博士論文

Effects of salinity intrusion on rice production in Red River Delta, Vietnam

– a case study of adaptation at 2 contrasting estuaries for sustainable development-

(ベトナム紅河デルタでの塩水遡上の稲作への影響 – 持続可能な開発のための対照的な2つの三角江での適応の事例研究—

Phan Thi Hai Luyen

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Summary

Seawater intrusion has potential negative impacts on rice production in Red River Delta (RRD), but its spatial variation had not been reported. There were technical limitations of rice production, included (1) high dose of N fertilizer which could be inefficiently used, (2) lower yield due to salinity but no resistant varieties used, and (3) reduction in the water availability for irrigation which can put rice production into the critical status. In additions, converting paddy fields into aquaculture pond were observed in RRD but the effectiveness of this conversion, as well as the effect to rice cultivation, had not evaluated in the relationship with salinity level. This research, therefore, aimed to quantify effects of salinity intrusion on grain yield variation between two estuaries, and within an estuary (Chapter 2); identify technical adaptations to improve rice production (Chapter 3); and analysing effects of salinity on economic efficiencies of rice and aquaculture production (Chapter 4) in RRD.

The on-farm surveys were conducted in total 63 farmer fields in 6 cropping seasons in 3 years to collect all the information about irrigation salinity dynamism, rice management and rice yield. These data were used to analyse salinity impact on rice yield and identifying current problems in rice production in RRD. In order to identify feasible technical adaptation in response of salinity intrusion (increasing salinity, reducing water irrigation) and overused N fertilizer, a series of on-farm experiments were set up in farmer fields (Salinity resistant varietal trial; Water-saving irrigation trial; survey of Nitrogen use efficiency in farmer fields and fertilizer response trial) in 4 cropping seasons and 3 communes. Finally, a questionnaire survey to collect input and output information on rice and aquaculture cultivation on 311 households with 473 rice fields and 572 aquaculture ponds were conducted.

Salinity intrusion in RRD was spatially and seasonally variated (Chapter 2). The effect of seasonal rainfall pattern (Fig 2.1) caused higher salinity in spring (0.82‰) than in summer (0.32‰). Using 2 estuaries as a case study, we have drawn the contracting picture of the spatial variation in its salinity intrusion intensity. Salinity intrusion to Day estuary (12± 5.7‰ in January at Nam Dien watergate) were higher than in Ba Lat estuary (7.7± 6.1‰ in January at Ngo Dong watergate), leading to higher salinity in the irrigation system of Nam Dien (1.1± 0.3‰ in spring and 0.6± 0.3‰ in summer rice) than in Giao Huong and Giao Thien (0.8± 0.3‰ in spring and 0.2 ± 0.2‰ in summer). The difference between tow estuaries also came from the difference in irrigation management. In Day estuary, where rice and aquaculture practice parallelly inside the dyke, water was intake directly in the nearby water gate with higher salinity water, maybe due to the preference of aquaculture farmers, thus saline stress happens frequently in the year. In Ba Lat estuary, where only rice was cultivated inside the dyke, water was intake by a further upstream gate with lower salinity water, hence saline stress

only happened at the beginning of the season. Consequently, GY in ND were reduced by 152 g/m^2 in summer rice and 184 g/m^2 in spring rice. compare to that in GH and GT. The severe salinity intrusion caused rice cultivation discontinuous in ND site while no or litter impact in GH and GT.

Within one estuary, salinity variation among field groups caused by field distance to the dyke or aquaculture area. Salinity was higher in fields near to the dyke or aquaculture area called at-risk fields (0.6‰) than in the other fields which named save fields (0.54‰). At-risk field, in addition, due to its location, was characterised by less soil fertility, higher sand content and higher water depth in the summer, resulting a lower yield (558 g/m^2) than the save fields (649 g/m^2). As adaptations, in at-risk fields, the farmers planted hybrid varieties in spring and tall local varieties in summer; and given smaller amounts of N fertilizer application particularly in summer.

N fertilizer in farmer fields was both overused and low efficiency. N fertilizer dose was high at 218 kg/ha in spring and 185 kg/ha in summer. NUEs were low in general, and spatial variated; e.g, N recovery efficiency (RE, g grain GY obtained per g N fertilizer applied) were higher in spring at 0.27, compared to summer at 0.23, particularly low in at-risk fields (0.19) (Table 3.9). The optimal dose of N fertilizer was 120-180 kg/ha and 100-150 kg/ha for spring and summer rice, respectively without yield penalty in GH, GT meanwhile achieved high values of NUEs.

Shallow water depth irrigation (<5 cm) could maintain a similar level of yield as compared to farmer conventional irrigation management under less-saline conditions (GH, GT fields), but resulted in yield reductions in high saline ND field. The two salinity resistant varieties M2, M14, which were claimed can resist salinity up to 3-5‰ had a lower yield potential than conventional variety in non-saline condition (632 g/m2, 618 g/m2 vs 751 g/m2 in safe field in GT) (Table 3.4), but achieved higher GY in high saline-stress condition of ND at 522 g/m2, 539 g/m2 compared with conventional variety at 348 g/m2. These results demonstrated the possibility of systematically applying technical adaptations in RRD to adapt to salinity intrusion problem, but also reducing inputs and increasing the economic efficiency of rice production

Another strategy for salinity intrusion could be diversifying land use pattern. Our results showed that coastal aquaculture generated a much higher income (3592 ± 7672 USD/ha/year) and employment (496 ± 362 manday/ha) than rice (1655 ± 581 USD/ha/year; 122 ± 37 manday/ha). However, the profit was higher in rice (436 ± 541 USD/ha/year) at the average salinity level of 0.4 ± 0.2‰ than aquaculture (109 ± 7853 USD/ha/year) at the average salinity level of 9 ± 8 ‰. Salinity reduced rice profit and is one of the most determining factors of rice profit meanwhile had no impact on the profit of freshwater marine aquaculture. Increasing in salinity reduced rice profit meanwhile have no impact on the profit of freshwater marine aquaculture. At average salinity 0.5‰, rice and aquaculture profit were equal, while at higher salinity (>0.5‰) aquaculture proved a higher profit and could be a potential adaptation to the negative impact of salinity on rice.

