CLIMATE CHANGE PROJECT (JIRCAS-CTU)

WORKSHOP

POLICY SUGGESTIONS CORRESPONDING TO TECHNOLOGY FOR THE MITIGATION OF GREENHOUSE GAS EMISSIONS FROM RICE CULTIVATION IN THE MEKONG DELTA, VIETNAM

An Giang, February 28, 2019

PROPOSAL FOR DISSEMINATING WATER-SAVING TECHNOLOGY IN PADDY FIELDS

1. INTRODUCTION

An international framework regarding climate change, the Paris Agreement, was set up in December 2015 and came into effect in November 2016, to be ratified by more than 120 countries including Vietnam and Japan. The agreement states that the increase in average global atmospheric temperatures shall be kept to less than 2 °C from pre-industrial times. In the Intended Nationally Determined Contribution (INDC), Vietnam expressed the commitment to reduce greenhouse gas (GHG) emissions from agriculture through the sustainable development of agriculture. While GHG emissions from paddy farming (44.6 million ton CO_2) accounts for approximately 18% of the emissions in Vietnam (246.8 million ton CO_2), paddy fields are expected to play important roles in reducing GHG.

The International Rice Research Institute (IRRI) and Ministry of Agriculture and Rural Development in Vietnam (MARD) have been implementing a water-saving procedure, namely the alternate drying and wetting (AWD) method. The AWD method is thought to reduce methane gas (CH_4) emissions from paddy fields because it changes the surface conditions of the paddy field from reducing conditions to oxidizing conditions by frequent contact with the air.

This report introduces the results of 5 years of accumulated data of CH_4 emissions and rice yields from paddy fields in An Giang Province in the Mekong Delta and discusses further implementation of AWD in the region based on the estimated positive effects of the AWD method.

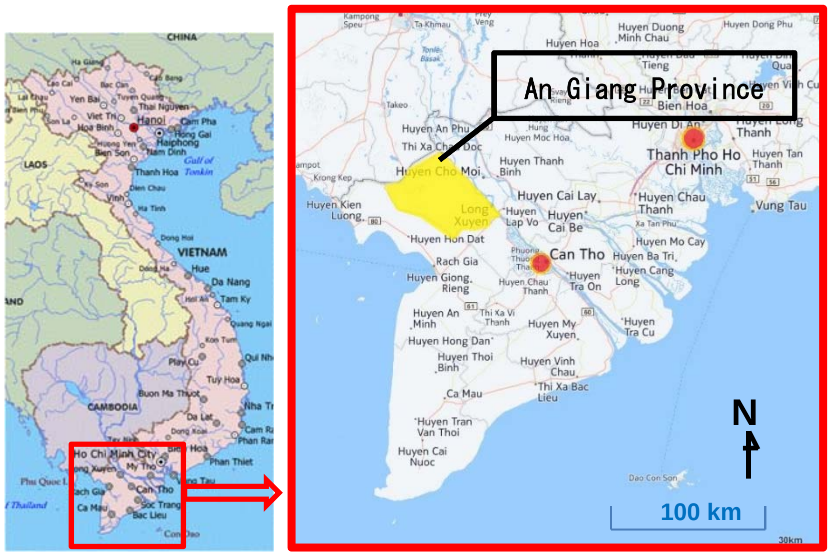


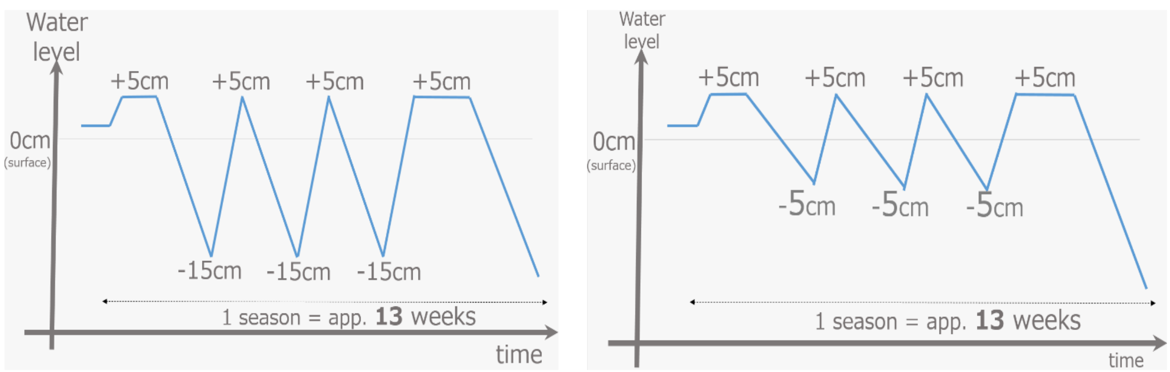
Fig. 1 Location

2 AWD AND FAWD

As the names suggest, AWD (alternate wetting and drying) and FAWD (farmers' AWD) are irrigation methods of water management that alternate wetting and drying. The drying period varies from one day to more than 10 days, depending on several factors, such as soil type, weather, and growth stage. In AWD, the following two water management procedures are performed and repeated during the after-flowering, grain filling, and ripening stages:

- When the water level reaches −15 cm from the surface, irrigation water is used to refill the paddy fields until the water level reaches 5 cm from the surface.
- Once the water is filled to 5 cm, the irrigation is stopped until the water level drops to −15 cm.

A practical way to implement AWD is to manage the water level by using a 'field water tube', which monitors the surface water/groundwater level on/in the paddy fields.



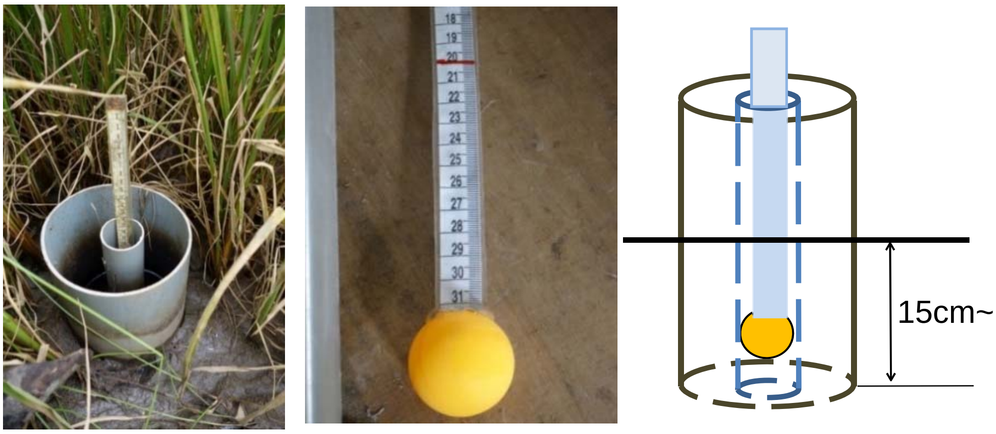


Fig. 2 Field water tube

For FAWD, the main object of this study, the water level was managed roughly—5 cm to −10 cm instead of −15 cm—to simplify the operation. When the lowest water level is set shallower, the operation becomes easier for farmers because they can roughly know the present water level by visual judgment or by touching their feet on the surface of the paddy field, even if they do not like performing complicated water level measurements by field water tubes.

