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A water productive and economically profitable paddy rice production method to adapt water scarcity in the Vu Gia-Thu Bon river basin, Vietnam

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Abstract

In Vu Gia-Thu Bon river basin, Vietnam, drought during the dry season affected negatively on rice production. High and uneven rainfall distribution cause flooding in the basin during wet season and cause severe agricultural drought during dry season.

This study aimed to point out a higher water productive and economically efficient rice production method to adapt water scarcity in the region. Based on available secondary data, water productivity is calculated for different water saving rice production methods, according to Pereira, et al, (2012)'s irrigation water productivity and total productivity equations. The profit of technological change is calculated by partial budget analysis of rice production in that area and a sensitivity analysis supports to point out which input factor is sensitive to farmer's benefit. Farmer's psychological and social beliefs are used to create fuzzy logic based decision making model. Although water productivities (ranging 0.441 kg/m^3/ha to 0.504 kg/m^3/ha) are ranked as the second after System of Rice Intensification, we demonstrated that Alternate Wetting and Drying method is a recommendable method to the farmer after considering economic profitability and technical simplicity. The System of Rice Intensification method also could be a suitable method to adopt because this method is the highest water productive method (Water Productivities are ranging from 0.77 kg/m^3/ha to 1.02 kg/m^3/ha) coupled with highest yield of rice, subject to certain ecosystem services and payment policies should be developed to subsidize the reduced benefit resulting from this method.

Introduction

Vietnam is the second largest rice exporter in the world (Vu, 2012). Due to frequent changes in climatic conditions, increased drought frequencies and intensities were observed to reduce rice crop productivity as reported in 2011 (Duc, 2011).

Vu Gia Thu Bon river basin (VGTB) shared most of NCC rice production areas (Quang Nam Statistical Office [QSO], 2010).According to the irrigation discharge record of Tu Cau pumping station (Duc, 2011), a larger amount of water is discharged when rice plants do not need so much water but less amount of water is discharged to the same area units when rice plants are in critical need. Water scarcity during flowering and grain filling time is more important for rice production than water scarcity at earlier time (Yoshida, 1981; Datta, 1981).

Previous studies and time series data sets of climatic conditions clearly indicate changes in the drought frequency and hence irrigation water availability. Therefore crop production can have severe ecological implications. Under extreme climate change and sea level rise scenario, Chen, et al. (2012) forecasted that Vietnam will go from being a rice exporter to an importer in 2030. Therefore experimental climate impact research in the field of agronomy and ecology has been strongly focused to find a better adaptation strategy of rice plants to gain higher yield.

Bouman, et al(2007) found that continuous flooding has less water productivity in their study in India and in the Philippines and they pointed out the "most promising option" for saving water and to get higher farm water productivity is "by reducing the depth of ponded water from 5 -10 cm to the level of soil saturation". In the case of VGTB river basin, change in technology suggested by Bouman, et al (2007) might not work since the water scarcity and lower water productivity is strongly related to rain events and salinity intrusion to inland water body from the sea. Duc (2011) recommended an adaptation strategy for water scarcity in the VGTB basin. His recommendation is to construct two reservoirs to store river water before the salinity was intruded or to harvest rain water. His suggestion for irrigation water deficit period is pumping salinity intruded water to the reservoirs and diluting the salinity to an acceptable degree and supplying the diluted water. His recommendation and suggestion might work for the short term but it might not work for long term since the quality of the reservoir will be affected by the pumped saline water after long term use.

Rice is the dominant crop in VGTB basin, and farmers' economy is strongly depended on success and failure of rice production (Ha, 2011). Although changing rice based farming system to other types of farming system could be a possible solution, there is almost no other alternative farming system to replace rice due to the environmental and social limitations (Ha, 2011). Therefore it is very important to adapt or mitigate the irrigation water scarcity by a better long term approach. For long term and sustainable adaptation of irrigation water scarcity in VGTB basin, United Nations Convention to Convert Desertification [UNCCD] (2009)'s idea, "changing cropping pattern or practices is one of the options to adapt agricultural water scarcity" should not be neglected. Changing rice cropping pattern or field irrigation management practices or cropping practices could be the best solution to adapt irrigation water scarcity in the VGTB basin. Therefore, this study seeks to address the following two objectives:

1. Finding a better solution to adapt water scarcity by means of cropping practices and crop management
2. Evaluate economically profitable and high water productive rice production methods.

Water wise rice production

Zawawi, et al., 2010 examined paddy rice water requirement in Seberang Perak rice cultivation area in Malaysia where the research area is characterized by humid monsoon climate with 2393 mm average annual rainfall and concluded that a growth cycle of 120 day rice crop needs 13,010 m^3 of water input (rainfall and irrigation) for a season of rice grown on 1.82 Ha land. Yoshida (1981) noted that rice crop need 180-300 mm/ha/month of water for evapotranspiration plus percolation and 1,240 mm/ha/month of water for overall field operation process of a crop cycle. Based on this fact, water need for a 4 month duration rice crop is assumed as 19,600 to 24,400 m^3/ha [(720 to 1200 mm for evapotranspiration plus percolation + 1240 mm for field operation) converted to a volumetric value of water for a ha].

