread	4
Decreasing poor grain filling	4

[Source] Second survey in September 2015.

2). Some also mentioned "promoting root spread" and "decreasing poor grain filling" (Table 2). According to comments by the communal staff members, the vigor of rice plants in paddies in which AWD was practiced was significantly apparent to farmers, and thus, some farmers who first observed the paddy with AWD practices of other farmers immediately decided to adopt AWD even without joining SDPPAG workshops.

Culm lodging often causes insufficient growth and harvest loss (Ebata and Yamada, 1977), and therefore, decreasing culm lodging leads to "increasing rice yield" answered by seven staff members. Of the seven communal staff members, six answered that the amount of rice yield had improved significantly after the adoption of AWD in the dry season farming, although the amount varied widely. A staff member of the Vong The commune mentioned that rice yields increased more than 30% after AWD adoption, while staff members from Vinh Phu and Phu Thuan communes reported limited effects on increasing the rice yields. A previous study reported that rice yield increased by approximately 6-15% with the use of AWD during dry-season farming in AG (Ha *et al.*, 2014).

Benefits of agrarian management

AWD improves rice growing, as mentioned above, which also has indirect positive effects on agrarian management. Eleven communal staff members mentioned that "decreasing harvesting cost" (Table 2) is a significant benefit for farmers. Introduction of combine harvesters has progressed owing to the 1M5R campaign, so that farmers are required to raise lodged rice before the operation of combine harvesters in their paddies. Moreover, if rice culms did not dry well due to lodging, they often become entwined around cutter blades of the harvesters, and therefore, famers need to reap them by hand. Therefore, the AWD effect of decreasing culm lodging resulted in decreasing harvesting costs. In addition, heavy combine harvesters often cannot enter wet paddies due to quagmire conditions even in the dry season. Although farmers begin to drain paddy water 20 days before harvest and dry their paddies, the soil remains too wet for combine harvesters to enter some paddies even during the dry season. AWD improves the quagmire problem in harvesting through multiple drainage.

Five communal staff members referred to "increasing selling price" (Table 2). Vietnam is one of the biggest rice exporters in the world; Vietnamese rice has been downgraded and its price kept in check compared with the prices of other countries (Ozawa, 2004). In our study, communal staff members mentioned that farmers' selling prices to intermediaries had been depressed due to poor grain filling. However, AWD improved grain filling conditions as answered by some (Table 2), leading to increased selling prices by farmers. In our previous survey (Yamaguchi *et al.*, 2016), farmers also reported that AWD increased the selling price of rice, supporting the validity of the statement from communal staff.

Factors restricting adoption of AWD (by the second survey)

In AG, AWD would have attracted local farmers due to the abovementioned benefits; however, there are many differences in the AWD adoption ratio among TS communes (Fig. 3). For instance, while the adoption ratio of Vinh Phu reached 98%, the adoption ratio of Dinh Thanh remained lower than 10%. We asked about the restriction factors on AWD adoption during the second survey, and summarized the answers by after-coding (Table 3). Although these restrictive factors are complexly related to actual rice farming, for descriptive purposes, we classified them into three categories, namely, natural settings, agro-engineering settings, and social settings.

Restrictive factors in natural settings

Five communal staff members mentioned "elevation of paddy plots" (Table 3). According to them, although elevation difference within a full-dike system was approximately 2 m at most, such difference caused a significant difference in water management. If paddy plots were located at a relatively higher elevation, such plots tended to have higher percolation and seepage rates than lower-lying paddy plots, which caused paddies to dry up easily. Moreover, in the middle of the dry season, small canals located at higher elevation are

Table 3. Restrictive factors in farmers' AWD adoption according to communal SDPPAG staff members.

Items of restriction factors	Number of answers (/17)
Elevation of paddy plots	5
Density and quality of water canals	5
Amount of precipitation	4
Pump ownership status	4
Surface leveling	3
Farmer's understanding of AWD	2
Contracted paddy cultivation	2
Synchronizing water management with neighboring plots	1

[Source] Second survey in September 2015.

easier to dry up than lower-lying ones owing to lack of proper maintenance, and thus, to avoid drought damage, farmers do not want to adopt AWD in higher-lying paddies. On the other hand, it is difficult to drain water naturally in lower-lying paddies, even during the dry season, which also prevents farmers adopting AWD.

