Rice-Based Cropping Systems in the Delta of the Vu Gia Thu Bon River Basin in Central Vietnam

Rui Pedroso, Dang Hoa Tran, Viet Quoc Trinh, Le Van An and Khac Phuc Le

Abstract Despite high pressures for agricultural land conversion, increasing competition for water, and the relatively low net benefits of rice production, rice is still by far the predominant farm occupation in the Vu Gia Thu Bon basin in Central Vietnam. This study examined the reasons for such persistence by surveying and analyzing a comprehensive set of qualitative (planting and harvesting dates) and quantitative data (yields, labor and nonlabor inputs, prices) for all the crops present in the cropping systems of 113 farms in the region. The net benefit derived from rice production was on average 23 M VND ha^{-1}, with a relatively low labor input of 144 man-days per ha^{-1}. The net benefits generated by vegetable production are more than 9 times higher (ca. 215 M VND ha^{-1}) with a labor demand of ca. 928 man-days ha^{-1}. Despite the very high net benefits of vegetable production, in this region they do not translate into an equivalently high added value per ha and man-day. These values are 'only' nearly double than those for rice, and not much higher than those for watermelon, chili, and groundnut. The results indicate that farmers' decisions for not rushing in diversifying production to vegetables are wise when looking at the high risks of vegetable production, shortage of on-farm labor resources, and high opportunity costs of nonfarm labor opportunities. Rice is a robust crop and a pillar of families' food security, demanding low labor inputs. Under current conditions, farmers will most probably continue predominantly cropping rice. There is nevertheless the need to improve the rice system. Technical efficiency of rice production in the delta of the VGTB basin is 78 %, a low figure if compared to recent average estimations of 86 % for the Vietnamese Mekong and Red River deltas. The small scale of production, land fragmentation and irrigation challenges due to salinity intrusion are the main factors impacting on technical efficiency in the region.

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Introduction

Vietnam is one of the biggest rice exporters worldwide, a success due to extensive land and market reforms and introduction of new technologies over the last 30 years. Rice production was decentralized and markets liberalized inducing higher rice prices. Farm profits are now retained by farmers giving people the incentives to invest on the farm These changes have induced an enormous increase in total factor productivity (TFP) and Vietnam managed to strongly reduce rural poverty during this period (Hansen and Nguyen 2007; Kompas et al. 2012) Nevertheless these achievements, there are strong signs of a TFP slowdown in Vietnam since 2002. This can be witnessed in all rice producing regions except for the Mekong River Delta (Kompas et al. 2012). The latter authors speak in this context from restrictions on land use and market regulations that still call for further reforms. The pursue of land consolidation by abolishing restrictions on land size and the effective development of real estate markets and land property rights are recognized here as decisive for setting TFP back on track. Land fragmentation is seen as a major factor explaining efficiency and productivity of rice production in Vietnam. The country's agricultural land fragmentation was mainly caused by the land allocation process during the reform years in the course of the Doi Moi policy (World Bank 2003; Van Hung et al. 2007; Linh 2012). The process of land allocation was based on strong equity principles between households, which led to the distribution of rather small land plots to households with different locations within the communes and land qualities (Ravallion and van de Walle 2001; Van Hung et al. 2007; Linh 2012). Moreover, the rapidly growing population and strong urban developments have reclaimed a huge amount of agricultural land for urban and industrial development; between 2001 and 2010 ca. 1 million hectares (World Bank 2011). The disruption of Rice landscapes can impact on irrigation systems and on rice production efficiency. The new official socioeconomic development plans for the Quang Nam province indicate high current and future rates of land conversion from agriculture to other uses specially tourism along the coastal line (PPC Quang Nam 2012; Quang et al. 2014). Despite these evidences, the official statistics regarding rice production for the whole province show only small acreage decreases since 2000. The cultivated area of rice per year in the Quang Nam province shows a change from 94,360 ha in year 2000 to 87,904 ha in year 2013, a decrease of 6456 ha (ca. 7 %). The lowest yearly cultivated area registered during this time was in year 2006, with a minimum of 83, 631 ha, a reduction of about 11 % (Fig. 1). According to these statistics, total rice output has kept a continuous positive trend in the last years, where decreases in planted area could be compensated by yield improvements (Fig. 2). The other two most important staples in the region are cassava and maize, which are growing at very high rates. The planted area of Maize has grown ca. 47 % between 2000 and 2013. Cassava shows the second highest growth rate with ca. 31 % in the same time period. According to key experts' interviews the high growth rates of these two crops is due to the higher demand for animal fodder in the case of Maize and in the case of Cassava due to the strong