After the first and second world water forum in 1997 and 2000, the need was recognized to find solutions to increase water use efficiency in agriculture since it is the highest water consuming production sector (Bindraban, 2001, pg. 5). Technologies to produce more rice with less water are under evaluation (ibid, 2001) and such technologies are generally named as water-wise rice production technologies or water saving rice production technologies by IRRI (Bouman, et al, 2002).

Some popular Water-wise rice production technologies across the world are 1) Alternate Wetting and Drying (AWD) [for more information, see: IRRI 2009a], 2) System of Rice Intensification (SRI) [for more information, see: Bouman, et al., 2002], 3) Aerobic rice production [for more information, see: IRRI, 2009b.]. Aerobic Rice production method is not included in this study since yield and return profit of rice by this method is lower than conventional methods in most of aerobic rice research (Bouman, et al., 2002) which against one of the objectives of this study: to maximize water productivity without affecting the economic profitability .

Water productivity

A good expression for "water productivity" is what agronomists say "More crop per drop" (FAO, 2000) and it is defined as the ratio of end product and water consumed during the production process (van Halsema, et al., 2012). Water productivity is widely used as Economic water productivity [EWP] and production water productivity [WP] but the basic theory holds a universal truth for both productivity calculations. Both EWP and WP follow the main definition (end product/water consumed) but EWP is calculated from economics point of view by using monetary unit for both numerator and denominator while WP is calculated from production point of view by using unit of products produced and unit of water consumed as numerator and denominator.

Water productivity is calculated for different scales in Agriculture from plant scale to irrigation system level without changing the main theory of WP. Water productivity is classified based on the scale where the productivity is calculated as Water Use Efficiency (WUE) for crop; farm WP for farm level to calculate WP from farmer's point of view of irrigation water productivity and Total WP [WP] for irrigation water use plus natural precipitation (Pereira, et al., 2012).

The term WP and WUE are mostly used in irrigation management field and some researchers use these two terms interchangeably. According to Barker et al. (2003) the definition of those two terms were confused till 1993 (some examples according to Barker et al.: Dinar, 1993 for economics literatures and Richards et al., 1993 for Plant science literatures). Barker, et al. mentioned that there is no single definition for both WUE and WP because these terms are used for different purposes such as field application efficiency, Conveyance efficiency which are different types of WUE and Total Factor productivity, Partial Factor productivity which are some types of WP. However, Barker, et al. differentiated WP and WUE in general. WP is a ratio of crop output to water input (the unit can be in monetary terms or weight of output per volume of water). WUE can be defined how much water is depleted beneficially for crop, in other words, how much water is consumed by crop.

Seckler, et al. (2003) pointed that WUE, especially with the term beneficial water use, is quite similar to the term productivity in WP but not exactly the same. WUE purely focuses on the physical flow of water while WP focused on the value of water.

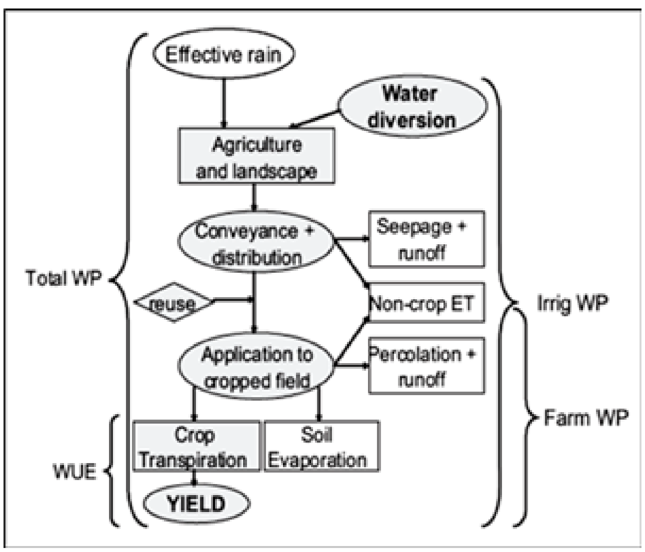

Figure 1. Water Productivity at different scale in Agricultural production. Source: Pereira, et al. 2012

Rice production system

There are very few cropping system classifications based on water management practices but the rice cropping system is one. Rice cropping patterns across the globe are generally classified into two systems: upland rice (depended solely on rainfall) and low land rice (water is available for crop in terms of rainfall and irrigation). Where there is no irrigation water available and rainfall is abundant, rain-fed lowland rice system is also common (Datta, 1981). For rain-fed low land rice system rain water is always ponded on the field. When rice is grown in a flood prone region with flooded water, that system of rice farming is named as "flood-prone rice" and commonly occurred in some delta regions (Taniyama, 2002).

Irrigated rice production is common in the VGTB river basin and rain-fed rice is a rare cropping practice (Ibid, 2011). Rice is cultivated as two crops per year: Winter-spring rice [WS or dry season rice] and Summer- Autumn Rice [SA or wet season rice] (Ha, 2011; Duc, 2011, Tenbrock, 2011). Water resources for rice production are precipitation and some irrigation water from certain sources such as reservoirs, pumping stations, etc. For the rice production in the study area, irrigation water is supplied by Tu Cau pumping station where water from the Vinh Dinh river is pumped (Duc, 2011; Tenbrock, 2011). Since Vinh Dinh River is intruded by salinity in dry season, pumping station have to stop irrigation water supply when salt concentration content is more than 0.8 ‰ and at that time there was a water shortage for rice farms (Duc, 2011). Tu Cau pumping station mostly cannot supply irrigation water for WS crop in March and July and August for SA crop.