This study compared GHG emissions and rice yields for each type of water management. In the first two years from the spring-summer 2013 crop to the winter-spring 2015 crop, AWD, FAWD, and the continuous flooding method (CF) were compared. In the following three years from the spring-summer 2015 crop to the winter-spring 2018 crop, the effects of FAWD were studied by comparing FAWD and CF with additional experimental sites.

3 OUTLINE OF THE STUDY

3.1 Location and brief description

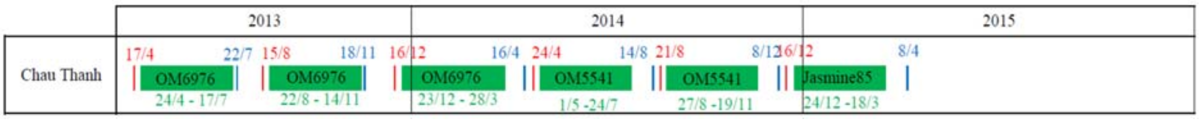
Six experimental sites were set up as shown in the following map. A brief description of each cropping season is explained in (1)–(3).

Fig. 3 Monitoring location

(1) Six cropping seasons from the spring-summer 2013 crop to the winter-spring 2015 crop

An experimental site with three types of water management (CF, FAWD, and AWD) was established in the Binh Hoa village of Chau Thanh District to monitor GHG emissions and yields. The sowing dates, GHG sampling periods, yield survey dates, and varieties are shown in Table 1.

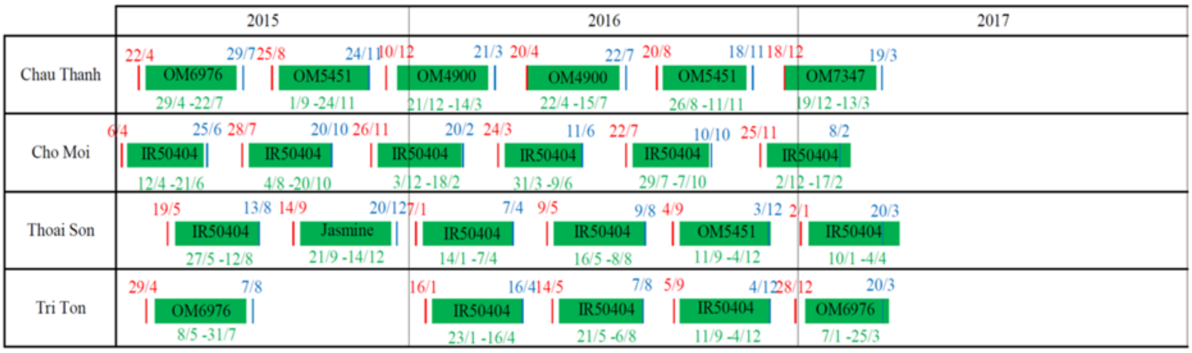
Table 1 Rice crop schedule and GHG sampling in Chau Thanh district during 2013–2015



(2) Four experimental sites with two types of water management (CF and FAWD) for six cropping seasons from the spring-summer 2015 crop to the winter-sprint 2017 crop, were established in four districts in An Giang Province (Chau Thanh, Cho Moi, Thoai Son, and Tri Ton District) to monitor GHG emissions and crop yields. The sowing dates, GHG sampling periods, yield survey dates, and varieties are shown in Table 2.

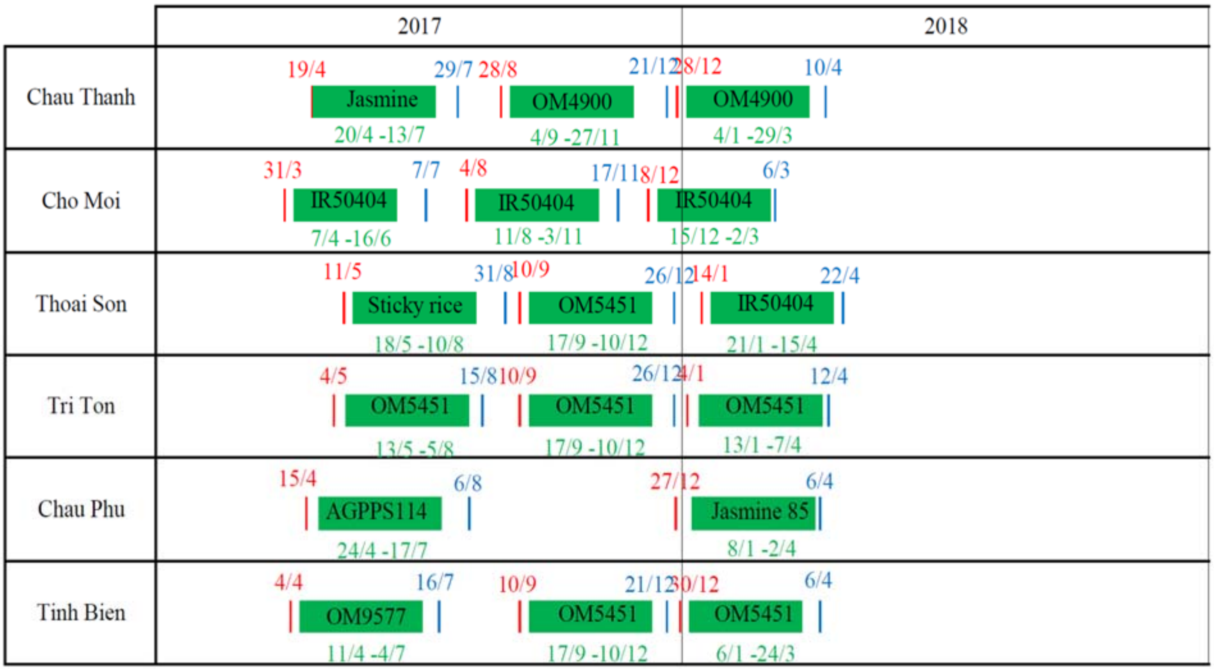
Table 2 Rice crop schedule and GHG sampling in Chau Thanh, Cho Moi, Thoai

Son, and Tri Ton during 2015–2017



(3) Six experimental sites with two types of water management (CF and FAWD) for three cropping seasons from the spring-summer 2017 crop to the winter-spring 2018 crop, were established in six districts in An Giang Province (Chau Thanh, Cho Moi, Thoai Son, Tri Ton, Chau Phu, and Tinh Bien District) to monitor GHG emissions and rice yields. The sowing dates, GHG sampling periods, yield survey dates, and varieties are shown in Table 3.