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1 Chapter 1. Research background

Saltwater intrusions in the Red river delta (RRD) due to seawater level increasing and lower river flow have received increased attention due to the increased levels and frequencies. The area of the RRD is approximately 14,800 km^2, entirely lying below three meters above sea level and much of it does not rise more than one meter above sea level (Luu et al., 2010). Seawater level increased by 20-50 cm during the last 50 years (MONRE, 2008), an isoline of 1% saline water in the river has been recorded intruding 30-50 km upstream (Ca et al., 1994). Thus, salinity intrusion has been threatened rice production in both of Vietnam main rice bowl, the RRD and the Mekong River Delta (MRD). The MRD, where seawater intrusion naturally happening as it is a tide-dominated delta and there were few protective infrastructures in place (Renaud and Kuenzer, 2012), has experienced many serious impacts such as the annual productivity loss by 2.5-4 ton/ha in the saline effected areas (Khai et al., 2018); rapidly converting rice area to develop of aquaculture (Sakamoto, Van Phung, Kotera, Nguyen, & Yokozawa, 2009) (Kotera, Sakamoto, Nguyen, & Yokozawa, 2008); as well as initiated new seawater control system in MRD (Tuong et al., 2003). Spatial distribution of salinity determined rice cropping intensity and land-use pattern in MRD (Kotera et al., 2008)(Renaud et al., 2015). Unlike in the MRD, RRD has been protected entirely by the river and sea dyke systems and sluices, thus salinity intrusion on inside the dyke fields, where rice was cultivated, were considered relatively minor, only, perhaps, due to leakage through dyke and seepage through sluices (Truc et al., 2019; Nguyen et al., 2014). But recently, marine aquaculture has developed sharply inside the dyke in some parts of coastal RRD, prompted greater intrusion of saline seawater. Nevertheless, as a vast delta with a total of 8 estuaries, the situation might be different among different estuary where salinity intrusion in the river was different evidently (Hien, Quy, & Viet, 2010). There is a question of how the salinity impacts on rice production among different estuary but have not been studied adequately yet.

At a mall scale, spatial variation of rice production in RRD were also reported. Kono & Tuan (1995) found a variation in water condition defined by micro-topography among rice fields in RRD. Nguyen et al., (2017) described that fields with far distance to the dyke yields, although the undergo factors had not defined clearly. Given the salinity intrusion problem, there might be variation in salinity intrusion, soil and water properties which lead to variation in grain yield at the small scale in RRD, but this knowledge still has not documented.

Rice production, as the first crop, has been playing an important role in national food security, as well as household livelihood. However, rice in RRD has been facing numerous problems in regard of technology inefficiency, threatens its sustainable development. New resistant varieties to adapt with the spatial variation of soil and water properties such as saline or flooding have not been paid attention properly while capability of salinity resistant of the current varieties were limited (T. Trinh, Tran, & Cao, 2016). Making resistant varitery available such as salinity resistant varieties to adapt with saline soil and water condition, or landrace varieties to adapt with flooding prone condition could secure the rice yield in the marginal condition. Secondly, since the Green Evolution, rice production in RRD has been recognized as overuse of agrichemical, especially N fertilizers (Thi Ut & KAJISA, 2006). N dose in the farmer field was recorded at ca. 200 kg/ha/crop, ca. 400 kg/ha/year (Nguyen et al., 2017); however, the efficiencies of this large amount application were not available. The excess of N use could result in low in nitrogen use efficiencies (NUEs); unnecessary increases production input hence reducing production profit; and cause severe adverse effects on the environment and human health (Hashimoto et al., 2007). Understanding on on-farm NUEs among farmer fields and identifying a proper N amount to which can achieve high NUEs with less scarified the grained yield was important for sustainable developing rice production in RRD. The third issue in RRD was the reduction of water for irrigation. Nguyen et al. (2017) report the were declining trends in the opening time for irrigation of the intake water gate, due to the increasing salinity in the river water. Increasing in water use of other economic sectors also could put water resource of RRD in a critical situation. Water use in agriculture, mainly for rice, alerted ever-increasing shortest challenge, which posed a question about the possibility to reduce water for rice irrigation. These technologies, if available, can contribute significantly to strengthening rice production in RRD

In addition to the technical approaches, strengthening rice production in RRD was involved other constraints of socioeconomic aspects. Small scale and fragmented of rice fields (Vu et al. , 2012; Cuc et al., 1993) were considered as a critical reason for low economic efficiencies (World Bank, 2016). The Government's policy was changed significantly, from “rice first” to more facilitated diversifying (M. T. Nguyen, Renaud, & Sebesvari, 2019), which enable farmer diversifying their agriculture land-use to seeking for income and employment opportunity (be introduced in the next paragraph). Moreover, the final goals of improving production efficiency are to turn it into adoption by most targeted farmers. Adoption decision making of the farmer is a complicated process influenced by a range of factors such as socio-demographics, perception of the farmer, and social milieu of the farmer (Edwards-Jones, 2006), which can be significant influenced and facilitated by agricultural extension system (Sall et al., 2000; Ahsan, 2011; Senthilkumar et al., 2008). However, regardless of a substantial change in the environments and farmer socioeconomic situation, the top-down approach of agriculture extension in RRD were improper and has not adapted effectively (De, Uchiyama, & Ohara, 2005). Given these challenge, a comprehensive viewpoint by synthetically using technological approaches (introduced in above paragraph) and socioeconomical approaches such as scale-up size of rice fields, diversifying their agriculture land-use, as well as improving approach of agriculture extension would be a critical requirements to develop and strengthen rice production in RRD.

Currently, the transformation of rice field to aquaculture was observed in RRD, which was initiated and explicitly encouraged by the government policies (Le et al., 2018). Most of the converted rice fields were in the salinity intrusion effected areas. It is considered that salinity caused disadvantage effect on rice production, thus rice profit; but its effect on aquaculture profit in RRD was unknown. There might be a relationship between salinity in the irrigation water and land-use profit (rice and aquaculture profit); which in turn, determine which land-use to be selected. Moreover, being developed inside the dyke area aquaculture, understand of salinity impact on rice and aquaculture profit are important knowledge to evaluating aquaculture as an adaptation to salinity intrusion.