Four communal staff members mentioned "amount of precipitation" (Table 3). The amount of precipitation exhibits little spatial variation in AG; however, it fluctuates yearly. For example, annual precipitation was 966 mm in 2009 and 1,739 mm in 2010 (SOAG, 2014). Although dry-season farming depends on canal irrigation, the canal water levels tend to decline earlier during years with less precipitation. Thus, for fear of drought damage, some farmers want to maintain high water levels in their paddies and will not adopt AWD.

Restrictive factors in agro-engineering settings

Five communal staff members mentioned "density and quality of water canals" (Table 3). In communes in which canal construction is not well developed, some paddies have to depend on plot-to-plot irrigation. In such paddies, farmers cannot control irrigation schedules by their own decisions, and thus, they do not adopt AWD. In addition, in the case of canal depth being partly unequal within the canal system, shallower canals tend to become dry earlier in the mid-dry season. In paddies irrigated with such shallow canals, farmers do not want to adopt AWD in order to avoid drought.

Four communal staff members referred to "pump ownership status" (Table 3). Not all farmers own irrigation pumps and many lease them on demand. If the number of pump borrowers exceeds the number of rental pumps substantially, it would be difficult for borrowers to control irrigation timing under AWD. Furthermore, farmers from the 10 full-dike systems collectively irrigate their paddies with large-capacity pumps, in which the watering schedule is dependent on the dike scale there, and thus, each individual farmer cannot control the water level under AWD based on each paddy condition.

Three communal staff members mentioned "surface leveling" (Table 3). Unleveled paddy surface within a paddy plot causes the variation in rice growth and development (Shoji *et al.*, 2005). Rice paddies originally were designed to have level surfaces in order to accumulate water; however, shallow water management of AWD requires more level surface conditions without harmful effects on rice production. Therefore, farmers tend not to adopt AWD in unleveled paddy plots. SDPPAG recommends laser-leveling technology in the 1M5R manual (SDPPAG, 2011); however, according to the provincial SDPPAG staff, the total area where the laser-leveling was finished from 2006 to 2014 was less than 1% of total paddies in AG.

Restrictive factors in social settings

Two communal staff members mentioned "farmers' understanding of AWD" (Table 3). AWD is a knowledge-intensive technology that does not require particular instruments; instead, farmers need to understand its logical background properly (e.g., Kurschner *et al.*, 2010). The SDPPAG has provided seasonal workshop on new technologies, including AWD, on a communal basis; however, communal staff members mentioned that some farmers persistently disapprove AWD. Based on an extensive survey in 2009 (Truong *et al.*, 2013), 7% of interviewed farmers answered that "it is always better for the plants to have more water," suggesting disparity between the AWD logic and local farmers' experiences.

Two communal staff members mentioned "contracted paddy cultivation" (Table 3). Some paddy owners live in areas located far from their paddies, and the owners seldom visit their paddies and contract cultivation of their fields out to other farmers who live nearby. In other cases, paddies are leased to people who live outside of the commune in which paddies are located; in general, such leased paddies are also cultivated by farmers who live nearby the fields under a sub-contract.[6] It is difficult to practice AWD under contract cultivation, because absentee landowners or borrowers generally do not provide detailed instructions to the contract farmers. Moreover, it is difficult for communal staff to transmit new technologies to land owners and borrowers who live far from the paddy locations.

Only one communal staff members mentioned "synchronizing water management with neighboring plot" (Table 3). When farmers attempt to practice AWD in their paddy plots, if neighboring paddies are flooded continuously, drainage often fails owing to lateral seepage from these neighboring paddies.

Compatibility between AWD and local agrarian situations

Compatibility between AWD and farmers' demands

Before the 1960s in the Mekong Delta, rice farming was restricted due to large-scale flooding in the rainy season and poor irrigation in the dry season. The latter problem was improved by the introduction of pump irrigation, enabling dry-season farming to be the main component of rice production of AG (Otsuka, 2014). Pump irrigation was widely diffused among AG farmers in the 1990s, and this would establish the basic agro-engineering setting for AWD diffusion. On the other hand, irrigation costs depressed farmers' incomes (Truong *et al*., 2013), and AWD would become well accepted by farmers in order to save irrigation costs.