Table 3 Rice crop schedule and GHG sampling in Chau Thanh, Cho Moi, Thoai Son, Tri Ton, Chau Phu, and Tinh Bien district during 2017–2018



3.2 Method of the survey

3.2.1 GHG Sampling method

Air was sampled once a week from day 7 after sowing at three sampling points in each site by the closing chamber method. Because one cropping season has approximately 13 weeks, the sampling was repeated 13 times at each sampling point.

Two air samples were taken, at the 3rd minute and at the 23rd minute after the chamber was closed at each point. The date and time of sampling, and air temperature were recorded at those times. The sampling and recording were implemented with the support of farmers and local officers.

Fig. 4 Gas sampling method

2.2.2 Measurement of water level

Water level was measured from the sowing day to the harvesting day with field water tubes at three points per experimental site.

Fig. 5 Measurement of water level

3.2.3 Measurement of yield

Three rice samples from 1 m^2 of the sampling area were taken for each type of water management treatment at each experimental site. The rice weight with 14% water content was calculated after wind-drying after the fresh water selection.

Fig. 6 Harvesting rice

2.2.4 GHG concentration analysis

The gas chromatograph (Shimadzu, Kyoto, Japan) installed at the JIRCAS office was used to analyze the concentrations of CH_4 and N_2O in the air samples.

Fig. 7 Gas chromatography (Shimadzu, Kyoto, Japan)

2.2.5 GHG emission calculation

Assuming a stable emission speed throughout the interval between two sampling times (3rd minute and 23rd minute), GHG emission flux was calculated according to the formula below:

$$m_{GHG,t} = \frac{M_c}{22.4} \times \frac{V_{height}}{100} \times S_t \times 3600 \times \frac{273}{273 + T_t}$$

Here, m_{GHG} = emission flux of GHG ($mg/m^2/h$); M_c = molecular weight of carbon (12 g/mol); 22.4 = molar volume; V_{height} = effective height of chamber (cm); S_t = approximate change of GHG concentration at time t (ppm/s); T_t = temperature in chamber at time t (°C).

4 RESULTS

4.1 Difference in water levels between CF plot and FAWD plot

The water level was managed by farmers and clearly differentiated in most of experimental sites. The average drying period, average number of drying periods, average water level, and average standard deviation from the spring-summer 2015 season to the winter-spring 2018 season are shown in Table 4 (Appendix).

Fig. 8 Number of days of water level below 0 cm in a season

The water management was performed properly in the FAWD and CF cases. The water management using the FAWD method exhibited a higher number of days of water below 0 cm (22.8–42 days) and number of drying periods (5.7–7.8 times), but lower water levels (−2.6 to 2.1 cm) than those of the CF method (2.5–11.8 days, 1.3–3.8 times, and 3.3–6.7 cm, respectively). There was no difference in the number of days of water below 0 cm, number of drying periods, or water levels among the three seasons.

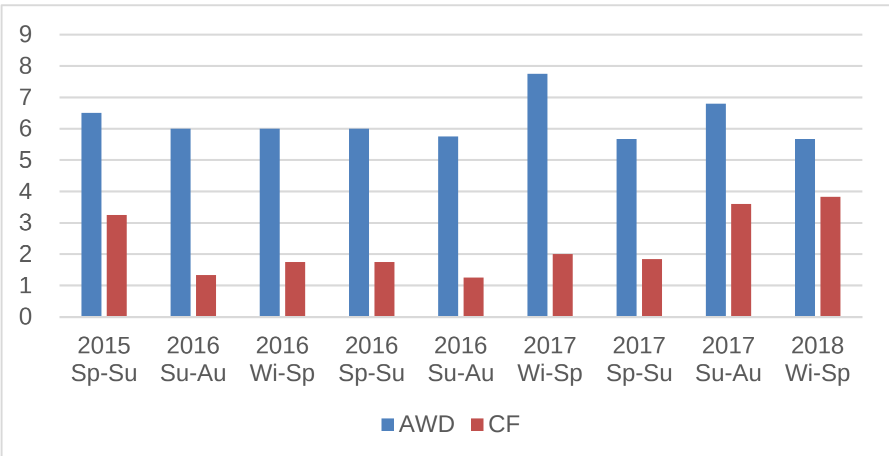


Fig. 10 Number of drying periods in a season

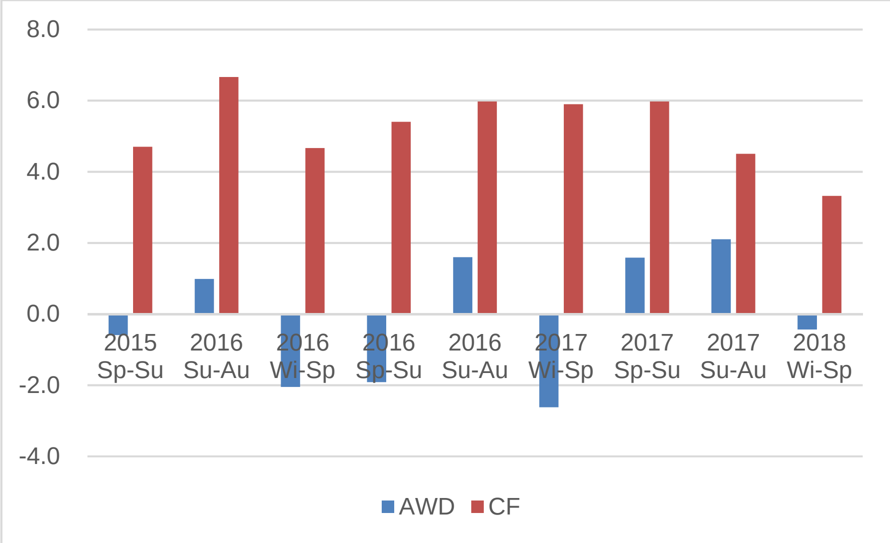


Fig. 11 Average water level in a season

4.2 AWD and FAWD

CH_4 emissions and crop yields were compared among AWD, FAWD, and CF from the spring-summer 2013 season to the winter-spring 2015 season. The result shows that CH_4 emissions from AWD fields were less than those from FAWD fields, and crop yields of AWD fields increased more than those of FAWD fields in most cases. For AWD, the water levels were controlled at −15 cm from the soil surface. There are less CH_4 emissions under aerobic soil conditions and more under anaerobic conditions in which the soil is saturated by water or stagnant; hence, more CH_4 emissions are evident in CF than in FAWD or AWD. The yield exhibited the opposite behavior, with higher yields in AWD and FAWD than in CF.