This study, therefore, armed to analyse effects of salinity intrusion on rice production in Red River Delta, Vietnam and search for feasible adaptations. The specific objectives of the study are:

1. Quantifying effects of salinity intrusion on grain yield between two estuaries of RRD => Chapter 2
2. Quantify a within-an-estuary, small-scale differences in rice yield = > Chapter 2
3. Identify technical adaptations to improve rice production in the coastal area, including improving NUEs, reducing water irrigation and testing performant of salinity resistant varieties => Chapter 3
4. Effect of salinity on the economic efficiency of rice and aquaculture production as an adaptation to salinity intrusion => Chapter 4

The hypothesis given for each objective respectively are:

1. There are seasonal and spatial variations in salinity intrusion among estuaries of RRD.
2. There are small-scale variations in salinity intrusion, soil and water properties which lead to variation in grain yield at the small-scale in RRD
3. There are technical adaptations, regard of nitrogen dose, water use and variety which can improve rice production in the coastal area, including improving NUEs, reducing water irrigation and resistant to the increasing salinity intrusion.
4. The salinity level in irrigation canals determines the profit of rice and marine aquaculture land-use in the RRD, consequently, determines the conversion from rice to marine aquaculture. Hence, comparing the relationship of salinity level and rice production profit with aquaculture production profit would identify the threshold of salinity for using aquaculture as adaptation of salinity intrusion.

Thesis framework and methodologies is present in Fig. 1.1.

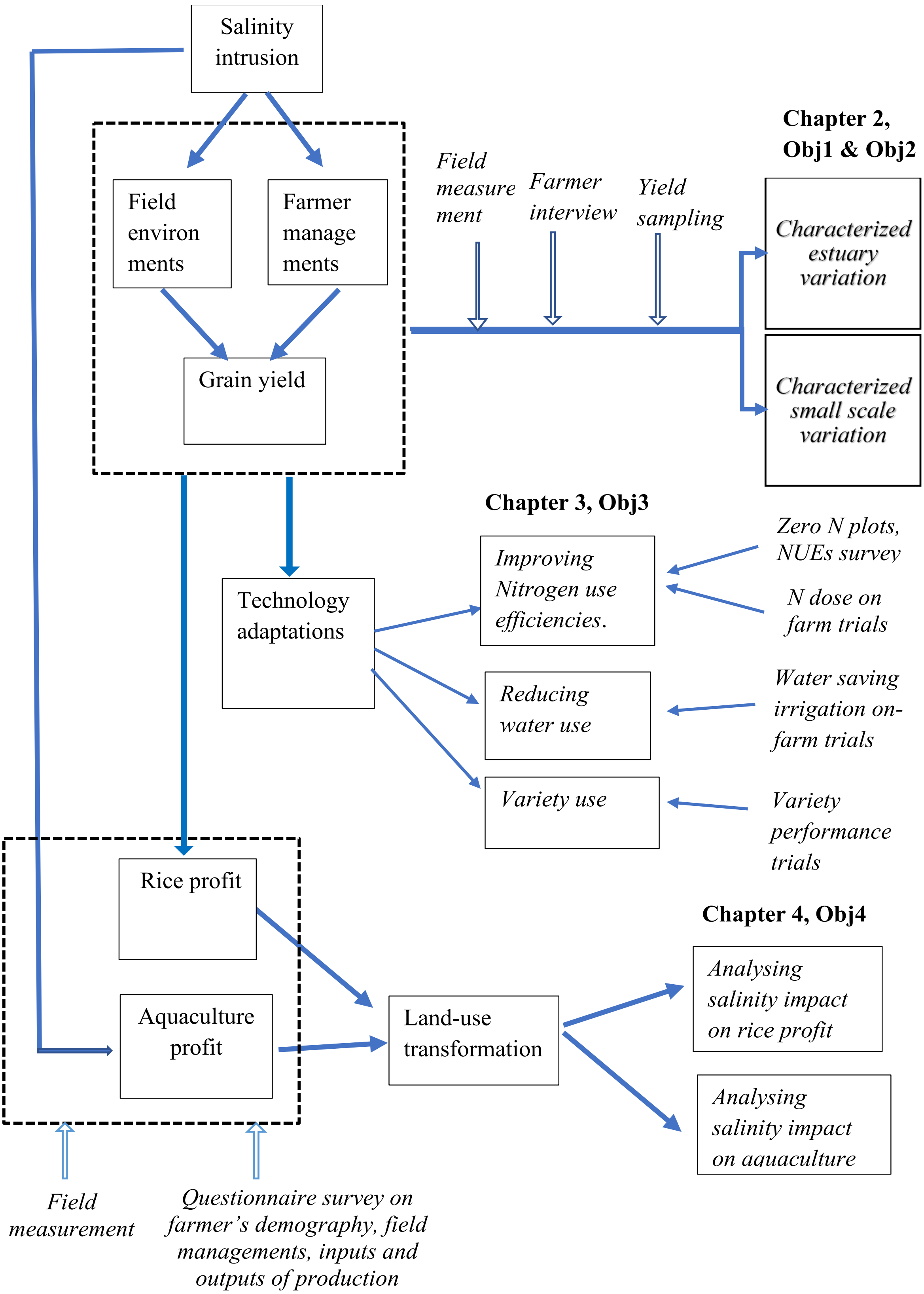

Figure 1.1 Research diagram

2 Chapter 2. Salinity intrusion reduces grain yield in coastal paddy fields: case study in two estuaries in the Red River Delta, Vietnam

2.1 Introduction

Salinity intrusion caused by increasing seawater level and low river-water flow has been threatening rice production in low-lying deltas in Asia such as Ganges Delta (Haque, 2006) and Mekong River Delta (Khang, Kotera, Sakamoto, & Yokozawa, 2008). The magnitude would be more severe nearby estuary and may differ depending on estuaries and rivers. Daily and monthly tidal fluctuations, as well as seasonal changes in river flow, would also affect seawater intrusion. It could reach upstream of the rivers from the estuary, which may limit usage of fresh water and spill saline water to rice fields in the delta.

The Red River Delta (RRD), the second largest rice production area at 1,094,400 ha (Statistic office, 2017) in Vietnam with dyke and sluice system having been constructed since 18th century, is also concerned about negative effects deriving from sea level rise of 20-50 cm during the last 50 years in Vietnam (MONRE, 2008). An isoline of 1% saline water was recorded in 1985 at the location 30-50 km upstream from the estuary of Red River (Ca et al., 1994) which has moved landward by 4-10 km in recent decades (Hanh et al., 2007; Thanh et al., 2004). However, fewer numbers of studies are available on the current status of salinity intrusion and its impact on rice production in RRD, as compared with Mekong Delta (e.g., Wassmann et al.,2004; Sakamoto et al., 2006 Khang, 2008; Kotera et al., 2008; Khai et al., 2018). Leakage through dyke and seepage through sluices were indicated to have negatively influenced rice production in RRD (Trucet al., 2019; Nguyen et al., 2017), but were sporadically reported; also how widely it spreads over different estuaries and how it differs seasonally and yearly were not investigated. Once aquaculture was introduced in a part of the delta near estuaries by changing from rice farming as prompted by greater intrusion of saline seawater, conflicts for irrigation water use would happen that may increase potential harm to rice production (Paul and Vogl 2011; Tho et al., 2008; Ali 2006), but the situation in RRD has never been reported.