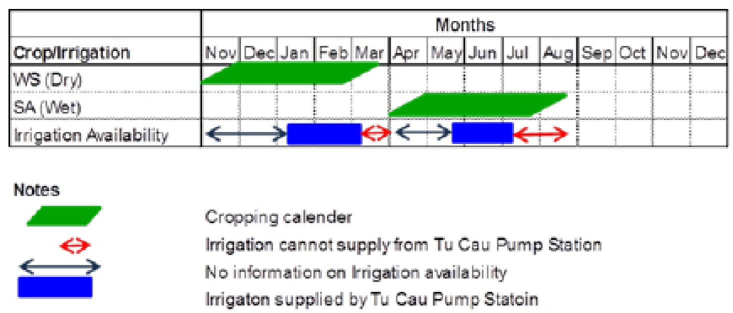

Figure 2. Rice crops and irrigation availability of a study site in VGTB river basin. Source: Adopted from Duc (2011)

Methodology

Study site

The Vu Gia Thu Bon [VGTB] river basin is one of the 9 biggest river basins in Vietnam. It is in Central Vietnam and covers major parts of Quang Nam Province, Da Nang province and a small part of Kon Tum Province. The two main rivers Vu Gia and Thu Bon which originated in the high mountains, Truong Son, are met by many tributes before flowing into the South China sea (Department of Natural Resources and Environment [DONRE], 2011 cited in Toan, 2011).

In Vietnam, especially in Vu Gia - Thu Bon river basin [VGTB], water related problems affect negatively on agricultural production (Ha, 2011). One main problem is water scarcity and drought during summer (Ibid, 2011; Duc, 2011). According to time series data from 1976 to 2010, rainfall distribution in VGTB basin is a unimodal distribution pattern where the rainfall is concentrated in around 4 months duration period (September to December). However, as the basin is in a coastal area, along with the occurrences of Typhoon, abnormal heavy rainfalls are likely to be occurring. Annual average rainfall (1976-2010) at Da Nang station in VGTB area is 2162.53 mm.

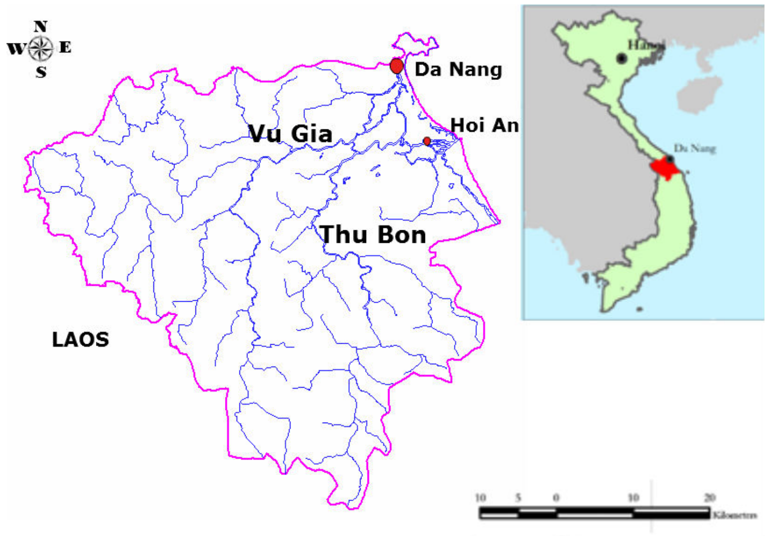

Figure 3. Location map of VGTB river basin.

Data analysis

To conduct our study, secondary data of the World Bank Statistics, Asia Development Bank's surveyed data, International Rice Research Institute's Statistics, Food and Agricultural Organization's Statistics and Vietnamese Statistical organizations such as General Statistical Office, Quang Nam province Statistical Office and statistical data from LUCCi project of the Institute of Technology and resources management in the Tropics and Subtropics [ITT] of Cologne University of Applied Science, cost of production of rice data set from Janaiah and colleagues (2004) are used.

Water productivity

According to Pereira, et al., 2012, irrigation WP [WP_{irri}] and WP are calculated by the following equation to point out irrigation water productivity at farm level.

$$WP_{irri} = Y_a/IWU$$

Where, WP_{irri} is irrigation water productivity at farm level, Y_a is actual yield and IWU is irrigation water used throughout a crop cycle.

$$WP_{Total} = Y_a/TWU$$

Where, WP_{irri} is irrigation water productivity at farm level, Y_a is actual yield and TWU is total water used throughout a crop circle (i.e. Irrigation water used +precipitation).

Economic profitability

Whenever making a decision of technology change, cost and benefit of changing to a new technology is taken into account by a decision maker. Cost benefit ratio is the most accurate "reflection of profitability of various investment opportunities" (Beierlein, et al, 1995, p-226). Partial Budget analysis is based on the household survey data (428 rice farmers in 11 village clusters) of Janaiah et al., (2004). Fixed cost of production for unit area of rice is excluded during partial budget analysis since the authors assumed that change in fixed cost due to technology change is negligible.