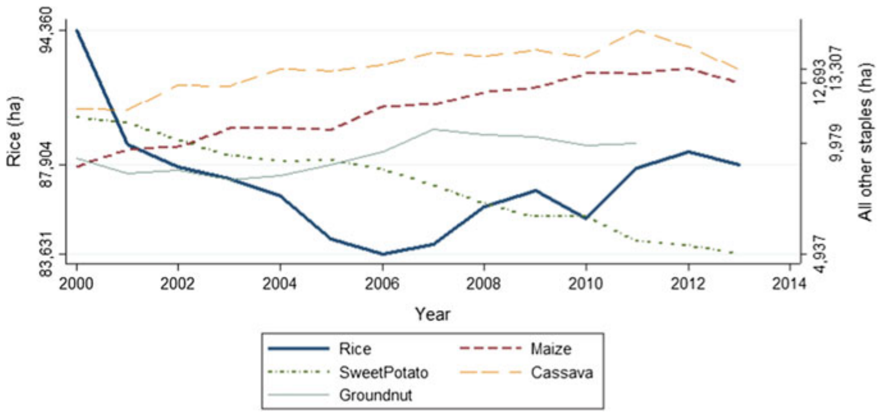

Fig. 1 Planted area (ha) of main staples for whole Quang Nam

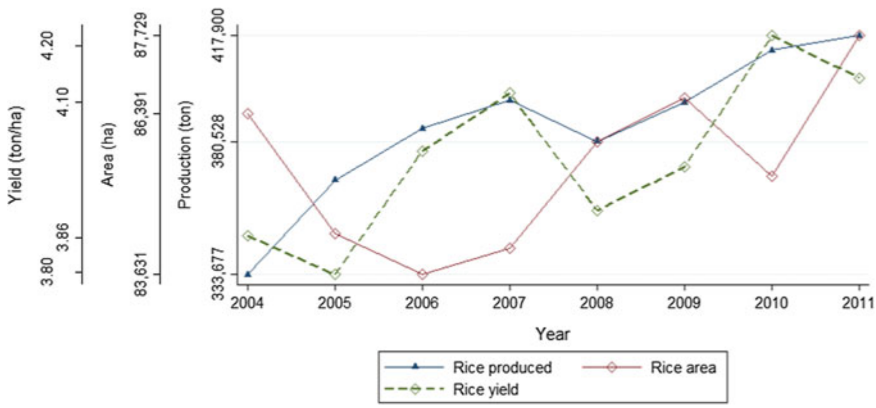

Fig. 2 Rice production, area and yields for the whole Quang Nam province

export demand, especially to China for biofuel processing. Groundnut is another staple of the region showing an increasingly importance for peoples livelihoods (see Fig. 1).

The spatial production distribution can be seen in Fig. 3 with acreage figures for the year 2013. Accordingly, the largest rice producers are the districts Thang Binh with over 15,900 ha, followed by Dien Ban (11,412 ha), Dai Loc (8,707 ha), Duy Xuyen (7,735 ha), Que Son (6,800 ha), Nui Thanh (7,515 ha) and Phu Ninh (6,767 ha). All other districts in Quang Nam show production levels lower than 5000 ha. Cassava is the second most produced staple; the districts located on the coast are again the largest producers with Que Son (2,552 ha), Nui Thanh (2,350 ha) and Thang Binh (1,193 ha). Maize is the third staple in Quang Nam and mostly produced in Dien Ban (2,133 ha), Dai Loc (1,778 ha) and Nam Giang (1,145 ha). Groundnut is typically cultivated in Thang Binh (2,284 ha), Dien Ban

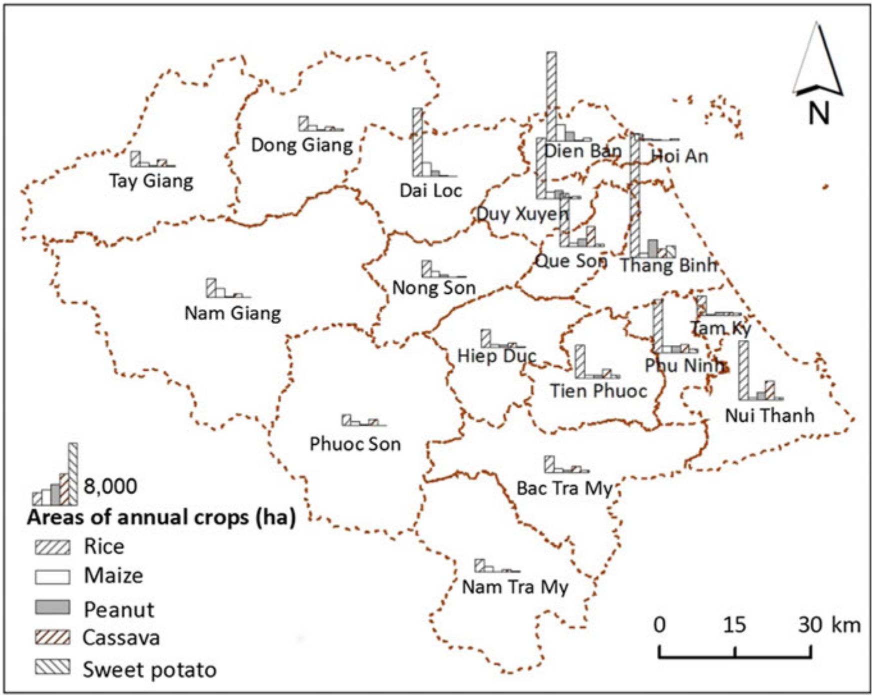

Fig. 3 Planted areas and spatial distribution of most important staples in Quang Nam for 2013

(1,164 ha) and Duy Xuyen (1,102 ha). Sweet potato is mainly produced in the Thang Binh district (1,601 ha), all other districts show acreage values under 500 ha for 2013. Agricultural production in the upland districts is quite marginal when compared with the acreages found in the lowlands of the Vu Gia Thu Bon delta.

Besides land conversion and fragmentation, another important pressure on agricultural communities in this region is the impact of climate change and climate variability. Vietnam's coast line and deltasDelta, where most rice is grown, are very much exposed to flooding, extreme weather events, sea level rise and salt water intrusion. These factors increase the population's vulnerability to food insecurity and poverty, making agriculture a hazardous proposition (MONRE 2009; Chung et al. 2015).

This study focus on the delta of the Vu Gia Thu Bon river basin (VGTB) mainly located in the Quang Nam province in Central Vietnam. The delta can be characterized by 13 rice irrigation zones delineated according to their hydraulic connectivity as in Fig. 4 (Viet 2014). The delta of the VGTB river basin is where the most fertile soils for rice production are found and where most of rice production takes place. Rice production is by far the most important activity and mainly found in the alluvial plains of the delta (see also Fig. 3).