RRD is the most densely settled rural areas in Asia at 949 people per km^2 (Vietnam Statistic department, 2012). The average farming area per household in RRD was small (0.28 ha, estimated in 2005) and fragment (Vu et al. , 2012; Cuc et al., 1993). Virtually every square centimeter of land, including sub-optimal, less fertile, more stress-prone fragile areas, has been developed as rice fields in the struggle to obtain enough food and energy to sustain this vast growing population. Under this intensive land use in RRD, some of the rice fields are less fertile or more prone to environmental stress such as submergence or salinity intrusion. The presence of such sub-optimal and more fragile fields was indicated as to be located very closely to the river dyke (Nguyen et al., 2017). Small-scale variability in production environments should be clarified for each village. Effects of salinity intrusion may be different depending on the location of paddy fields within a village. Clarification of such small-scale variability can help agriculture extension to provide more effective technical advice for production and management of environmental stresses.

This research, therefore, aimed to (1) compare possible negative effects of salinity intrusion on rice yield between two estuaries in coastal RRD and (2) quantify small-scale differences in rice yield within a village between (i) apparently optimal fields (as named as ordinary field group) and (ii) sub-optimal and more stress-prone fields located at closer distance to the estuaries (as named as fragile field).

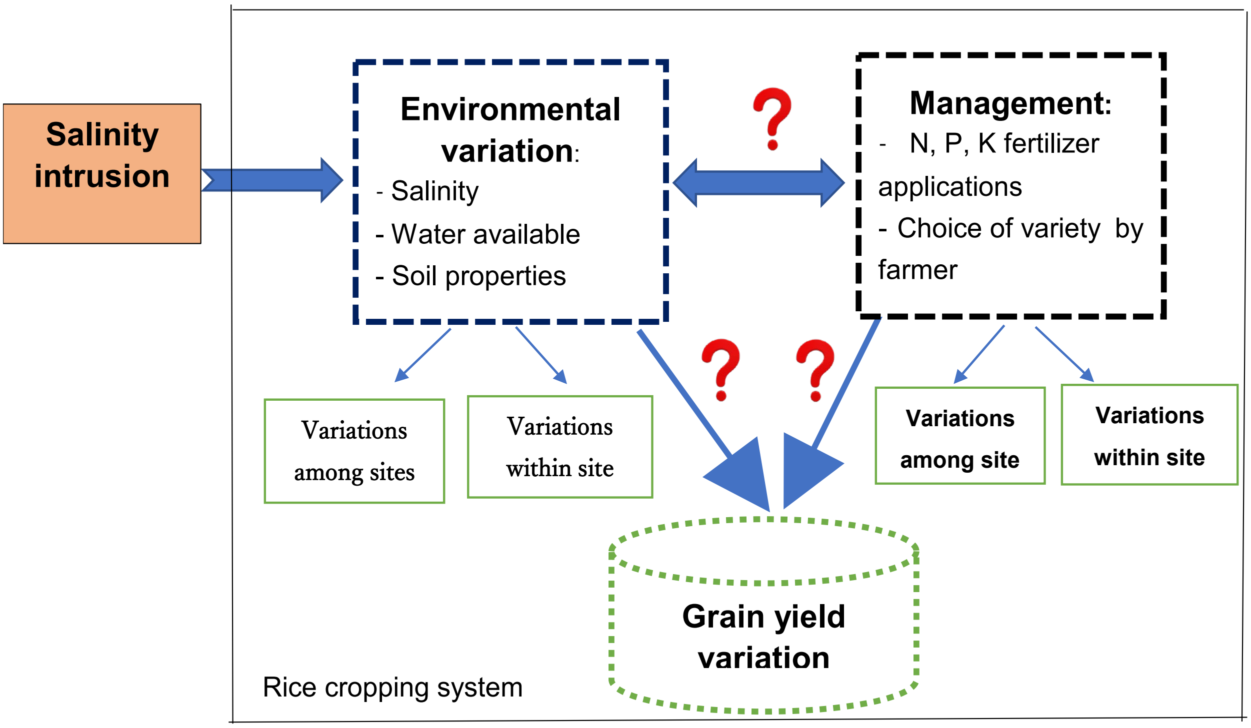

Figure 2.1 Research diagram in Chapter 2.

Research diagram of this chapter is shown in Fig. 2.1. Salinity intrusion spatially and seasonally affected rice cropping environments (including salinity concentration, water availability and soil properties). Research started detecting the variations of environment coming from different estuaries and small-scale spatial differences within a site. Farmers adapt to these environmental variations through different managements (N, P, K fertilizer applications and choice of variety) which consequently affected grain yield.

2.2 Methodology

2.2.1 **Study site**

The study site was conducted in two coastal districts Giao Thuy and Nghia Hung at the estuary of Red River system in Nam Dinh province. Among the four coastal provinces (Nam Dinh, Thai Binh, Ninh Binh and Hai Phong) of the Red River Delta (Fig. 2.2), Nam Dinh has the longest coastal line, and hence considered as possibly most vulnerable to salinity intrusion. Giao Thuy district had 32 km of coastal line with the area of 23,776 ha and the population of about 190,291 in 2015 (Nam Dinh statistic office, 2015). Nghia Hung had 12 km of coastal line with the area of 25,890 ha with the population about 179,715 (Nam Dinh statistic office, 2015). Similar with other regions in the Red river delta, the two districts has sub-tropical monsoon climate with the distinct dry (November to April) and rainy (May to October) season. Average temperature ranges from 18 ºC (Dec and Jan) to 30ºC (Jun to Aug). Annual rainfall around 2000 mm (Fig.2.1). Topography of the area is generally flat, sloped from north to south, with densely distributed river and canal systems. Irrigation water source mainly comes from the Red River system which original from China's Yunnan, flowing southeastward, passing through Nam Dinh province at downstream before entering the sea at Ba Lat estuary (in Giao Thuy district), Day estuary and Ninh Co estuary (in Nghia Hung district) (Fig. 2.2). Water flow in the river is lowest in January, February and March, with minimum water level is +0.4 – (-0.1) m, highest in July, August, September with maximum water level is 1.68 -3.44 m.