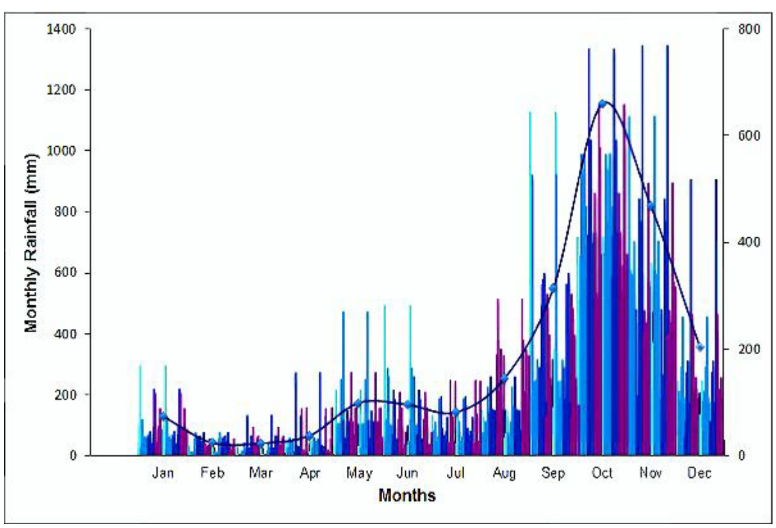

Figure 4. Monthly rainfall distribution (mm) in VGTB river basin (Da Nang station: 1976-2010). Sources: Data from Thomas, et al, 2010; Duc, 2011; GSO, 2012

Fuzzy logic and decision making model

Rule based fuzzy set is applied as Bozma, et al. (2005) applied in their research on framers' motivation to adopt integrated farming in Vietnam. This fuzzy set theory is applied since Zhang and Liu (2006) recommend it as a good method to model human decision making. Economic criteria (Total Variable Cost and Return on resources, i.e., Fertilizer, Labor, Irrigation water) were used to compare economic efficiency. Yield of rice produced per unit water (irrigation and precipitation) was used as a criterion for water productivity. For social and environmental criteria, since there is no primary data to refer, criteria are assumed based on Thompson, et al. (n.d) and Pannel, et al., (2006). Based on those major criteria, a decision matrix shown in Table (1) was developed to create a prototype fuzzy logic model (see Dunn, et al., 1995 for more information).

To predict farmers' adoption to new technology, a set of fuzzy logic rules are developed based on Pannel, et al. (2006)'s description on farmer's adoption behavior and criteria in the table (1). The rules are:

Rule 1: the method which has higher WP and higher benefit will be accepted by farmers.

Rule 2: the method which has higher WP but which has medium return will be accepted by farmers.

Rule 3: the method which has high WP and low benefit will not be accepted because farmers do care more on benefit than WP.

Rule 4: the method which has medium WP and higher benefit will be accepted because this method will produce higher yield although water need is still less than conventional method.

Rule 5: the method which has medium WP and medium benefit will be accepted since this method can produce higher yield than conventional method and also save more water than conventional method.

Rule 6: the method which has medium WP and low benefit will not be accepted because of its lower benefit.

Rule 7: the method which has low WP will not be accepted even it produce higher yield since there is limited agricultural water resource.

Table 1. Sample Decision matrix used to create the prototype fuzzy logic model. Source: Adapted from Dunn, et al., 1995.

	Technology	Criteria (highest=10, lowest=0)							
		Economics				Water	Social	Environmental	
		RF	RL	RI	TVC	WP	PI	*rf*	*ir*
Alt. 1	Con.	5	8	2	6	1	3	8	9
Alt. 2	AWD	4	5	8	8	7	6	8	9
Alt. 3	SRI	6	3	8	3	9	2	8	9

Notes: Con.= Conventional; AWD= Alternate Wetting and Drying; SRI= System of Rice Intensification; Alt. 1,2,3= Alternative 1,2,3; RF = Return on fertilizer use; RL = Return on Labour use; RI = Return on Irrigation applied; TVC= Total Variable Cost; WP = Water productivity; PI = Farmer's interest to adopt; *rf*= possibility of environmental hazard due to the applied fertilizer; *ir*= Impacts on regional water cycle due to irrigation water waste in Con.; due to alternate wetting and drying process in AWD and SRI.

Based on the results of water productivity and economic profitability calculation and fuzzy logic sets and rules, a decision making model was developed as shown in figure (5).