The main objective of this study is to characterize rice production in the delta of the VGTB river basinRiver basin in terms of yields, crop benefits, input demand,

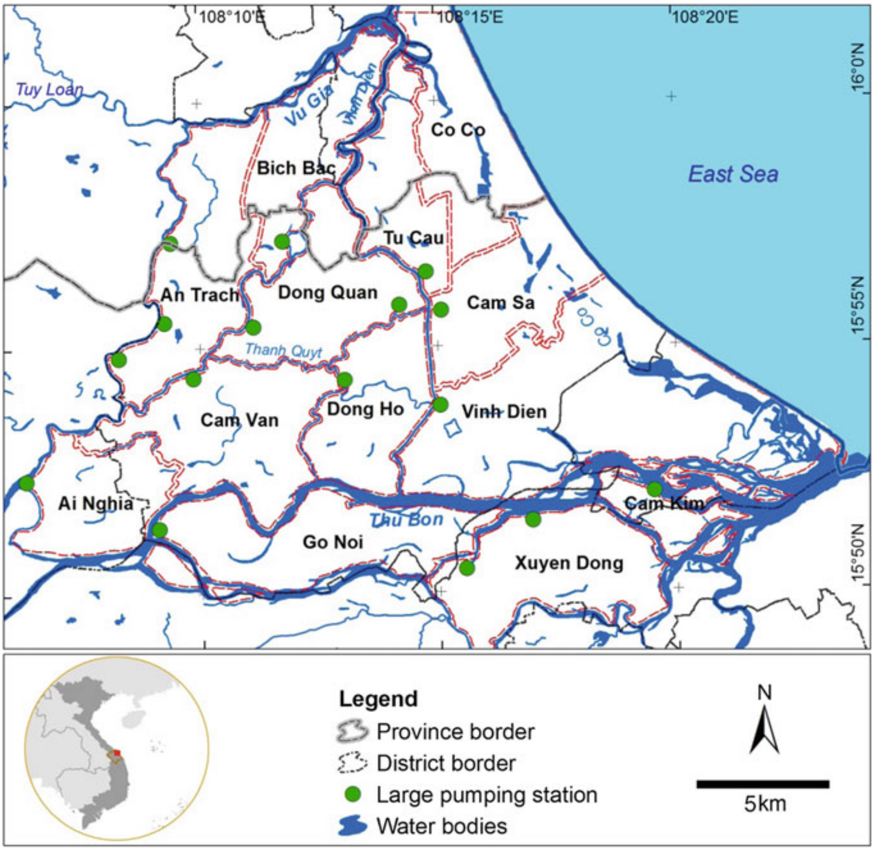

Fig. 4 Study region in the delta of the VGTB river basin, Quang Nam province

profitability, and technical efficiency (TE). The analyses are divided in two main sections: a more descriptive one, where rice production is compared to the other most important crops in the delta, and a more strict section, where we apply stochastic frontier methods to analyze the average TE of rice production at different temporal and spatial scales, i.e., across the WSp and SA seasons, and also across the different irrigation zones.

Descriptive Analysis of Crop Production in the Delta of the VGTB River Basin

A survey was performed in 2013 with a sample of 113 farmers from most representative communes for the different lowland irrigation zones (Fig. 4). The choice of representative communes from which farmers were randomly chosen was based

Table 1 Representative communes for the irrigation zones

Irrigation zone	Commune
Ai Nghia	Dai Hoa
Cam Van	Dien Tho
An Trach	Dien Tien
Dong Quang & Bich Bac	Dien Hoa
Dong Ho	Dien An
Go Noi	Dien Quang
Tu Cau & CoCo	Dien Ngoc
Cam Sa & Vienh Dien	Cam Ha
Xuyen Dong & Cam Kim	Duy Phuoc

on interviews with key informants and local authorities in the lowlands districts Dai Loc, Dien Ban, Duy Xuyen, and Hoi An (Table 1).

The sampling procedure was a compromise between budget constraints and statistical representativeness. A comprehensive questionnaire was applied to each of the selected farm households including sections on: (1) household characteristics, (2) yields for all crops, rotations and crop calendar, (3) inputs of crop production, (4) disposal and marketing of agricultural products, and other relevant sections. All prices in this study refer to 2013 levels. One can say that the survey results will remain valid for a considerable period of time before becoming obsolete. This assumption is based on the fact that inflation in Vietnam is under control (ca. 4.1 % between 2011 and 2015, World-Bank 2016). The study fits in the five year plan (2010–2015) of the Provincial People's Committee (PPC) so that cropping patterns are not expected to change much in this period.

We have calculated farm household's crop net benefits per hectare, where net benefits are defined here as the difference between total gross benefits and total variable costs. This can also be called the gross benefits to a family's labor, management, land, and capital. The total gross benefit calculated for rice and groundnut included the opportunity value of home consumption. Gross benefit is, for these two crops, calculated as the sum of the annual production sold in the market, the amount disposed for paying wages, or feeding animals, and multiplied by the farm gate price, plus the opportunity value of the proportion of total production further processed and consumed by the family. For all other crops gross benefits equal only total production multiplied by the farm gate price. Rice and groundnut are two crops in the region for which more than 50 and 75 % of production, respectively, is consumed by the family. Not accounting for the opportunity value of the crops would lead to an undervaluation of the farm household crop benefit. The rice reserved for home consumption is milled in local mills after harvest and stored at home. We assume that only 62 % of this rice is actually consumed after accounting for whole processing losses (assumption based on interviews with local key informants). The rice consumed is valued at 13,000 VND Kg^{-1}. The farm gate price for rough rice is 7,000 VND Kg^{-1} on average. Groundnut is basically produced in the WSp season under rain-fed conditions. Local households further process groundnut to cooking oil. We assume, based on key informants' interviews, that from 100 kg of harvested rough groundnut, 70 kg are grains (70 %). Furthermore and also based on experienced key informants, we assume that 3 kg of groundnut grains produce 1 L of cooking oil. The farm gate price for rough groundnut is on average 25,842 VND Kg^{-1}, the price for one liter groundnut oil was judged at 100,000 VND L^{-1}.

Subtracting total costs incurred for seeds, organic and chemical fertilizers, pesticides, hired labor, irrigation costs, and any other variable costs, we calculate the net benefits to families' labor, management, land, and capital. Added value per hectare and man-day was calculated by excluding hired labor costs from the total costs calculation (i.e., net benefits to the production factors labor, land and management) and divided by the labor demand.