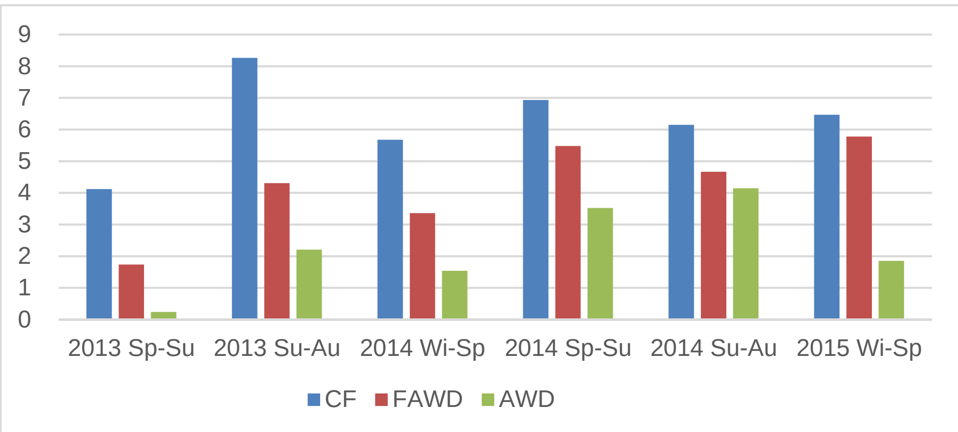


Fig. 12 CH_4 emissions in each season (ton CO_2/ha) in Chau Thanh district during 2013–2015

Table 4 Crop yield in each season (ton/ha)

	2013 Sp-Su	2013 Su-Au	2014 Wi-Sp	2014 Sp-Su	2014 Su-Au	2015 Wi-Sp
CF	5.73	6.50	8.33	6.74	5.54	5.84
FAWD	5.77	6.52	8.51	6.92	5.55	6.63
AWD	5.40	6.54	8.68	7.10	6.56	6.88

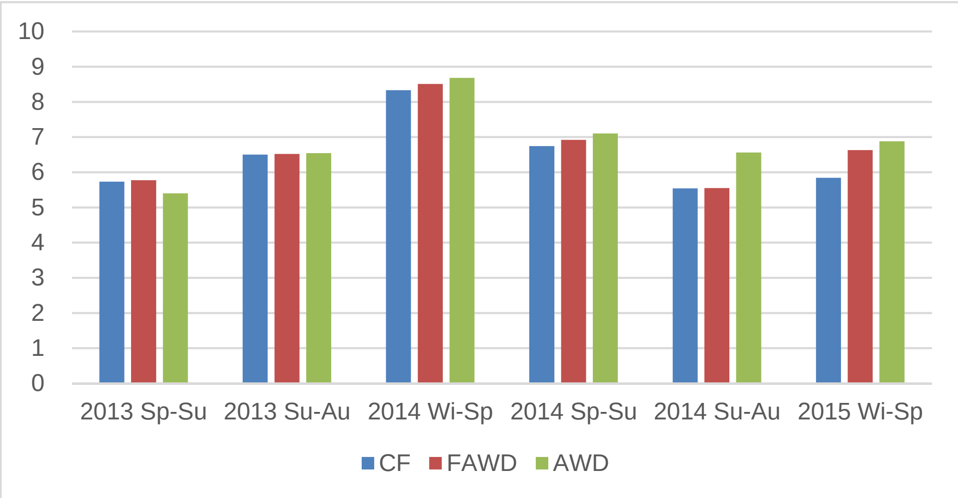


Fig. 13 Crop yield in Chau Thanh district during 2013–2015

4.3 GHG emission reduction effect

4.3.1 Methane gas (CH_4)

The global warming potential (GWP) was calculated by determining the CO_2 equivalent from CH_4 by using a conversion factor 28. In the nine cropping seasons from the spring-summer 2015 crop to the winter-spring 2018 crop, the CH_4 emissions in FAWD 2.72 ton CO_2/ha/season was lower than that under CF conditions 4.55 ton CO_2/ha/season. The soil type and seasonal effects did not affect the CH_4 emissions. The application of water management under FAWD conditions resulted in a 40% reduction (1.83 ton CO_2/ha/season) compared to CF, while reductions of 23.8% (0.98 ton CO_2/ha/season) and 55.4% (2.85 ton CO_2/ha/season) were found for the acid sulfate soil and in alluvial soil sites, respectively. The CH_4 emissions for CF were in the range of 0–12 ton CO_2/ha/season in the study by M. Su et al. (2017) and lower in the range of 18–440 ton CO_2/ha/season in the study by S. K. Malayan et al. (2016), whereas the emissions for AWD were in the range of 0–5.78 ton CO_2/ha/season (G.T. Lattue et al. 2016; A. Lagomarisno et al. 2016; S. K. Malayan 2016; K. Liang et al. 2016,

M. Su et al. 2017).

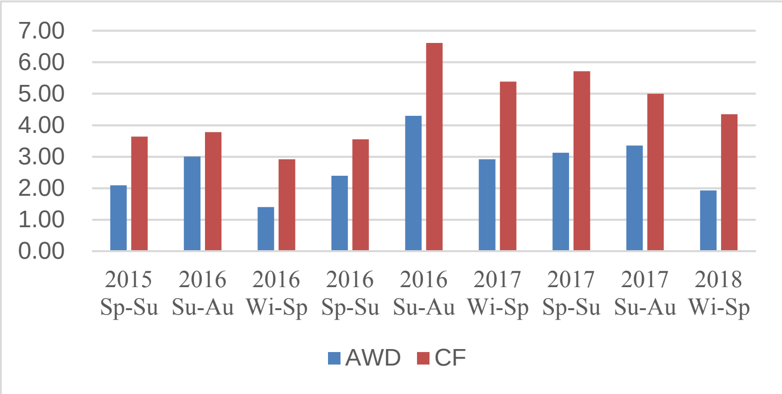


Fig. 14 Average CH_4 emissions per season (ton CO_2/ha/season)