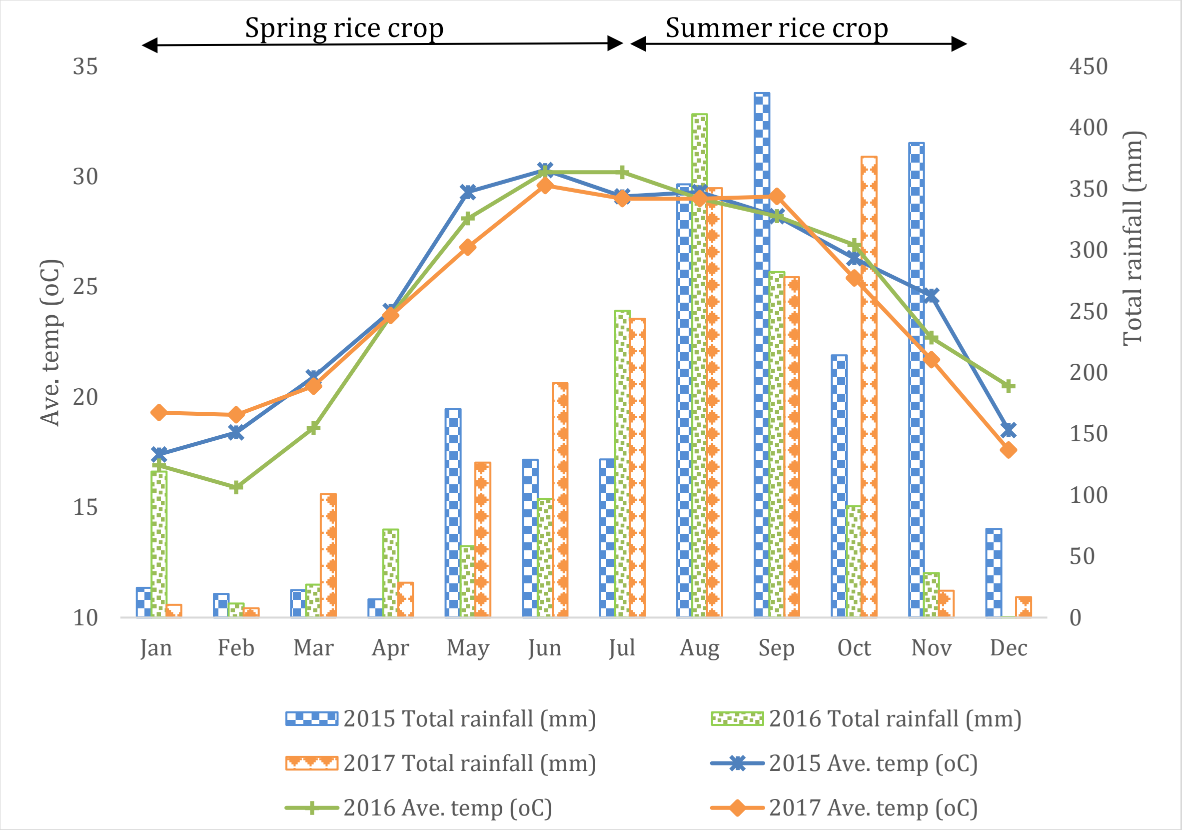

Figure 2.2 Seasonal change of temperature and rainfall in research area. Data shows monthly data of daily temperature and total rainfall in three years (2015-2016), recorded at Van Ly station (20.007° N, 106.018° E) located in a neighbor Hai Hau district at ca. 30 km distance from the two research sites

The agriculture land in Giao Thuy was 16,615.7 ha, in which crop area was 9,181 ha (with 7,722 ha was rice) and aquaculture area was 5116 ha in 2015 (Nam Dinh statistic office, 2015). The agriculture land in Nghia Hung was 16,761 ha, in which crop area was 10,655 ha (with 10,083 ha was rice) and aquaculture area was 3806 ha (Nam Dinh statistic office, 2015). Agricultural sector contributed about 58 % to the economy of and involved about 70% of the population of the district (Nam Dinh statistic office, 2015). Rice production is a main agricultural activity in the two districts. There are two crops of rice in a year, the spring rice (vu Xuan) from January to June and the summer rice (vu Mua) from July to November. Aquaculture has recently developed, occupied about 30% of the agriculture land in Giao Thuy, and about 23% of agriculture land in Nghia Hung, but has been increasing significantly and mainly been converted from coastal paddy rice.

2.2.2 Surveyed fields selection

In order to understand the impact of salinity on rice production in the study area, 64 rice fields in three communes which located along the river mouth or the sea water namely Giao Huong (GH), Giao Thien (GT) and Nam Dien (ND). In each commune, the fields were categorized into either ordinary group or fragile group based on their location and be characterized based on farmer perception (Fig. 2.2). The ordinary group located closer to the main irrigation source (122 ± 162 m) and further to the dyke (264 ± 337 m), thus was characterized by less risky of salinity intrusion and water available. In contracts, the fragile group located further to the irrigation source (522 ± 424 m) and closer to dyke or aquaculture area (113± 143 m), thus was characterized by under the risk of either salinity intrusion or water likely being inundation (Table 2.1)