The net benefits for vegetables were calculated for each individual family species and averaged. The vegetable labor demands were assessed for each field operation. For comparing different vegetable species, calculations should be done not only on a per unit of area basis but also on per unit of time in the field (Huong et al. 2013b). The vegetable values in this study were converted to units per hectare (ha) and per growing day (Gday) on the field. Household labor power supply was defined in terms of those individual members who participate in income activities. It included persons who are part of the family unit, reside at the household site and are actively involved in generating income. A man-day of work was defined here as the amount of work that can be carried out by an adult male in an 8-hour work day. Because the work productivity differs between males, females and people in different ages, we have calculated the household's on-farm labor supply in terms of man-day equivalent. This calculation is normally done by using standard conversion weights applied to males and females in different age groups (see Norman 1973).[1]

Cropping Pattern in the VGTB Delta Region

The typical cropping pattern of the average farm household across the four cropping seasons can be seen in Table 2. The total sample area dedicated to each crop in the respective season was averaged across the 113 farmers found in the sample (the number of farmers in the sample cultivating a crop in the season can be seen in brackets). The two main rice cropping seasons are the Winter–Spring (WSp) season starting around December 25 and ending by mid-May and the Summer–Autumn (SA) season, starting by the end of May until mid-September (rice–rice system). The Spring–Summer season (SpS) starts in April, and the Autumn–Winter

[1]Labor supply calculations are presented in a submitted different article. Information can be provided on request.

Table 2 Average area (sao) allocated per farm and season to the main annual crops

Crop	WSp		SpS		SA		AW	
Rice	4.31	(113)			4.36	(113)		
Maize	1.25	(50)	0.13	(9)	1.95	(66)	0.02	(1)
Groundnut	1.24	(62)			0.05	(2)		
Watermelon	0.35	(7)	0.16	(2)				
Chili	0.32	(14)						
Vegetables	0.16	(15)	0.06	(7)	0.05	(7)	0.06	(9)
Tobacco	0.10	(4)						
Mung bean	0.06	(3)	0.60	(22)	0.54	(20)		
Sweetpotato^{+}	0.06	(4)	0.01	(2)	0.08	(6)	0.11	(8)
Sesame	0.01	(1)	0.08	(3)	0.26	(17)		
Cassava	0.01	(2)	0.03	(2)				
Kumquat	0.06	(3)	0.06	(3)	0.06	(3)	0.06	(3)
Banana	0.01	(1)	0.01	(1)	0.01	(1)	0.01	(1)
Fallow	0.0		6.8		0.5		7.6	
Cultivated	7.9		1.1		7.4		0.3	

1 sao = 500 m^2
In brackets is the number of farmers cultivating the crop in the season
$^{+}$Sweetpotato for roots

(AW) starts around September, both seasons are not foreseen for rice. In the WSp and SA rice seasons nearly 100 % of the farm is cultivated, while in the SpS 14 % and in the AW season only 3 % of the farm is under cultivation. The sample average farm size is 7.9 sao, which is about 0.4 ha (1 sao equals 500 m^2). The main crops cultivated per farm in the WSp season are rice (4.31 sao), maize (1.25 sao) and groundnut (1.24 sao). They are followed by watermelon (0.35 sao), chili (0.32 sao), vegetables (0.12 sao) and tobacco (0.10 sao). All other crops have very small average acreages, e.g., cassava is of nearly no importance in the delta region, it is however the second most important staple in the whole Quang Nam district. Vegetables are basically grown all-year round, the species found in the sample are amaranth, bitter gourd, bottle gourd, chinese mustard, coriander, cucumber, lettuce, malabar spinach, sweet potato (vines), mint, okra, spring onion, water spinach, and wax gourd. Kumquat[2] and banana are typical perennial crops of the region but not grown by many farmers. In the SA season, rice is again the main crop (4.36 sao) followed by maize once more (1.95 sao). Groundnut is basically substituted by mung bean (0.54 sao) and sesame (0.26 sao). Sesame is a drought resistant crop and very much suitable for the SA season.

[2]Kumquat is an evergreen tree, producing edible golden-yellow fruits resembling small oranges. Mostly found in the coastal areas.

Production

The study region is mostly characterized by fertile alluvial soils and good irrigation conditions (Viet 2014), we estimate rice yields of 5.5 t ha^{-1} in the WSp season and 5.1 t ha^{-1} in the SA season. Maize achieves average yields of ca 5.6 t ha^{-1}, which can be considered rather high for the region (Ha et al. 2004). Groundnut is the third most important staple achieving yields of 2.45 t ha^{-1}. The most important cash crops in the WSp season are watermelon, chili, vegetables, and tobacco. Vegetables are grown all year-round with a yearly average of ca. 27 t ha^{-1}. Tobacco is mostly grown in the WSp season and yields reach 2.7 t ha^{-1} on average. In the SA season groundnut is no longer grown, instead of it mung bean (2.5 t ha^{-1}) and sesame (0.5 t ha^{-1}). Sweet potato is cultivated all-year round either for home consumption (vines as family vegetables, and roots for animal feeding) or as cash crop, i.e., for selling vines only. When cultivated for the family sweet potato shows little inputs, yields and net benefits. When cultivated for vines, sweet potato is followed by farmers as intensive vegetable cultivation, the level of inputs is very high, as well as yields and net benefits (detailed production data is presented in Pedroso et al. 2017).

Inputs

Regarding the labor inputs, the total average labor use in rice is 144 man-days ha^{-1}, which is, after sesame with 119 man-days ha^{-1}, the lowest labor input of all crops. Maize shows an average labor input of 213 man-days ha^{-1} and groundnut 215 man-days ha^{-1}. The vegetables labor input is calculated per hectare and per growing day in the field (Gday). The vegetables labor demand averaged over all the different species is 9.1 man-day ha^{-1} $Gday^{-1}$. Taking the vegetables average growth duration of 102 Gday and multiplying both figures gives a 928 man-day ha^{-1} average labor demand for vegetables (A detailed analysis of labor and nonlabor inputs is presented in Pedroso et al. 2017).

Profitability of Crop Production

The average yearly net benefits for the most relevant crops in the lowlands can be seen for the two main seasons in Table 3. Rice and maize net benefits in the WSp season are relatively low, achieving ca. 24 M VND ha^{-1} and 21 M VND ha^{-1} respectively.[3] The average value for rice slightly declines in the SA season to ca. 22 M VND ha^{-1}, which is about the same value of maize in this season. The low

[3]The average exchange rate for the year 2013 was ca. 26,000 VND EUR^{-1}. This means that the 24 M VND ha^{-1} net benefits for rice are equivalent to ca. 923 EUR ha^{-1}.