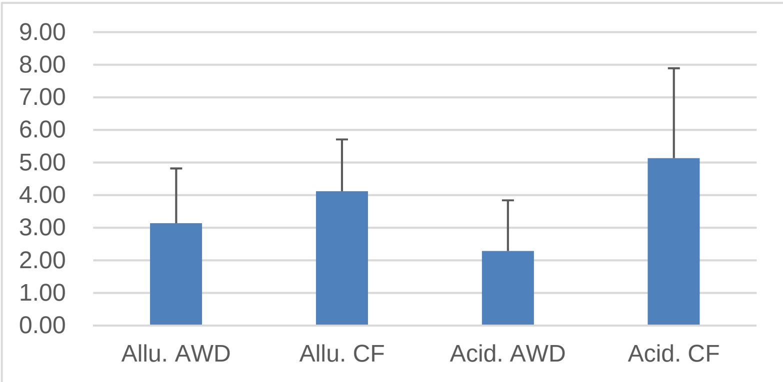


Fig. 15 Average CH_4 emissions in different soil types and water management (ton CO_2/ha/season)

4.3.2 Nitrous oxide gas (N_2O)

The global warming potential (GWP) was calculated by the CO_2 equivalent of N_2O by using conversion factor 298. The N_2O emissions did not exhibit a marked difference among the water management cases (2.76–4.66 ton CO_2/ha/season), soil type cases (3.64–3.76 ton CO_2/ha/season), and changes in season (3.15–4.4 ton CO_2/ha/season) because of the large variance shown in these three types of cases (G.T. Lattue et al., 2016; A. Lagomarisno et al., 2016; S. M. Su et al., 2017).

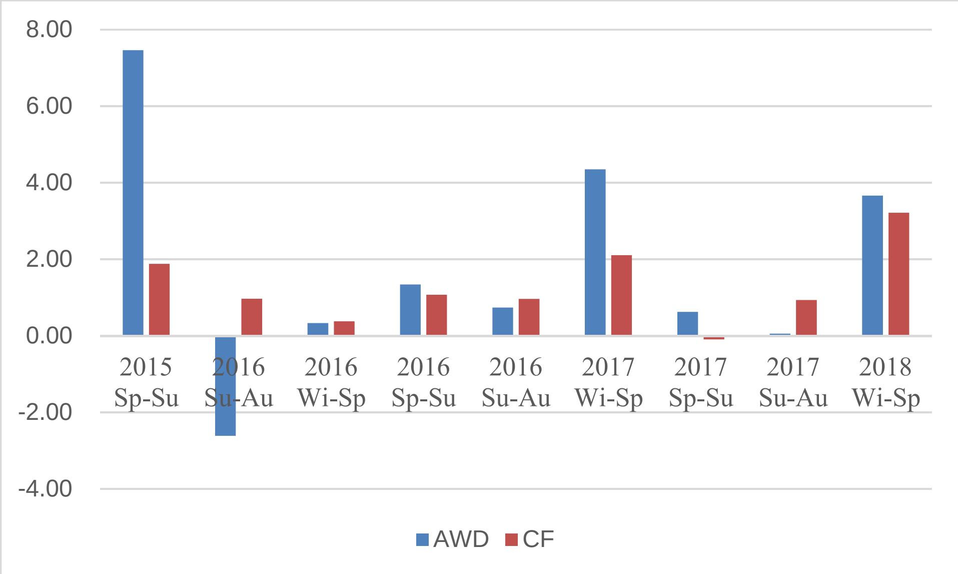


Fig. 16 Average N_2O emissions per season (ton CO_2/ha/season)

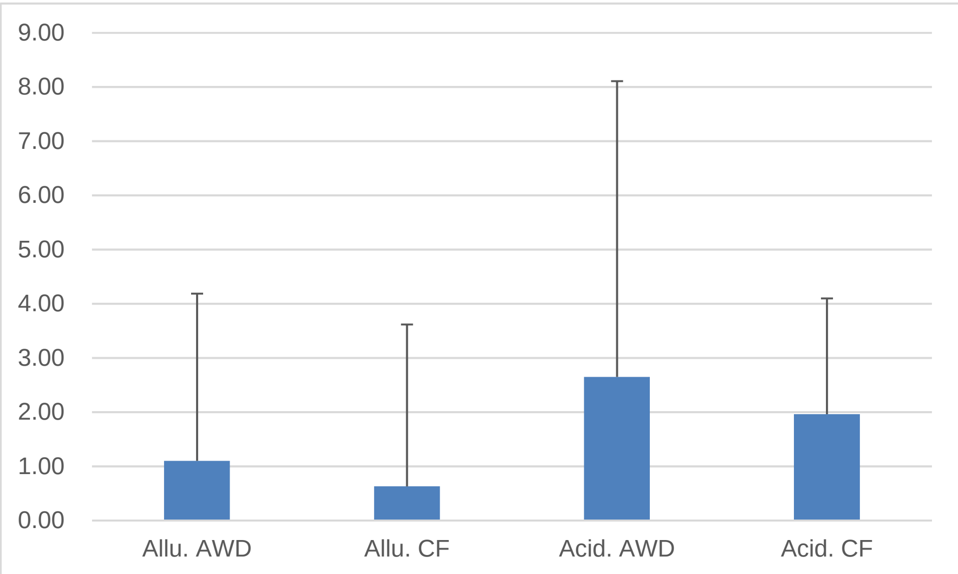


Fig. 17 Average N_2O emissions in each soil variety and water management (ton CO_2/ha/season)

4.4 Yield increase effect

In the nine cropping seasons from the spring-summer 2015 crop to the winter-spring 2018 crop, the crop yield in the FAWD sites significantly increased by approximately 1.19 ton/ha (4.98 → 6.17 ton/ha) on average compared with CF sites. The yield was not markedly different between the soil type and season effects. For the alluvial and acid sulfate soils, the yields for CF were 5.21 and 4.61 ton/ha/season, while the yields for FAWD were 6.85 and 5.75 ton/ha/season, respectively.