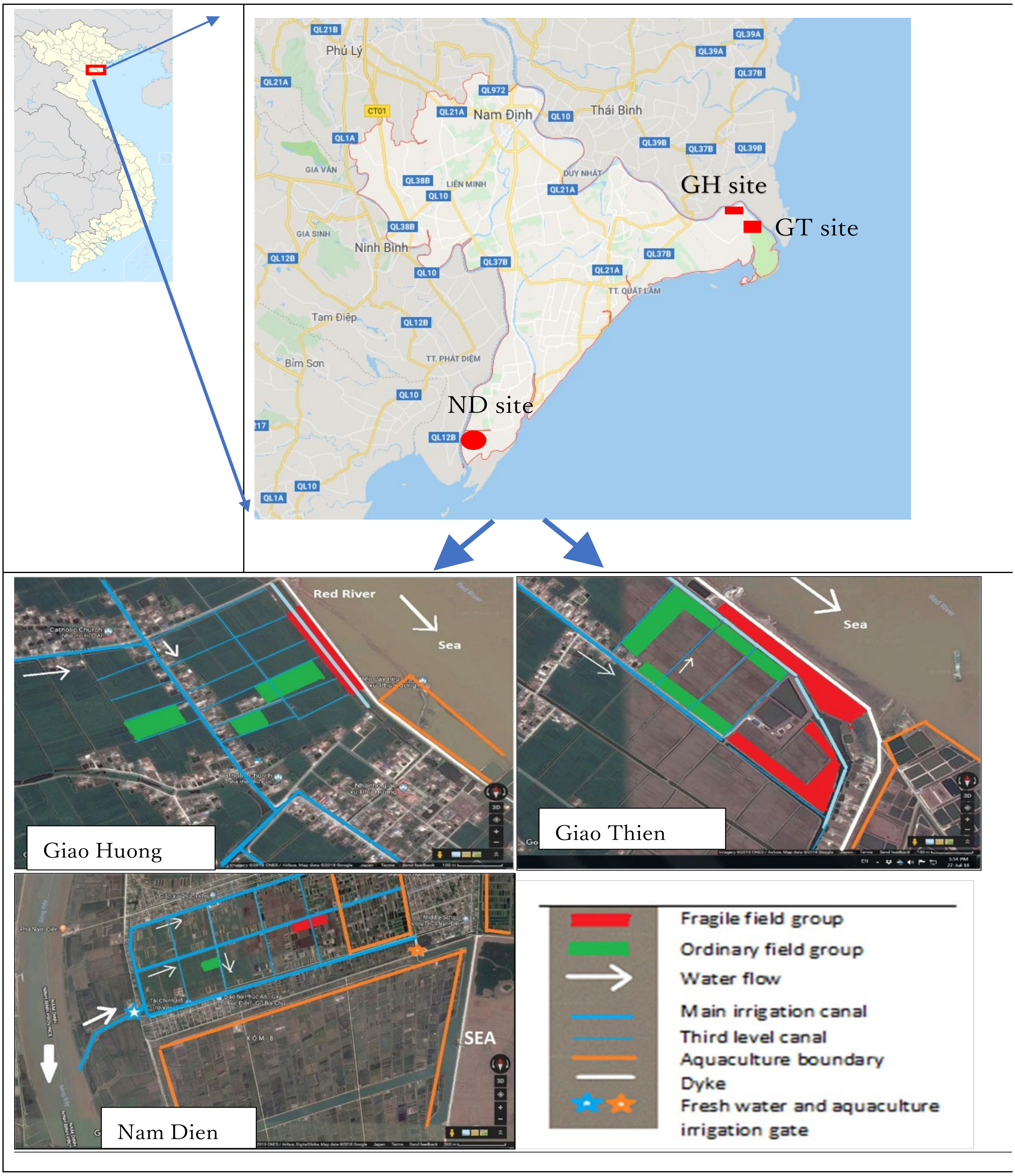

Figure 2.2 Location of research site and categorizing of field group in the research.

GH and GT sites located near Ba Lat estuary; ND located in Day estuary. In 3 site, 63 field were selected and categorized into ordinary and fragile field groups based on the relative distance to saltwater source (dyke and/ aquaculture fields). Imageries taken from Google map satellite image 2016

Table 2.1 Number and description of surveyed fields

Site	Field group	Number of selected fields	Distant to the dyke or aquaculture (m)	Distant to the main irrigation water source (m)
GH	ordinary	10	173 ± 104	81 ±49
	fragile	5	8 ±7	199 ± 7
GT	ordinary	16	91 ± 49	41 ± 65
	fragile	17	34 ± 54	259 ± 88
ND	ordinary	5	1000 ± 24	462 ± 24
	fragile	10	300 ± 92	1131 ± 62
Total		**63**	**187 ± 266**	**325 ± 379**

2.2.3 **Data collection**

Salinity information of the river at the intake watergates namely Nam Dien at NamDien site and Ngo Dong at GH and GT sites were collected from records of the Nghia Hung irrigation joint stock company and Giao Thuy irrigation joint stock company respectively, from 2005 to 2015. Daily maximum salinity concentration was calculated as average value in January when salinity level was often highest due to serious sea water intrusion in RRD (Nguyen et al., 2017). Duration of opening the intake gates for irrigation was calculated.

Rice fields were surveyed from spring rice season 2015 to summer rice season 2017. Salinity concentration and standing water depth in the fields were measured 10 days interval from translating time to doughy grain stage by ATA0023-PAL-ES2 (Japan) salinity meter. Average of five readings in each measuring occasion were recorded for one field. Rice plant were harvested the above ground parts by the sampling of 3 quadrats of approximately 1 m^2 for each field at the harvested time. Plant height and number of hills were measured, after that were dried at 80°C under 72 hours to estimate total dry grain weight, dry grain straw and total biomass. Grain yield were calculated by adding 14% moisture to dry grain weight.

Information on field management (i.e. variety; fertilizer type, amount and splitting times; and other information affecting on grain yield) was obtained by interviewing the field owners during and the end of each rice season.

Soil sample were collected in Nov 2015 and Oct 2017 to analyze soil property. Soil were collected at the surface level from 0-15 cm depth by the crossing method.

Data of grain yield and application rates of N, P, K fertilizers were analyzed by ANOVA in SPSS to test the effect of year, season, site and field group, and their combinational interactions.

Multiple group comparison was conducted by one-way ANOVA using Turkey to test the different in 6 combination locations from site and field group.

2.3 Results

2.3.1 Salinity intrusion in two estuaries

Salinity concentration in Day estuary (Nam Dien intake water gate) was generally higher than in Balat estuary (Ngo Dong intake water gate) (Fig. 2.3ab). Salinity concentration was higher in over the year in Nam Dien gate, while in Ngo Dong gate it was high as well (ca. 15 ‰) in January 2010 due to the extreme drought. Due to higher salinity in Day estuary, the opening duration for irrigation in Nam Dien gates was much shorter than that in Ngo Dong gate except for January 2010 (Fig. 2.3cd). In 2012-2014, opening duration in Nam Dien gate became longer which led highly saline water taken up to the canal to ND fields.