Table 3 Average benefits, variable costs and added values (‘00000 Dong ha^{-1}) for the crops of the two main seasons and year-round vegetables

Gross benefit per hectare						Variable costs per hectare				Net benefits per hectare to family labor, land, management and capital				Added value per man-day			
	N	Mean	Min	Max	CV	Mean	Min	Max	CV	Mean	Min	Max	CV	Mean	Min	Max	CV
WSp season																	
Rice	113	420	98	681	0.25	184	90	306	0.20	236	−44	438	0.44	1.7	−0.2	3	0.41
Groundnut	62	626	126	2022	0.59	85	35	185	0.36	541	57	1928	0.67	2.5	0.3	9	0.67
Maize	50	363	146	700	0.29	153	10	469	0.62	210	−142	470	0.57	1.0	−0.7	2	0.56
Chili	14	999	504	1733	0.36	317	92	674	0.51	682	188	1553	0.57	2.9	0.8	7	0.56
Watermelon	7	947	300	2400	0.71	136	71	216	0.46	810	91	2327	0.88	3.1	0.4	9	0.87
Tobacco	4	1004	570	1540	0.41	149	101	190	0.25	854	4	1390	0.48	2.2	1.1	4	0.47
Sweet potato[+]	4	9.9	5.3	15	0.44	6.5	2.5	15	0.89	3.4	−3.2	12	1.95	0.01	−0.01	0.04	1.95
SA season																	
Rice	113	401	53	2236	0.53	180	85	417	0.26	221	−62	1925	0.89	1.6	−0.2	9	0.84
Maize	66	335	131	786	0.32	115	5	278	0.42	220	−47	653	0.49	1.0	−0.2	3	0.48
Mung bean	20	382	10	846	0.45	69	34	166	0.55	313	−32	800	0.56	1.4	−0.1	4	0.56
Sesame	17	149	32	480	0.72	36	10	108	0.77	112	18	372	0.84	0.9	0.2	3	0.83
Sweet potato[+]	6	13	1.3	41	1.10	27	6.8	60	0.73	−14	−33	4.5	−0.86	−0.1	−0.1	0.0	−0.86
Year-round																	
Vegetables*	23	2332	540	5760	0.70	247	21	812	0.67	2084	227	5483	0.75	3.2	0.5	11	0.69

[+]Cultivation for home consumption only (vines for the family, roots for livestock feeding). Values for vines for the market are presented in Pedroso et al. (2017)

*Detailed statistics for each vegetable species and planting dates are found in Pedroso et al. (2017)

values are mostly connected with the low farm gate prices of ca. 7,000 VND Kg^{-1} for rice and ca. 6,200 VND Kg^{-1} for maize. Groundnut shows the highest net benefit of the three staple crops with 54 M VND ha^{-1}. The average added values per man-day are 165 K VND man-day^{-1} for rice, 102 K VND man-day^{-1} for maize, and 252 K VND man-day^{-1} for groundnut. Added value man-day^{-1} for rice and maize are low and below the region's average wage rate of ca. 200 K VND man-day^{-1}. As a result, the added value per man-day of groundnut cultivation is 2.5 times that of maize and ca. 1.5 times higher than that for rice. This is mainly because of the high groundnut farm gate price of ca. 26,000 VND Kg^{-1}, and the further processing of groundnut to cooking oil.

The cash crops sesame and mung beans are grown mainly in the SA season and present modest net benefits of ca. 11 M and 31 M VND ha^{-1}. The other cash crops chili, watermelon, tobacco, and vegetables, present much higher net benefits per hectare, achieving nearly 70 M VND ha^{-1} for chili, to over 215 M VND ha^{-1} for vegetables (see Table 3). The vegetable net benefits are nearly 9 times higher than those of rice. Because of the very high labor requirements of vegetables, the relatively very high net benefits of vegetables crops do not translate into equivalently high added value per man-day. Vegetables have an added value of ca. 320 K VND man-day^{-1}, which although nearly double that for rice, is only slightly higher than watermelon and chili, and not much higher than groundnut. The relatively very low labor demand of the rice crop translates into an added value per man-day that is higher than maize, mung bean and sesame, and not much lower than tobacco.

Technical Efficiency in Rice Production in the VGTB River Basin

We follow an output oriented specification of the stochastic frontier production function (Kumbhakar and Lovell 2000)

$$\ln y_i = f(\boldsymbol{x}_i; \beta) + v_i - u_i \tag{1}$$

In Eq. (1) the i subscript denotes observations (farms), y_i is a scalar of observed output, $f(\boldsymbol{x}_i; \beta)$ is a log-linear Cobb–Douglas production function, where x_i is a $1 \times J$ vector of input variables (factors of production), β is the corresponding $J \times 1$ vector of coefficients. The random error v_i is assumed as having zero-mean and normal distributed, and the production inefficiency error term u_i is assumed to have a half-normal distribution. We account for heteroscedasticity in the modelModel. Ignoring it in v_i would produce biased estimates of technical inefficiency and a downward biased estimate of the intercept in β. Ignoring heteroscedasticity in u_i causes biased estimates of the β parameters and of technical inefficiency estimates (Kumbhakar and Lovell 2000; Wang and Schmidt 2002). Because we have assumed a half-normal distribution of u_i, heteroscedasticity is dealt with in this study by parametrizing σ_u^2 (for more details Caudill et al. 1993; Hadri 1999; Battese and Coelli 1995; Wang and Schmidt 2002). The Cobb–Douglas specification in Eq. (1) was chosen including originally in x the variables[4]: *land* (sao), *labor* (man-day sao^{-1}), *capital* (VND) and variable costs *varc* (VND). The variable *land* (sao) representing the acreage for rice in each farm was dropped from the Cobb–Douglas function in the final specification due to collinearity problems. This variable was however included in the heteroscedasticity equation, where several other variables possibly related to technical inefficiency were also included. These variables are related to land fragmentation (the total number of plots in the farm, the average plot area, or the distance from the plots to the homestead and to the nearest market), variables related to education and experience (school attendance and age), or variables related to environmental factors (perceived soil fertility and a proxy for salinity water intrusion in the SA season). The model parameters are estimated through maximization of the log likelihood function (see Kumbhakar and Lovell 2000).