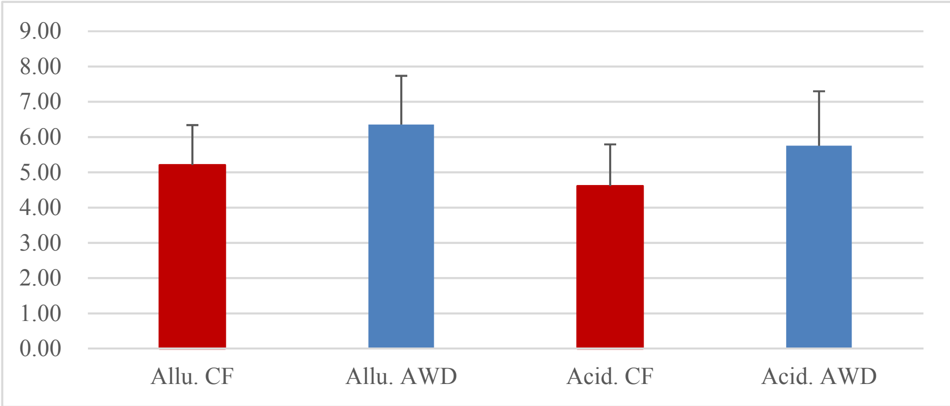


Fig. 18 Average yield in each soil variety and type of water management (ton/ha)

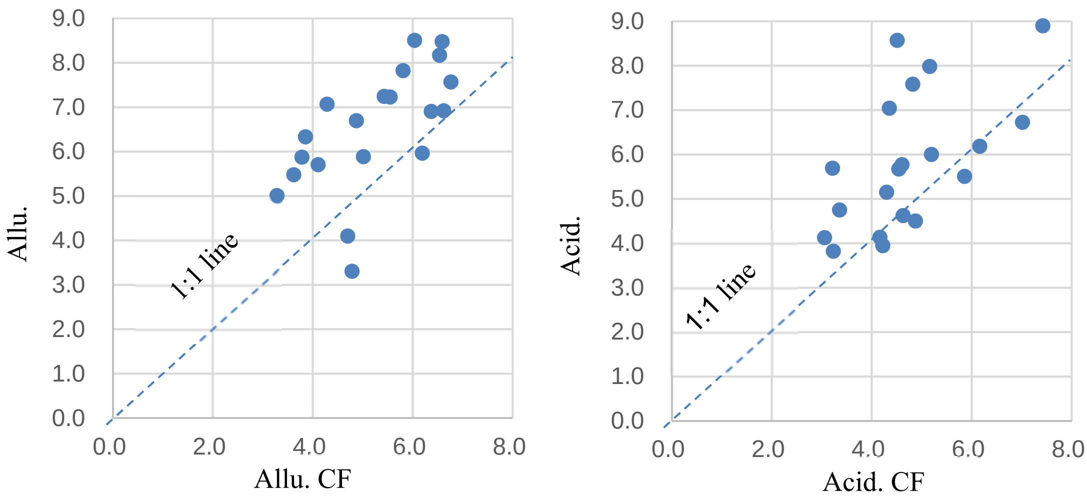


Fig. 19 Comparison of yields between FAWD and CF in each site (2015–2018)

4.5 Pumping operation cost saving effect

According to the questionnaires for farmers for the spring-summer 2015 to winter-spring 2018 crops, the pumping cost was reduced by 305,000 VND/ha/season 1,013,000 VND → 708,000 VND） from CF to FAWD. The number of pumping operations were also significantly reduced by 3.0 per ha per season (8.95 → 5.95). In addition, the number of pumping operations was significantly lower in Su-Au (6.08) than in Wi-Sp (8.97), while the number of pumping operations in Sp-Au (7.28) was not significantly different from Su-Au or Wi-Sp.

4.6 Rough estimation of economic advantage by FAWD implementation

The positive effects brought by FAWD implementation introduced in Chapter 4 are summarized as below:

- ❖ GHG reduction effect … 1.91 ton CO_2/ha/season
- ❖ Yield increase effect… 1.19 ton/ha/season
- ❖ Pumping operation cost saving effect … 305,000 VND/ha/season.

Although the unit price of CO_2 emission trading is always changing, 10 USD/ton CO_2 (230,000 VND) is applied in this rough estimation of the GHG reduction effect. As for the yield increase effect, we estimated that a 1 kg increase corresponds to 5500 VND, considering the standard rice market prices in An Giang Province.

Currently, triple cropping of paddy is typically practiced in An Giang Province; however, considering the political implications of double cropping, double cropping is applied in this estimation. We applied a social discount rate of 6% to estimate the future economic value, according to the Vietnam 10-year government bond.

With these assumptions above, the monetary value of implementing FAWD in a CF field per hectare per season is as follows:

- ❖ GHG reduction: 1.91 ton CO_2/ha/season × 230,000 VND/ton CO_2 × 2 seasons = 878,600 VND
- ❖ Yield increase: 1.19 ton/ha/season × 5,500,000 VND/ton × 2 seasons = 13,090,000 VND
- ❖ Pumping cost savings: 305,000 VND/ha/season × 2 seasons = 610,000 VND
- ❖ Total: 14,578,600 VND/ha/y

Therefore, the grand total monetary value for the continuous implementation of FAWD over 10 years can be calculated as follows:

14,541,800 VND/y $\times \sum_{k=1}^{10}(1-6\%)^{k}$= **<u>105,379,416 VND/ha/10 y</u>**

Table 5 Monetary value for each year and accumulation

year	Social discount rate in the year	Monetary value in the year	accumulation
1	94%	13,703,884	13,703,884
2	88%	12,881,651	26,585,535
3	83%	12,108,752	38,694,287
4	78%	11,382,227	50,076,514
5	73%	10,699,293	60,775,807
6	69%	10,057,336	70,833,142
7	65%	9,453,895	80,287,038
8	61%	8,886,662	89,173,700
9	57%	8,353,462	97,527,162
10	54%	7,852,254	105,379,416

Other positive effects such as water savings, or favorable influences, such as the improvement in the international status of Vietnam by fulfilling the INDC, are not included in the monetary value estimation. Although the rice price will probably increase through inflation, offsetting the effects of the social discount rates, this factor is not considered.

This result can justify the investment of approximately 100,000,000 VND/ha for FAWD continuously implemented for longer than 10 years.

4.7 Simplified estimation of GHG emission

Ideally speaking, GHG emission or reduction should be measured by on-site air sampling and gas chromatography in a lab. However, it is impossible for farmers to measure the GHG emissions in all the paddy fields. On the other hand, to estimate how much GHG is reduced in a region toward INDC implementation, criteria will be necessary to determine whether a paddy field is AWD or not.

For the matter, we introduce simple and provisional criteria.

4.7.1 Tentative criterion to determine AWD or CF

To determine (F)AWD or not, a criterion with the number of drying periods or the drying period length should be available if the water level can be measured frequently. For instance, according to the data in Section 4.1, FAWD exhibited an average drying period of 33 d and average number of drying periods of 6.2, while CF exhibited an average drying period of 7.2 d and an average number of drying periods of 2.3. Thus, we may set up a criterion with a number and length of drying periods based on the values above.