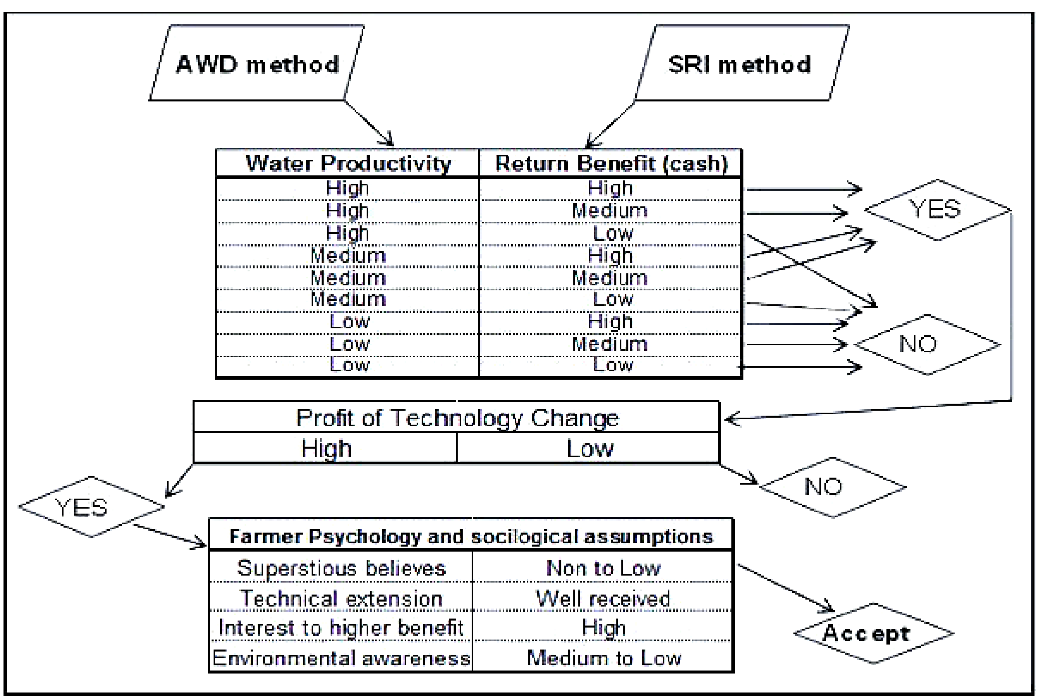

Figure 5. Diagrammatic presentation of the Conceptual decision making model applied in this study.

Result and discussion

Water Productivity

WP_{irri} and WP_{Total} of Current rice production methods in the VGTB river basin is as low as 0.267 Kg/m^3/ha and 0.246 kg/m^3/ha in dry season rice (November to March). In the wet season (May to September), WP_{irri} and WP_{Total} are 0.389 Kg/m^3/ha and 0.277 Kg/m^3/ha. For dry Season Crop, WP_{irri} of conventional method 0.267 kg/m^3/ha is a bit lower than the minimal WP value (0.4 kg/m^3/ha) resulted in the research under similar condition in the Philippines (Tuong and Bouman, 2003 cited in Zwart and Bastiaanssen, 2004). Moreover, this result is still lower than WP (Irrigation is excluded) in Vietnam which resulted 0.30 Kg/m^3 (Mainuddin and Kirby, 2009). For wet season Crop, WP_{irri} of the conventional method is higher than that of dry season and the result is comparable to the result of Mainuddin and Kirby (2009). Moreover, it is just slightly lower than that of Tuong and Bouman (2003)'s result.

Both WP_{irri} and WP_{total} are calculated by using minimal water used to leachsoil salinity and percolation according to the recommendation of previous researche. However WP_{irri} of dry season rice modeled in this study is lower than that of minimal WP value resulted in replicated researches under similar situations. This study excluded water leakage from the ponded field because of data unavailability. Therefore, in real situation, WP_{irri} may lower than the current modeled result.

In dry season, WP_{total} of conventional method doesn't differ so much from that of WP_{irri} since dry season rainfall is very low in the study site (23.58 to 98.70 mm/month/annum) and irrigation water shared a larger amount of dry season total water use. However, wet season WP_{irri} differs slightly between each other since 80% of annual precipitation is concentrated in wet season (ranging from 145.11 to 659.59 mm/month/annum). Moreover, farmers apply additional irrigation water to the fields. Therefore total WP for wet season rice (0.277 kg/m^3) is lower than that of wet season WP_{irri} (0.388 kg/m^3). This lower total WP in wet season seems to be because of mismanagement of rain water. If rain water is harvested effectively and managed efficiently, additional irrigation water may not be needed for wet season rice production.

Water-wise rice production methods accepted by the International Rice Research Institute (IRRI) are modeled by using the same data applied to conventional methods and theoretical assumptions based on literatures of Hoek, et al., 2001; Bouman, et al., 2002; Bouman, et al, 2007. Both Alternate Wetting and Drying method (AWD) and System of Rice Intensification (SRI) methods resulted in 0.441 kg/m^3/ha^1 and 0.770 kg/m^3/ha^1 respectively for dry season total WP; 0.479 kg/m^3/ha^1 and 0.835 kg/m^3/ha^1 respectively for dry season irrigation WP. In Wet season, total WPs of AWD and SRI resulted as 0.504 kg/m^3/ha^1 and 1.02 kg/m^3/ha^1 respectively and irrigation WPs of AWD and SRI resulted as 0.703 kg/m^3/ha^1 and 0.770 kg/m^3/ha^1 respectively. SRI resulted with the highest water productivity and AWD followed after SRI. WPs of SRI are almost two times higher than that of AWD in both dry and wet season. Although irrigation management of SRI and AWD are similar (Bouman, et al, 2002), the modeled WPs of SRI resulted significantly higher than that of AWD. Among three methods, SRI resulted with the highest water productivity and AWD and Conventional method followed respectively.