In addition to save irrigation cost, AWD may improve culm lodging, insect resistance, disease tolerance, rice yield, and grain filling, at least according to the SDPPAG staff's observation, while many of the field experiments in the Philippines (Lampayan *et al*., 2015) and China (Belder *et al*., 2004) have reported that AWD did not have significant positive effects on rice yield and growth.[7)] Moreover, it was reported that excessive nitrogen fertilization should cause more culm lodging in the Mekong Delta (Xuan *et al*., 1981); proper fertilization methods have been promoted concurrently with AWD under the campaign of 1M5R. Therefore, it might be difficult to conclude that the improvement of rice yield and growth as above mentioned is only the result of AWD. However, in our previous survey in AG (Yamaguchi *et al*., 2016; Yokoyama *et al*., 2016), households mentioned common improvement effects of AWD with the items of Table 2. Additionally, a diffusion project in the flood plains of Bangladesh (Kurschner *et al*., 2010) reported that AWD improved culm loding, disease tolerance, and rice yield. Therefore, it is possible that AWD has positive effects on rice yield and growth in the flood plain condition.

No studies properly explain why AWD improved rice yield and growth in the flood plain areas. However, the case of a Japanese rice irrigation technique called *nakaboshi* might provide a relevant reference. *Nakaboshi* denotes mid-season drainage for approximately 10 days during the late tillering stage. Both *nakaboshi* and AWD are categorized as intermittently flooded irrigation methods by the Intergovernmental Panel on Climate Change (IPCC), although their aeration times are categorized as single and multiple respectively (IPCC, 2006). *Nakasboshi* restricts the generation of non-effective tillers and alleviates the high reduction potential in the soil of wet paddies, which produces the effects of decreasing culm lodging, promoting root spread, and increasing grain filling (Kubota, 1990). These effects are similar to the benefits of AWD's in terms of plant physiology (Table 2).

AG has a number of wet paddies in which the soil is highly reductive due to the flood plain location. The field survey on farming practice revealed that rice production in the Mekong Delta has been impacted heavily by root rot and culm lodging (Pinnschmidt *et al*., 1995). Under such situations, AWD improves the reductive conditions by soil aeration in the same way as *nakaboshi* does, which might lead to promoting root spread and decreasing culm lodging. Although AWD's positive effects on rice yield and growth should be tested by rigid field experiments, these positive effects coincide well with local agrarian issues, which would be the basis for favorable diffusion of AWD in AG.

Compatible agrarian settings for AWD adoption

The original concept of compatibility in diffusion studies questioned the compatibility of innovations with the adopter's sense of values, past experiences, and demands (Rogers, 2003). However, with regard to adoption of agrarian technologies, there were debates on compatibility between a new technology and environmental conditions (e.g., Hayami, 1974), and between a new technology and currently adopted practices and technologies by farmers (Atwell *et al*., 2009). In other words, adoption of agrarian technologies needs to be discussed with due consideration of local agrarian systems, including their natural and social settings. Therefore, it is natural that AWD adoption is restricted by natural settings, agro-engineering settings, and social settings.

Although we categorized the restriction factors into three categories for descriptive purposes, each factor was related to each other. For instance, we categorized "density and quality of water canal" into restriction factors of agro-engineering. However, whether canal density is sufficient depends on topographic conditions; sloped areas tend to have smaller paddy plots than relatively level areas, and thus, require more detailed canal networks. Moreover, communal staff members stated that some farmers disapproved of AWD ("farmer's understanding of AWD" in Table 3). For them, continuous flooding was a more rational choice than AWD to reduce the risk of drought, especially in fields at higher elevations. During the decision-making process regarding whether to adopt AWD, farmers valued communication with neighbors as much as government guidance (Yamaguchi *et al*., 2016). In particular, they judged the efficacy of AWD based on the experiences of their peers in similar conditions. Therefore, we should accurately understand the whole agrarian system of local communities, and then consider solutions to the restriction factors of AWD.

In addition, we should note that the restrictive factors of AWD are similar to those of *nakaboshi*. In an extensive survey on Japanese rice farming in 1966 (SSDEABMAF, 1967), the adoption ratio of *nakaboshi* reached 63% by area, except for Hokkaido. This survey listed the reasons that farmers did not adopt *nakaboshi* as follows: paddies with defective irrigation systems (31%); paddies with poor drainage (22%); they considered it unnecessary (13%); defect in irrigation practice (10%); water-leaking paddies (7%); and labor shortage (6%). Although this report didn't explain how practice of *nakaboshi* was restricted, the listed items are similar to the restrictive factors of AWD (Table 3).