Stochastic Frontier and Inefficiency Model Estimates for Rice Production

The technical efficiency in rice production is compared for the WSp and SA seasons by using the same specification in both models. The variables in the inefficiency models related to education, age, the total number of plots in the farm, the average plot area, or the distance from the plots to the homestead and to the nearest market, as well as soil fertility, were found not significant in both WSp and SA models and dropped from the specifications.[5] The estimates are presented in Table 4 (least squares models indicated as OLS and stochastic frontier models as SF).

The signs of the elasticity coefficients of the SF functions are as expected and are highly significant in both season models. The sum of elasticities for the input variables gives 1.24 in the WSp and 1.18 in the SA model. The hypotheses of constant returns to scale (CRTS) cannot be rejected in any of the models of Table 4 as given by the χ_1^2 statistic. The likelihood ratio test (LR) against the null hypothesis of no technical inefficiency (OLS) (three degrees of freedom), has a value of 12.672 in the WSp model and a value of 17.459 in the SA model. The critical value at the 0.01 significance level is 10.501 (see Kodde and Palm 1986). It can be understood hereafter that the null hypotheses of no technical inefficiency can be rejected for both WSp and SA models.

In the inefficiency model, the estimated coefficients of *land* (rice acreage) and *rplots* (number of rice plots on the farm) are both significant for the WSp season, *rplots* appears slightly nonsignificant in the SA model.

[4]Descriptive statistics on these variables are presented in a forthcoming study by the authors. Information can nevertheless be delivered upon request.

[5]Descriptive statistics on these variables are presented in a forthcoming study by the authors.

Table 4 Maximum likelihood and OLS estimates

	WSp		SA		
Independent variable ln prod	OLS	SF	OLS	SF1	SF2
ln labor	0.382*** (4.46)	0.323*** (4.07)	0.482*** (5.18)	0.374*** (4.66)	0.378*** (5.08)
ln capital	0.323** (2.11)	0.291** (2.08)	0.221 (1.06)	0.306** (2.03)	0.272 (1.88)
ln varc	0.643*** (7.64)	0.622*** (8.30)	0.537*** (5.76)	0.497*** (5.59)	0.506 (6.56)
Intercept	−1.152 (−1.40)	−0.398 (−0.52)	−3.924*** (−2.73)	−3.03*** (−2.49)	−3.094*** (−2.82)
Sum of coefficients χ^2_1 statistic for CRTS		1.24 2.37		1.18 1.38	1.16 1.17
ln σ^2_υ		−3.140*** (−10.92)		−3.544*** (−10.17)	−3.374*** (3.46)
Inefficiency model					
land		−0.509** (−2.15)		−0.387** (−2.33)	−0.490** (−2.34)
rplots		0.490* (1.81)		0.204 (1.13)	0.362 (1.54)
pumping					−0.318*** (−4.08)
intercept		−1.678*** (−2.80)		−0.688 (−1.46)	5.47*** (3.46)
R^2	0.81		0.80		
Log likelihood		−11.99		−21.27	−6.725
LR statistic+		12.67		17.46	46.54
Observations 113					

t Statistics in parentheses
**p* < 0.10, ***p* < 0.05, ****p* < 0.01
+The likelihood ratio test statistic $LR = -2log[Likelihood(H_0)] - log[Likelihood(H_1)]$, has a chi-squared distribution with degrees of freedom (*df*) equal to the number of parameters assumed to be zero in the null hypotheses, H_0, provided H_0 is true. The critical values of the distribution for three *df* 10.501 for significance level of 1 %
Kodde and Palm (1986)

For the WSp model, the calculated marginal effects of *land* on the unconditional mean of u_i is negative and equals −0.060. The level of inefficiency can be reduced, on average, by 6 percent for every 1 percentage increase in land acreage. The marginal effects of *rplots* are positive and equal 0.05. This means that the level of inefficiency rises, on average, by 5 percent for every 1 percentage increase in *rplots*.

For the SA model, the calculated marginal effects of *land* and *rplots* on the unconditional mean of u_i, are similar to the WSp. The calculated marginal effect of

Table 5 Technical efficiency estimations for the delta irrigation zones

	WSp (%)	SA (%)	Rice area (ha) in 2010
Ai Nghia	84.1	82.3	876.3
Cam Van	86.2	79.5	2037.5
An Trach	84.3	72.8	1553.1
Dong Quang & Bich Bac	72.6	71.1	1724.9
Dong Ho	84.1	79.4	1265.8
Go Noi	81.0	77.6	941.9
Tu Cau & Co Co	76.1	50.5	808.8
Cam Sa & Vienh Dien	77.6	70.8	2130.7
Xuyen Dong & Cam Kim	82.2	78.9	1627.7
	81	74	12,966.9

the variable pumping is in the SA negative and equals -0.041. The level of inefficiency can be reduced, on average, by 4.1 percent for every 1 percentage increase in the available time for pumping (salinity reduction). The efficiency scores were calculated for each farm individually and averaged for each irrigation zone (Table 5). The temporal and spatial distribution of efficiencies is quite interesting and corresponds to expectations. We calculate an average TE of 81 % for the WSp and 74 % for the SA season (weighted according to the 2010 areas of the irrigation zones). As expected the efficiencies are lower in the SA season. This season presents a greater challenge to farmers in terms of irrigation management (water availability and salinity intrusion events). This seems to have severe impacts on TE in the affected irrigation zones (see Fig. 4).