Benefit and cost of technology change

Sensitivity of input uses on benefit is analyzed decreasing and increasing the input uses to 30%, 20% and 10 %. The cost of irrigation and water management per hectare of rice field in the VGTB river basin is the third sensitive factor on benefit after cost of labor (the first sensitive) and the cost of fertilizer (the second).

Based on the farm budget of the conventional rice production studied in Janaiah, et al. (2004), cost and benefit of rice production by AWD and SRI is modeled. Benefit and Cost of production practices change resulted as BC ratio of changing Conventional to AWD is higher than that of Conventional to SRI.

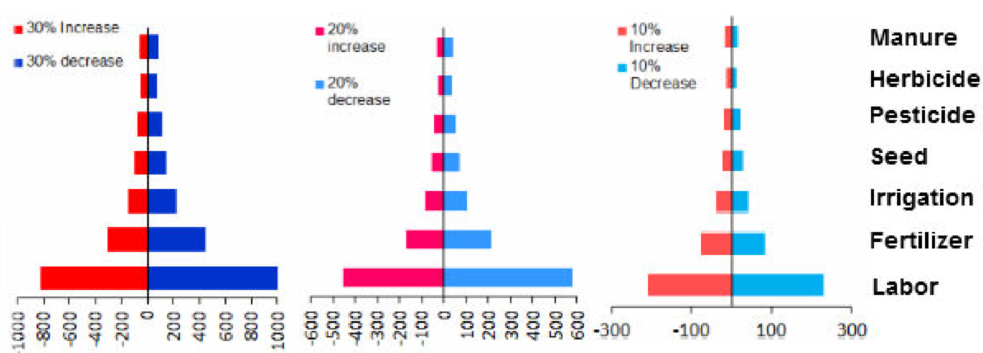

Figure 6. Tornado diagrams of change in benefit of rice production (, 000 VND) due to change in input use (+/- 10%, +/- 20% and +/- 30%). Source: Data from Janiah, et al, 2004 and Duc 2011.

Decision making model

The calculated result of WPs and economic profitability of different cropping methods are compared as shown in figure (6). It was clear that AWD method is a new technology which resulted highest economic profitability with reasonable WPs.

As described in the model (figure. 5), after the comparison of new technologies in terms of WPs and economic efficiency, a prototype fuzzy logic model was developed based on criteria described in Table (2) and rules described in section (2.2.3) of this article. The result of the model was that farmers will likely adopt to the AWD method because of its higher WPs than conventional rice production method and because of its highest economic profitability.

Table 2. Benefit and cost of changing conventional rice production method to water wise methods for a Hector of rice farm.

	Conventional		AWD		Δ Revenue, cost and benefit		SRI		Δ Revenue, cost and benefit	
	VND (,000)	EURO	VND (,000)	EURO	VND (,000)	EURO	VND (,000)	EURO	VND (,000)	EURO
Revenue	9,861.00	505.04	13,840.00	708.83	3,979.00	203.79	13,840.00	708.83	3,979.00	203.79
Cost	7,781.00	398.53	7,976.00	408.51	195.00	9.98	10,917.00	559.11	3,136.00	160.58
Benefit	2,080.00	106.51	5,864.00	300.32	3,784.00	193.81	2,923.00	149.72	843.00	43.21

Source: Data from Janiah, et al, 2004, Duc, 2011.

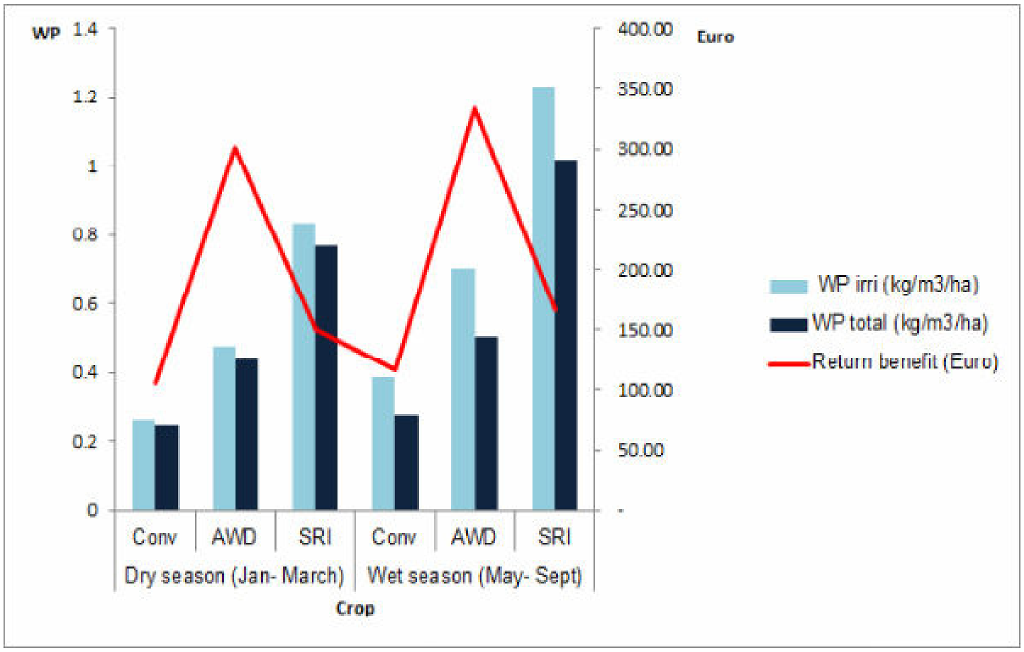

Figure 7. WPs and return benefit calculated and modeled for different cropping methods
Source: Data from Janiah, et al, 2004, Duc, 2011.