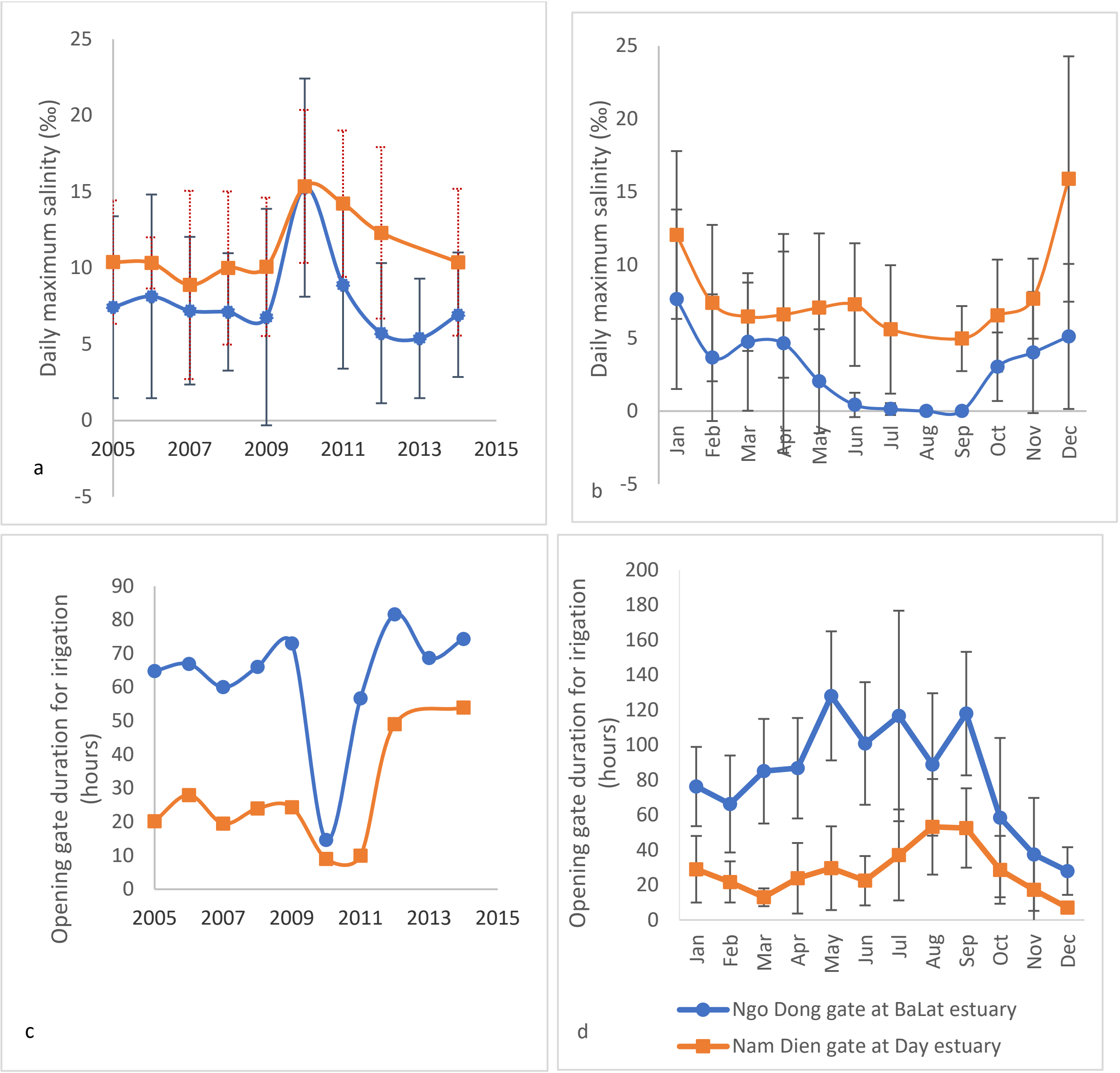

Figure 2.3. Salinity intrusion in the main intake water gates for research sites: Nam Dien gate in Day estuary (ND site), Ngo Dong gate in Balat estuary (GH and GT sites). Daily maximum salinity from 2005 to 2014(a) and its seasonal change**(b). Duration of opening gate for irrigation from 2005 to 2014*(c) and its seasonal change (d). Error bars shows SDs. *Presented as values in January. No record at Nam Dien gate in 2013 because of closure for maintenance.**No record at Nam Dien gate in August because of no salinity intrusion in this month due to heavy rain and strong river flow.*

2.3.2 **Planting of rice in 3 sites**

The severe situation in salinity leading paddy fields in ND become non-arable (Table 2.2). In spring 2015, ND had 10 fragile fields (with yield of 311 g/m^2) and 5 ordinary fields (553 g/m^2), but these fragile fields got abandoned from summer rice 2015. Ordinary fields in ND also got abandoned from spring 2017. Gradually, all the 300 ha paddy fields in ND were converted into aquaculture by summer 2017. Meanwhile GT and GH rice were continuously cultivated without no clear harmful effects of salinity stress.

Table 2.2 Cultivation status of the surveyed fields in 3 research sites from 2015-2017. ○, △, ×: means full, partial and no cultivation of rice, respectively.

Site	Field group	Number of original selected field	Cultivated status of surveyed fields					
			2015 spring	2015 summer	2016 spring	2016 summer	2017 spring	2017 summer
GH	Ordinary	10	○	○	○	○	○	○
	Fragile	5	○	○	○	○	○	○
GT	Ordinary	16	○	○	○	○	○	○
	Fragile	17	○	○	○	○	○	○
ND	Ordinary	5	○	○	○	○	×	×
	Fragile	10	○	△	×	×	×	×
Total harvested field		63	63	56	47	49	45	44

2.3.3 **Environmental variation**

2.3.3.1 Salinity concentration in the standing water

Salinity concentration in the field water tended to reduce gradually from Feb to Oct (Fig. 2.4). Salinity concentration in ND was 1.1± 0.3‰ in spring and 0.6± 0.3‰ in summer rice, which were higher than those of GH and GT (0.8±0.3‰ in spring and 0.2 ±0.2‰ in summer). Salinity concentration fluctuated due to irrigation water dynamism, as was clearly shown in summer rice in ND.

Salinity in ordinary field group was lower than in the fragile group in both spring and summer at all 3 research sites. For example, salinity in GT spring rice was 0.68 ± 0.13‰ in ordinary group compare with 0.85± 0.17 ‰ in fragile group (Table 2.3). Salinity in the ordinary group of GH and GT were below 1 ‰ after mid-March in spring rice whereas those in fragile fields were frequently higher than 1 ‰ until mid Apr (Fig. 2.5).