4.7.2 Rough estimation of GHG emission reduction

The average GHG reduction of all sites and seasons was 1.89 ton CO_2/ha/season; thus, we can estimate the entire reduction amount in the region by multiplying the area by 1.89, which satisfies the tentative criterion above. We also need to note the periodical analysis and gas chromatography for the closed chamber method because CH_4 emissions highly fluctuate according to place and season.

4.8 Future of agricultural development and research toward further implementation of AWD

The implementation rate of AWD in An Giang Province has improved drastically due to the local government's continuous efforts, as shown in the Table below:

Table 6 AWD rate in An Giang Province from 2010 to 2017

	2010	2011	2012	2013	2014	2015	2016	2017
AWD implementation rate in An Giang Province (%)	8.6	33.7	41.9	48	49.9	55.1	56.7	52.1

On the other hand, the increase in the AWD applied area has plateaued in recent years. It is considered that the remaining paddy field may have difficulties in the implementation of AWD. Though identifying the obstructive factors is not the object of this study, it should be noted that there are plot-to-plot irrigation fields in the region. In plot-to-plot irrigation fields, controlling the water level to the cultivator's desire is difficult, making AWD application challenging.

In addition, the burden of daily water level measurement is one of the obstructive factors. FAWD's "sensual measurement" is the very method to improve the point, but the ideal water level management is to measure numerically by a field water tube or similar device every day. The more precise the water level measurement is taken, the more reduction of GHG emissions can be expected (as Section 4.3

shows). Therefore, alleviating farmers' burden on the water measurement should be important.

From these viewpoints, we introduce the future of agricultural development and related research for reference.

4.8.1 Farmland consolidation

As described above, farmers in a paddy field without direct connection to/from irrigation or drainage canals need to adjust or negotiate with adjacent farmers when controlling the water level. Thus, farmland consolidation and construction of isolated irrigation/drainage canals will be necessary. Considering the implementation of AWD, farmland levelling should be done carefully; otherwise, the field water tube would indicate an incorrect water level.

Farmland consolidation on a large scale needs farmer consensus; however, the investment would be paid off in the long run according to the benefits introduced in Chapter 4. Farmland consolidation and irrigation/drainage canal development not only promotes AWD application but is also an essential investment in the modernization of agriculture and improvement of agricultural production.

Usually, the beneficiaries of farmland consolidation are farmers. However, considering the multiple benefits of GHG emission reduction for society in general, the investment of public funds to support the farmland consolidation projects can be justified.

4.8.2 Remote water level measurement by a simple ICT device

Farmers must spend a great deal of time measuring the daily water level in implementing AWD. The necessary day-by-day operation is probably a major factor discouraging many farmers from applying AWD. In fact, a cooperative farmer for this study changed their water management from AWD to CF because of less understanding and awareness of AWD. These problems may be solved if the farmers could know the water level on the paddy fields in their houses.

Recently in Japan, the research and development on remote-measuring/remote-controlling of irrigation water have been promoted for the further modernization of agriculture against an aging society. Our research focuses on a trial study measuring the water level on a paddy field around Can Tho City, Vietnam.

Furthermore, if numerous field water level could be accumulated automatically, the data of water level history covering every single field may become very strong evidence for INDC implementation and very useful data for agricultural development.

To realize such a system, further and continual study will be necessary. This system is suitable for political promotion, advancing ideas such as AWD implementation or the practice of smart agriculture in Vietnam. This system would be worth consideration in the spectrum of political ideas.

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APPENDIX

Table 1 Results of water management

Season	Water management	Average drying period (d)	Average number of drying periods	Average Water level (cm)	Average of standard deviation (cm)
2015 Sp-Su	FAWD	34.5	6.5	-0.6	6.7
2015 Sp-Su	CF	10.0	3.3	4.7	3.4
2016 Su-Au	FAWD	32.3	6.0	1.0	6.8
2016 Su-Au	CF	5.7	1.3	6.7	4.1
2016 Wi-Sp	FAWD	41.5	6.0	-2.1	7.3
2016 Wi-Sp	CF	4.8	1.8	4.7	3.9
2016 Sp-Su	FAWD	37.0	6.0	-1.9	7.8
2016 Sp-Su	CF	8.0	1.8	5.4	5.0
2016 Su-Au	FAWD	22.8	5.8	1.6	6.2
2016 Su-Au	CF	2.5	1.3	6.0	3.3
2017 Wi-Sp	FAWD	42.0	7.8	-2.6	8.2
2017 Wi-Sp	CF	6.5	2.0	5.9	4.3
2017 Sp-Su	FAWD	26.8	5.7	1.6	6.1
2017 Sp-Su	CF	4.5	1.8	6.0	3.7
2017 Su-Au	FAWD	25.8	6.8	2.1	7.2
2017 Su-Au	CF	11.8	3.6	4.5	6.1
2018 Wi-Sp	FAWD	33.8	5.7	-0.4	6.5
2018 Wi-Sp	CF	11.5	3.8	3.3	5.0

Table 2 CH_4 emissions in each season (ton CO_2/ha)

	2013 Sp-Su	2013 Su-Au	2014 Wi-Sp	2014 Sp-Su	2014 Su-Au	2015 Wi-Sp
CF	4.118	8.261	5.674	6.930	6.146	6.465
FAWD	1.737	4.307	3.361	5.478	4.662	5.776
AWD	0.237	2.204	1.539	3.520	4.142	1.850

Table 3 CH_4 emissions data in each experimental site (ton CO_2/ha)

	2015 Sp-Su		2015 Su-Au		2016 Wi-Sp		2016 Sp-Su		2016 Su-Au		2017 Wi-Sp	
	AWD	CF	AWD	CF	AWD	CF	AWD	CF	AWD	CF	AWD	CF
Chau Thanh	1.66	3.88	2.39	4.07	2.74	4.97	5.68	4.99	6.82	7.88	4.36	4.69
Cho Moi	3.99	6.28	1.90	2.25	1.66	2.07	1.81	3.09	1.72	2.37	3.23	3.91
Thoai Son	1.80	3.56	4.73	5.01	0.71	2.56	1.58	4.46	5.32	10.71	2.79	5.70
Tri Ton	0.92	0.84			0.50	2.07	0.53	1.67	3.32	5.47	1.29	7.24

	2017 Sp-Su		2017 Su-Au		2018 Wi-Sp	
	AWD	CF	AWD	CF	AWD	CF
Chau Thanh	5.30	6.96	5.46	4.44	4.12	3.05
Cho Moi	3.38	3.19	2.26	4.73	1.53	1.96
Thoai Son	2.08	4.98	2.76	6.58	2.16	6.41
Tri Ton	0.84	3.33	3.33	4.38	0.28	3.59
Chau Phu	1.87	4.10	-	-	0.93	3.53
Tinh Bien	5.28	11.73	2.97	4.84	2.56	7.54