This is most evident in the Tu Cau and Co Co irrigation zones, where we have a dramatic drop on efficiency from 76.1 % in the WSp to 50.5 % in the SA season. These irrigation zones are very much affected by salinity intrusion in the SA season. Salinity intrusion reduces water availability and difficulties irrigation management, which is expected to impact on yields and efficiencies. The Tu Cau irrigationIrrigation zone receives water from the Vinh Dien river, which is extremely affected by salinity intrusion. The Co Co irrigation water comes from small lakes along coastal line, which are feed by the return flows of Tu Cau zone. Thus, the salinity intrusion in the Co Co is highly correlated with salinity intrusion in the Tu Cau irrigation zone (see Fig. 4). Technical efficiency in the Cam Sa and Vienh Dien irrigation zones is also very much impacted by salinity intrusion in the SA season although not as much as in Tu Cao and Co Co. Salinity intrusion in the affected irrigation zones is controlled at the pumping station level by constraining the available pumping hours to the irrigation zone. During events of salinity intrusion irrigation is stopped, i.e., the available water (available pumping time) for the respective irrigation zone is reduced.[6] Based on several years of operation data for the individual pumping stations, we constructed a risk index, the variable

[6]Events with salinity levels over the local threshold of 1.0 g L^{-1}.

pumping, expressing the available pumping hours under the impacts of saltwater intrusion (see Table 6). As the duration of available pumping hours is less than 3, pumping stations cannot operate to provide water for irrigation. As the duration of "fresh" water ranges from 4 to 12 h, it is unable to provide sufficient water. As the duration of "fresh" water ranges from 12 to 24 h, pumping stations can operate to provide sufficient water with care on unpredictable high saltwater intrusion.

We tested the hypotheses regarding the negative impact of salinity intrusion on technical efficiency by including the proxy variable *pumping* in the SA stochastic frontier model specification (see SF2 in Table 4). As it can be seen, the variable *pumping* is highly significant in the SA season and also negative, meaning that an increase in the available pumping hours (salinity reduction) would reduce technical inefficiency. Dong Quang and Bich Bac show very low efficiency levels as well. For Dong Quang these low levels seem to be related to salinity intrusion (see the east part of the irrigation zone along the Vinh Dien river in Fig. 4). For Bich Bac the low efficiency levels are most probably a consequence of the strong urbanization in the area and consequent land fragmentation. An analysis on the rates of land conversion in the last 15 years sheds some light on the causes for Bich Bac (see Table 7).

High-resolution land use maps (scale of 1:2000 and 1:10,000) in 2000 and 2010 were used to detect spatial changes in paddy rice and other annual crops during this period. The conversion of planted areas of paddy rice and other annual crops to

Table 6 Available pumping time for underthreshold salinity intrusion

Level	Hours
High	<3
Medium	4–12
Low	12–24
No	>24

Table 7 Land conversion changes (%) between 2000 and 2015

	Paddy	Other annuals
Ai Nghia	−2	0
An Trach	−3	−3
Bich Bac	−64	−45
Cam Kim	0	0
Cam Sa	−8	−5
Cam Van	−2	−2
Co Co	−48	−64
Dong Ho	−1	0
Dong Quang	−9	−4
Go Noi	−1	0
Tu Cau	−26	−10
Vinh Dien	−1	−3
Xuyen Dong	−2	−5

nonagricultural land uses for the 2010–2015 period is determined through updating urban development maps of both Quang Nam and Da Nang. In Bich Bac there were major land conversions to urban uses and road construction in the last 15 years, where ca. 64 % of paddy fields and 45 % of land for annual crops were lost. The urban development and road construction strongly impact on the irrigation system by disrupting connectivity, fragmenting and isolating large areas of paddy fields and making irrigation management extremely difficult (personal communication with the Irrigation Management Company in Quang Nam and own observations). The high land conversion rates impact on efficiencies as seen in the importance of factors like the scale of operations and fragmentation delivered in Tables 4 and 5. The Tu Cau and Co Co irrigation zones are other areas very much affected by land conversion and in this case also affected by salinity. Both factors impact on efficiency with dramatic consequences for the affected communes as can be seen in Tables 4 and 5 (Fig. 5).