Conclusion

Our findings contribute to finding a better solution to mitigate water scarcity by means of cropping practices and crop management in the area and further reviews the production profitability based on rice production methods discussed in the study.

This study pointed out one possibility of water demand management by changing cropping practices to obtain higher agricultural water productivity without affecting farmers benefit. The research focused only on the farm scale level by objectives to point out a suitable higher water productive rice production method to adapt regional water scarcity with economic efficiency for farmers. The study not only focuses on water productivity, crop harvestable yield but tries to include socioeconomic factors as well. Our study found that, AWD is the most suitable method to attain all objectives of this study but this result is only for the current water scarcity scenario.

On the other hand, since SRI resulted in the highest water productivity by all means and highest return benefits, SRI method could be a suitable method to adopt if the local or central government will manage certain ecosystem services and payment policy for farmers. By this means, the VGTB basin will have higher agricultural water productivity together with higher rice yield and higher benefit of rice farmers live by means of income from SRI method plus payments for ecosystem services for adopting highest water productive SRI method. SRI methods plus certain ecosystem services and payment policies could be a better solution to the water scarcity in the VGTB river basin under the worse water scarcity.

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References

Barker, R., et al. 2003. Economics of Water Productivity in Managing Water for Agriculture. In: Kijne, J. W. II. Barker, Randolph. III. Molden, D. J. (Eds) 2003. Water productivity in agriculture: limits and opportunities for improvement. CABI international. Wallingford, Oxon, UK.

Beierlein, J. C., et al. 1995, Principles of Agribusiness management. Second edition. P-226. Waveland Press, Inc. Illinois.

Bindraban, P. S. 2001. Water for food: Converting inundated rice into dry rice. In: Hengsdijk, H. and Bindraban, P. (Eds), 2001. Water saving rice production systems: proceedings of an international work shop on water saving rice production systems at Nanjing University, China, April 2-4, 2001. Wageningen, Plant Research International B.V. The Netherlands.

Bouman, B.A.M, et al. 2002. Water-wise rice production. Proceedings of the International Workshop on Water-wise Rice Production, 8-11 April 2002, Los Baños, Philippines. Los Baños (Philippines): International Rice Research Institute.

Bouman, B.A.M, et al. 2007. Water Management in Irrigated Rice: Coping with Water Scarcity. [book] Los Baños (Philippines): International Rice Research Institute.

Bozma, R, et al. 2005. Fuzzy Modeling of Farmer Motivations for Integrated Farming in the Vietnamese Mekong Delta. In The 2005 IEEE International Conference on Fuzzy Systems.[internet] Available: http://www.afi.wur.nl/nr/rdonlyres/95cb715b-04cc-4529-a9dd- d85b69fe6fea/25433/ieee_final.pdf. [Accessed 20 June 2012]

Chen, C., et al. (2012). Climate change, sea level rise and rice: global market implications. Climatic Change (2012) 110:543–560.

Datta., S. K. 1981. Principles and practices of rice production. First edition. John Wiley & Sons, Inc. A Wiley-Interscience Publication. New York.

Duc, V. N. 2011. [unpublished work] Improvement of water supply for agricultural production through operation and management by considering salinity intrusion adaptation. [MSc. Thesis submitted to ITT, Cologne University of Applied Science]

Dunn, E.G., et al. 1995. Extending the Application of Fuzzy Sets to the Problem of Agricultural1 Sustainability. Proceedings of ISUMA-NAFIPS '95.

Food and Agriculture Organization [FAO], 2000. Crops and Drops: Making the best use of water for Agriculture [pdf] ftp://ftp.fao.org/docrep/fao/005/y3918e/y3918e00.pdf. Accessed on: 01.05.2012.

General Statistical Office [GSO]. 2012. Production of Paddy by Provinces. [html] Available: http://www.gso.gov.vn/default_en.aspx?tabid=469&idmid=3&ItemID=11772. Accessed on :20.04.2012.

Ha, N. V. 2011. [Unpublished work] Low land farming system in the Vu Gia - Thu Bon river basin in climate change context: Case study in Que Xuan 1, Que Xuan 2 communes (Que Son district). [M.Sc. Thesis submitted to ITT, Cologne University of Applied Science]

Hoek, van der Wim, et al. 2001. Alternate wet/dry rice cultivation: a practical way to save water and to control malaria and Japanese enchapilitis?. Research report 47. Columbo, Sri Lanka: International Water Management Institute.

IRRI [International Rice Research Institute], 2009a. IRRI fact sheet on Alternate Wetting Drying irrigation method. [pdf] Available: http://www.knowledgebank.irri.org/factsheetsPDFs/watermanagement_FSAWD3.pdf. Accessed on 05.03.2012.