Table 4 N_2O emissions data in each experimental site (ton CO_2/ha)

	2015 Sp-Su		2015 Su-Au		2016 Wi-Sp		2016 Sp-Su		2016 Su-Au		2017 Wi-Sp	
	AWD	CF	AWD	CF	AWD	CF	AWD	CF	AWD	CF	AWD	CF
Chau Thanh	7.41	0.90	-1.72	2.54	2.36	-0.37	1.97	-2.04	0.64	0.00	1.47	2.05
Cho Moi	-0.95	0.61	-4.87	1.35	0.15	0.72	1.98	3.46	-1.22	-1.16	-1.09	2.15
Thoai Son	2.56	1.93	-1.25	-1.00	0.04	0.10	-0.14	0.85	-1.45	1.60	10.99	2.12
Tri Ton	20.84	4.08			-1.23	1.05	1.54	2.03	4.98	3.41	6.01	2.10

	2017 Sp-Su		2017 Su-Au		2018 Wi-Sp	
	AWD	CF	AWD	CF	AWD	CF
Chau Thanh	4.60	1.98	1.57	-3.08	3.27	0.11
Cho Moi	-1.94	-7.35	0.57	-2.60	-0.61	3.11
Thoai Son	-0.25	-0.77	-0.63	2.70	2.80	1.45
Tri Ton	-0.92	2.34	-2.99	3.67	7.05	8.27
Chau Phu	0.33	3.51			8.08	6.70
Tinh Bien	1.92	-0.29	1.74	3.97	1.39	-0.36

Table 5 Yield data in each alluvial soil site (ton/ha)

Season	Site	CF	FAWD
2014 Sp-Su	Chau Thanh	5.81	7.82
2014 Sp-Su	Cho Moi	6.62	6.92
2014 Su-Au	Chau Thanh	6.54	8.17
2014 Su-Au	Cho Moi	5.43	7.24
2015 Wi-Sp	Chau Thanh	6.04	8.50
2015 Wi-Sp	Cho Moi	6.77	7.57
2015 Sp-Su	Chau Thanh	3.29	5.01
2015 Sp-Su	Cho Moi	4.11	5.70
2015 Su-Au	Chau Thanh	4.70	4.10
2015 Su-Au	Cho Moi	6.19	5.96
2016 Wi-Sp	Chau Thanh	5.55	7.23
2016 Wi-Sp	Cho Moi	3.79	5.87
2016 Sp-Su	Chau Thanh	3.62	5.48
2016 Sp-Su	Cho Moi	3.86	6.33
2016 Sp-Su	Chau Phu	6.37	6.91
2016 Su-Au	Chau Thanh	5.02	5.88
2016 Su-Au	Cho Moi	4.79	3.30
2017 Wi-Sp	Chau Thanh	4.29	7.07
2017 Wi-Sp	Cho Moi	4.88	6.69
2017 Wi-Sp	Chau Phu	6.59	8.47

Table 6 Yield data in each acid sulfate site (ton/ha)

Season	Site	CF	FAWD
2014 Sp-Su	Thoai Son	4.23	3.95
2014 Sp-Su	Tri Ton	3.06	4.13
2014 Su-Au	Thoai Son	4.88	4.50
2015 Wi-Sp	Thoai Son	7.43	8.89
2015 Wi-Sp	Tri Ton	4.82	7.58
2015 Sp-Su	Thoai Son	4.55	5.67
2015 Sp-Su	Tri Ton	3.22	5.69
2015 Su-Au	Thoai Son	6.17	6.18
2015 Su-Au	Tri Ton	4.36	7.04
2016 Wi-Sp	Thoai Son	3.24	3.82
2016 Wi-Sp	Tri Ton	3.36	4.75
2016 Sp-Su	Thoai Son	4.63	4.62
2016 Sp-Su	Tri Ton	5.20	6.00
2016 Sp-Su	Tinh Bien	4.30	5.15
2016 Su-Au	Thoai Son	4.61	5.77
2016 Su-Au	Tri Ton	4.51	8.57
2016 Su-Au	Tinh Bien	5.86	5.51
2017 Wi-Sp	Thoai Son	4.17	4.13
2017 Wi-Sp	Tri Ton	5.16	7.98
2017 Wi-Sp	Tinh Bien	7.02	6.72

Table 7 Operation cost of pumping in each site (thousand VND/ha/season)

	2015 Sp-Su		2016 Su-Au		2016 Wi-Sp		2016 Sp-Su		2016 Su-Au		2017 Wi-Sp	
	FAWD	CF	FAWD	CF	FAWD	CF	FAWD	CF	FAWD	CF	FAWD	CF
Chau Thanh	533	2,000	400	600	480	578	320	560	80	80	240	580
Cho Moi	1,500	2,780	1,500	2,140	1,400	2,400	1,100	1,600	800	1,100	550	650
Thoai Son	450	600	320	440	400	680	340	660	400	400	1,120	1,360
Tri Ton	-	-	-		558	683	311	341	225	234	775	775

	2017 Sp-Su		2017 Su-Au		2018 Wi-Sp	
	FAWD	CF	FAWD	CF	FAWD	CF
Chau Thanh	160	800	240	800	240	897
Cho Moi	450	650	350	500	300	500
Thoai Son	2,154	2,874	2,314	2,714	2,154	2,474
Tri Ton	650	537	525	767	825	804
Chau Phu	320	320	-	-	2,030	2,320
Tinh Bien	280	160	120	160	-	-

Table 9 Frequency of pumping operation in each site per ha per season

	2015 Sp-Su		2016 Su-Au		2016 Wi-Sp		2016 Sp-Su		2016 Su-Au		2017 Wi-Sp	
	FAWD	CF	FAWD	CF	FAWD	CF	FAWD	CF	FAWD	CF	FAWD	CF
Chau Thanh	5	10	4	6	6	7	4	7	1	1	3	7
Cho Moi	7	11	5	8	7	12	6	9	7	10	11	13
Thoai Son	6	7	4	6	5	9	6	9	3	3	9	12
Tri Ton	-	-	-	-	11	14	5	6	4	6	11	15

	2017 Sp-Su		2017 Su-Au		2018 Wi-Sp	
	FAWD	CF	FAWD	CF	FAWD	CF
Chau Thanh	2	10	3	10	3	9
Cho Moi	8	12	7	10	6	10
Thoai Son	7	17	9	14	7	11
Tri Ton	8	8	7	11	8	10
Chau Phu	4	4	-	-	7	8