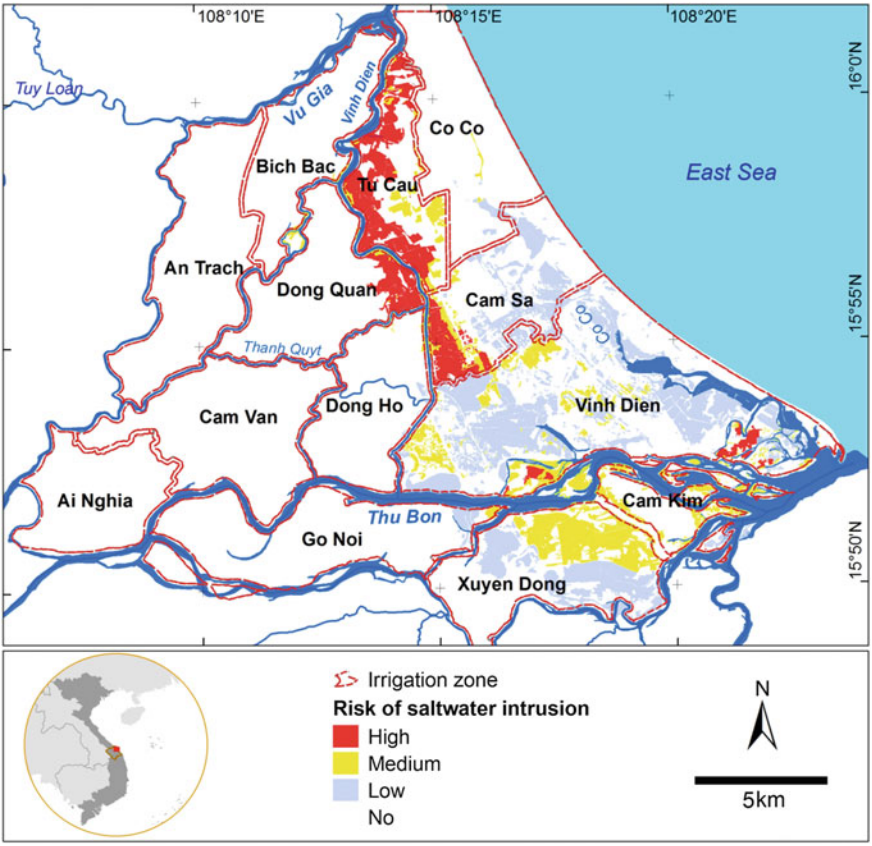

Fig. 5 Delta irrigation zones and salinity intrusion risk

Discussion

The results show that despite the low net benefits and added values of rice production, rice is still by far the dominant crop of the VGTB delta region. Rice plays a crucial role in families' food security and has an invaluable cultural role in the region. Furthermore, it is also a very robust crop, and by far the crop that demands the lowest labor inputs. The temporal distribution of labor demands is another advantage of rice production. Most labor is required at the beginning of the season for land preparation and sowing and again at the end of the season for harvesting and postharvest activities. During the season, the rice crop demands almost no labor from the farm household. This is a great advantage because the household can engage in nonfarm income activities. Maize is the second most important crop but shows very low net benefits and added value per man-day. Maize cultivation seems to be justifiable only because of the major role that maize plays in livestock feeding in the region (more than 40 % of own production is destined for feeding own animals). The market situation for maize is nevertheless changing rapidly in the region. The main driving factor is the growing demand for livestock fodder and the settlement of an international maize fodder processing company in the Dien Ban district (personal communication). These developments will surely bring some changes in the actual prices paid for maize. Groundnut is a very attractive crop not only because of its stable market demand and price, but also because farmers can process it into cooking oil if prices are not attractive enough. Despite the high net benefits of cash crops (especially vegetables) and increasing pressure on farmers for changing cropping patterns toward high value crops, farmers are reluctant to do so and areas used for high value crops are still very low. The main cause of this wise behavior of farmers lies in the very high labor demands and an added value per man-day that fall behind expectations. The households' labor force available for on-farm work is ca. 1.9 persons (for details see Pedroso et al. 2017). This labor force after conversion to equivalent man-days translates to only 1.6 man-days.[7] The typical farm size in the region is 0.4 ha, or 4000 m^2. Let us imagine a farm-household growing year-round vegetable on 1000 m^2, with an average net benefit of ca. 210 M VND ha^{-1}, and a labor requirement of 9.1 man-days ha^{-1} $Gday^{-1}$. This means that the family would need 0.91 man-day/1000 m^2/Gday. The vegetable labor demand would require about 60 % of the total available on-farm labor power (See Jansen et al. 1996; Huong et al. 2013a, b). If farmers increase the acreage of vegetables to 2000 m^2, they would need 1.8 man-days/2000 m^2/Gday, which now clearly exceeds the available labor power of 1.6 man-days equivalent available. Even though farmers would have enough labor power for cultivating vegetables on 1000 m^2, those growing vegetables only use 700 m^2 (1.4 sao) on average (for details see: Pedroso et al. 2017). The reasons for farmers' reluctance to diversify toward cash crops, in particular vegetables are nevertheless not exclusively related to the very high labor inputs. Many other reasons discourage farmers, e.g., high biotic and abiotic risks like high disease

[7]See Norman (1973) for an explanation of the weighting scheme.

and pest incidences, climatic conditions, lack of knowledge about vegetables technologies, or price risks. Moreover, the local value chains are rudimentary and do not ensure a reliable and fast marketing of highly perishable products, in particular to Da Nang city. The very small scale of vegetable production is another problem that causes lack of marketing control by the farmers.

The production of rice in the delta of the VGTB shows TE levels of 81 % in the WSp season and 74 % in the SA season, a yearly average of 78 %. This level of TE is quite lower than the value of 86 % currently found for the Mekong River Delta (MRD) and Red River Delta (RRD) (see Kompas et al. 2012). These authors also used stochastic production frontier (SFA) methods with a Cobb–Douglas (CD) production function specification. The authors use an own farm survey from 2004 for the Mekong River Delta (MRD) and Red River Delta (RRD). The main hypothesis of the study was that land consolidation in Vietnam is a challenge for increasing productivity and efficiency. The authors isolated the effects of farm size and average plot size as representatives for land fragmentation, as well as soil quality, irrigation quality and education level rankings. The total farm size and the average plot size of rice farmers are found to have a significant positive impact on efficiency, i.e., increasing farm and plot average size will increase farm efficiency. Our results for TE in the delta of the VGTB river basin also show similar results regarding the scale of production (the rice acreage) and the land fragmentation problem (the number of rice plots on the farm).

Conclusions

There is an increasing pressure on rice cultivation in the region, given high rates of land conversion for urbanization and industrial purposes, and also high competing demand for water in the SA season. There is also a broad discussion in favor of reducing rice acreages and intensifying agriculture toward high value crops like vegetables. The high net benefits achieved with vegetable production are known to the general public and decision makers in the region. Information on net benefits alone is however asymmetric, and in this way the public debate is biased. Current vegetable cultivation in the region, when analyzed in terms of added value per man-day^{-1}, is no longer as attractive as it seems at first glance. The very high labor demands for vegetables in the region do not allow the very high net benefits to translate into high added value per ha and man-day. The present study shows that farmers keep on holding to rice as the main crop and this decision is wise, and can be understood against the background of lack of on-farm labor force in the family, aging, increasing nonfarm income opportunities, and the lower than expected added value per man-day in respect of vegetables.

We think that before farmers are willing to take the high risks and increase their vegetable acreages, an effort must be made to improve labor efficiencies, improve vegetable technologies, reduce marketing risks, and to solve the problem of small scales of production. Regarding the latter, farmers could organize themselves into producer organizations for better bargaining positions in input and output markets, and also allow a better development of integrated production and marketing value chains. We see the need for a more gradual diversification toward high value vegetables.

Against this background and regarding rice, it is inevitable that there must be an increase in TE if rice should further play a determinant role in food security and conservation of cultural values of rural populations. The TE of rice production in the delta of the VGTB river basin is with 78 % quite lower than the 86 % found for the MRD and RRD regions. Efficiency can greatly be improved in the region if policy measures are undertaken for increasing the scale of production and also for land consolidation. The intrusion of salinity is a major problem for some of the irrigation zones and innovative adaptation methods are needed in rice irrigation scheduling and irrigation engineering for increasing technical efficiency of rice production in the region.

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