IRRI[International Rice Research Institute] , 2009b. IRRI fact sheet on aerobic rice. [pdf] Available: http://www.knowledgebank.irri.org/factsheetsPDFs/watermanagement_FSAerobicRice3.pdfAccessed on 06.03.2012.

Janaiah, et al., 2004. ADB/WB 2004 report. Report of the Project Poverty Reduction Impact of Public Spending on Large-Scale Irrigation Systems in Vietnam. [submitted to Asia Development and World Bank]

Mainuddin, M. and Kirby, J.M. 2009. Spatial and temporal trend of water productivity in the lower Mekong river basin. Agricultural Water Management. 96(11): 1567–1578

Pereira, L.S., et al. 2012. Improved indicators of water use performance and productivity for sustainable water conservation and saving. [Journal Article] Agricultural Water Management. Number 108 (2012) P. 39– 51.

Quang Nam Statistical Office [QSO]. 2010. Planted Area of Paddy by district. [html] Available: http://www.qso.gov.vn/NGTKweb10/home1024.htm. Accessed on: 20.04.2012.

Sato, S. and Norman U. 2007. Raising factor productivity in irrigated rice production: opportunities with the system of rice intensification. [Internet] Available at: http://www.iai.ga.a.u-tokyo.ac.jp/j-sri/meeting/sri-uphoff-sato.pdf. [Accessed 07 March 2012.]

Seckler, D. et al. 2003. The Concept of Efficiency in Water resources Management and Policy. In: Kijne, J. W. II. Barker, Randolph. III. Molden, D. J. (Eds) 2003. Water productivity in agriculture: limits and opportunities for improvement. CABI international. Wallingford, Oxon, UK.

Taniyama, S. 2002. Water Resources and Rice Paddy Cultivation in the Asian Monsoon Region. [internet] Available at: http://www.bvsde.paho.org/bvsacd/dialogo/taniyama.pdf. [Accessed on 28 April 2012]

Tenbrock, M. 2011.Unpublished work. The Impact of Irrigation with Saline Water on the Soil Status in Vu Gia-Thu Bon River Basin, Central Vietnam. [M.Sc. Thesis submitted to ITT, Cologne University of Applied Science]

Thomas, Timothy; Christiaensen, Luc; Do, Quy Toan; Trung, Le Dang. 2010. Natural disasters and household welfare : evidence from Vietnam. Policy Research working paper No. WPS 5491. VN-Natural Disasters Management In Vietnam And Weather Insurance Project P103757. [html] Available: http://econ.worldbank.org/external/default/main?pagePK=64165259&theSitePK=469372& piPK=64165421&menuPK=64166093&entityID=000158349_20101203104559. Accessed on 20.04.2012.

Thompson, L. n.d. A farmer-centric approach to decision-making and behavior change: unpacking the 'black-box' of decision making theories in agriculture. [Internet] Available at: http://www.tasa.org.au/conferences/conferencepapers09/papers/Thompson,%20Lyndal-Joy.pdf. [Accessed on 10 June 2012]

Toan, P. P. 2011. Adaptive water-sharing in the Vu Gia-Thu Bon Basin. CRBOM Small Publications Series No. 32. [Internet] Available at: http://www.crbom.org/SPS/Docs/SPS32-VGTB.pdf. [Accessed 21 April 2012]

Tung, H. T. and Yoshiro H. 2010. Risk management for Rice value chain to adapt with climate change in the Mekong river delta, Vietnam (University of Tsukuba's Publication. [Internet] Available at: http://jsrsai.envr.tsukuba.ac.jp/Annual_Meeting/PROG_48/Resume4/rD04-2%20HoangTung.pdf. [Accessed 14 April 2012].

United Nations Convention to Convert Desertification [UNCCD] .2009. Water scarcity and desertification. UNCCD thematic fact sheet series. No. 2. [Fact sheet] Available at: http://www.unccd.int/Lists/SiteDocumentLibrary/Publications/Desertificationandwater.pdf [Accessed 07 March 2012.]

van Halsema, G. E. and Linden V. 2012. Efficiency and productivity terms for water management: A matter of contextual relativism versus general absolutism. [Journal Article] Agricultural Water Management. Number 108 (2012) P. 9– 15.

Vu, H. L. 2012 Efficiency of rice farming households in Vietnam, International Journal of Development Issues, Vol. 11 Issue: 1, pp.60 – 73.

Yoshida, S. 1981. Fundamentals of Rice Crop Science. First edition. IRRI, Los Banos, the Philippine.

Zhang, H. and Liu D. 2006. Fuzzing modeling and fuzzing control. Birkhäuser Boston.

Zawawi, M. A. M., et al. 2010. Determination of Water Requirement in a Paddy Field at Seberang Perak Rice Cultivation Area. The Institution of Engineers, Malaysia [online] 71 (4) Available at: http://dspace.unimap.edu.my/dspace/bitstream/123456789/13717/1/032-041Determination%20of%20Water%206pp.pdf [Accessed 26 April 2012]

Zwart, S. J. and Wim G.M. B. 2004. Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Agricultural Water Management. Vol 69. Issue 2. P 115-133.