The adoption ratio of *nakaboshi* was expected to reach more than 80% on a national scale based on an extensive household survey in 2015 (CEGEFS, 2016: 24). The precedent case showing how the restriction factors of *nakaboshi* have been eliminated in Japanese rice farming should become a good reference for AWD diffusion.

The word *nakaboshi* began to appear in historical agrarian books in the latter half of the Edo period (~1750 AD), and has since been practiced by farmers. An important issue that is emphasized in the diffusion process of *nakaboshi* is the trade-off between its merits and drought risk (Tanaka, 1969). For example, in the Aichi Prefecture (ECRFA, 1991), although farmers have practiced *nakaboshi* under well-irrigated conditions, when the paddies might experience a water shortage, farmers retain deep water to reserve enough water for flowering, rejecting *nakaboshi*. Moreover, practicing *nakaboshi* occasionally exacerbates weed problems in paddies (Nagata, 1964) and might also be harmful in paddies that receive less fertilization (Tanaka, 1969). After the 1950s, such incompatible conditions were gradually solved through construction of irrigation infrastructure and the introduction of improved agricultural materials, such as herbicides and fertilizers. Consequently, *nakaboshi* diffused widely throughout Japan (Horikawa *et al*., 2011).

Similar to the historical changes during the adoption of *nakaboshi* in Japan, this study illustrated that AWD is also associated with drought risk, especially in paddies at high elevations and during years with low precipitation. Therefore, although AWD has been developed as a water saving technology, its feasibility should be assessed while considering field water conditions. Additionally, although AWD is recognized as a knowledge intensive technology and no specific equipment is needed (Kurschner *et al*., 2010), this study revealed that AWD requires preconditions, such as well-leveled paddies or a well-maintained canal network in the diffusion process. Therefore, further research in needed to clarify the requirements for AWD diffusion.

Conclusion

Based on interviews with the communal SDP-PAG staff in TS, we illustrated the adoption and actual practices of AWD in TS (Fig. 4), verified compatibility between AWD efficacies and farmers' demands (Table 2), and examined compatible agrarian settings for AWD adoption (Table 3).

Diangkinay-Quicho (2013) showed the relative advantage of AWD's water-savings effects in an economy, and insisted on its importance in AWD diffusion in AG. Certainly, water-savings are an essential aspect of efficacy for farmers in TS, but other efficacies are also important, such as decreasing lodging, diseases, and insect damage, which facilitated successful AWD diffusion in AG.

Communal staff members mentioned that the difficulty of understanding AWD is one of the restrictive factors in AWD adoption, thereby supporting the recommendation by Lampayan *et al*., (2015) that local government guidance would alleviate the complexity of AWD. However, there are other restrictive factors in AWD adoption, such as natural or agro-engineering settings, that need to be solved for the sake of further diffusion.

This study highlights the importance of compatibility between AWD and the local agriculture in the diffusion process based on a qualitative survey in TS, which should be quantitatively verified with statistical data and satellite images on a wider scale. Furthermore, this study showed the similarities between AWD and *nakaboshi* in their adoption processes, and therefore, comparable studies on similar irrigation technologies to AWD, such as *nakaboshi*, (e.g., Horikawa *et al*., 2011) should be utilized for AWD diffusion.

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Footnote

1) Vietnam is generally subdivided into three administrative levels: province (*tỉnh*); district (*huyện*); and commune (*xã*, *thị trấn*, and *phường*),
2) The 1M5R agrarian campaign promotes the use of certified seeds by official institutions among rice farmers and the reduction of seed quantity, fertilizer, pesticide, irrigation water, and post-harvest loss (Truong *et al*., 2013).
3) During dry-season farming in AG, pump-borrowing households are required to pay approximately five times the irrigation cost of pump-owning households (Yamaguchi *et al*. 2016).
4) Although the goal of the 1M5R campaign is to improve rice farming during all three seasons, saving water is emphasized primarily during dry-season farming, and thus the AWD process mainly focuses on dry-season farming.
5) Only one staff member did not state "decreasing irrigation cost," because the practice of AWD had not diffused throughout his commune (6.2% by area) (SDPPAG, 2015).
6) The contracts generally were not based on lending and borrowing land, and thus, were different from tenant farming.
7) A reason for AWD exhibiting positive effects on rice yield and growth in AG might be related to the distribution of acid sulfate soil (Yamaguchi *et al*. 2016). However, case studies from the Philippines, China, and AG have several differences in agrarian factors, such as climate, cultivar use, and fertilizer management; thus, it is difficult to directly compare them.

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