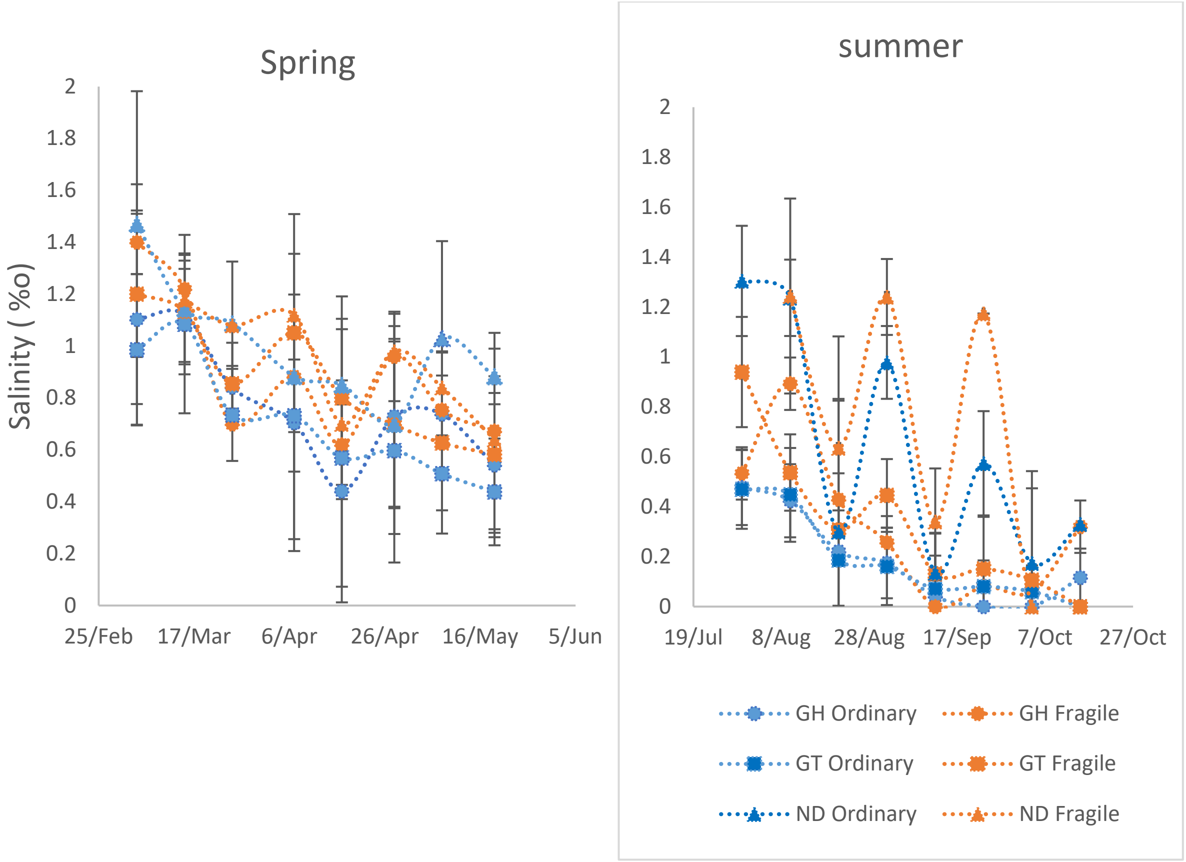

Figure 2.4 Dynamism of salinity of 2 field types in 3 sites over rice plant developing duration. Data shows as average value in 3 years

Table 2.3 Average salinity and average daily maximum water depth through entire cultivating time in spring and summer seasons. N: field number x measurement occasions, Data shows as average of 3 years ± SD.

	Field group	N (field numbers x measurement occasions)	Salinity (‰)		Water depth (cm)	
			Spring	summer	spring	summer
GH	ordinary	480 (10 x 48)	0.75 ± 0.15	0.2± 0.05	11.2 ±1.7	20.9±2.4
	fragile	240 (5 x 48)	0.76 ± 0.17	0.3± 0.12	15.4 ±1.4	27.3±1.7
GT	ordinary	768 (16 x 48)	0.68 ± 0.13	0.2± 0.06	12.3 ± 1.8	13.6±2.5
	fragile	816 (17 x 48)	0.85 ± 0.17	0.3± 0.15	16.2±2.2	25.2±4.5
ND	ordinary	160 (5 x 32)	1.05 ± 0.22	0.6± 0.31	14.0±1.9	24.6±0.6
	fragile	160 (10 x 16)	1.11 ± 0.3	0.8± 0.05	10.9±3.1	15.5±1.6

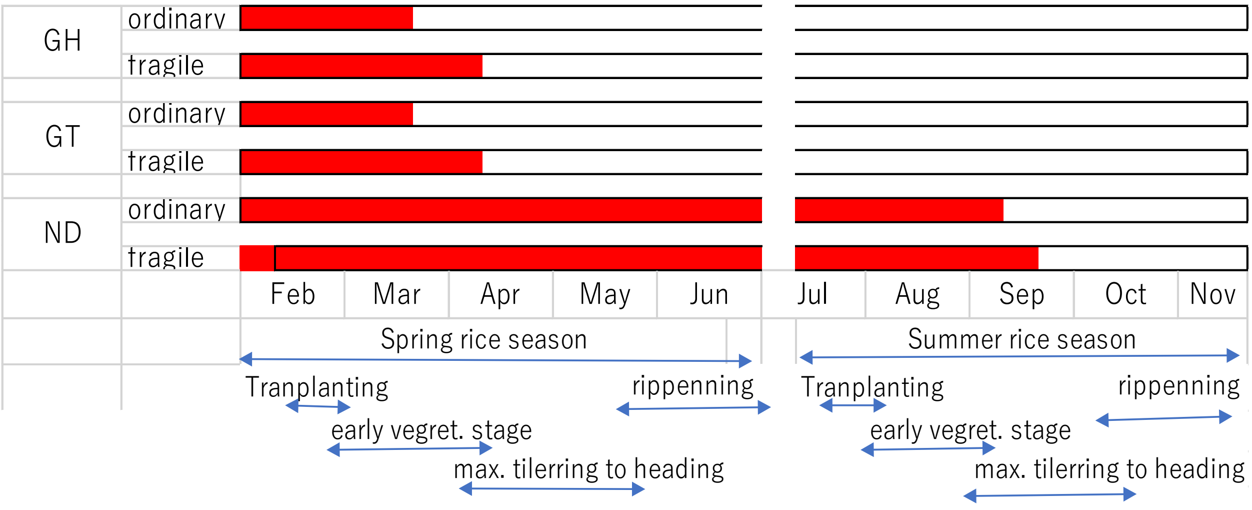

Figure 2.5 Time when salinity stress (salinity >1‰) frequently occurred and corresponding rice developing stage in of 2 field types in 3 sites. Summarized data from measurement during 6 seasons in 3 years of 2015-2017.

2.3.3.2 Depth of the standing water

Standing water depth was lower in spring (7.1±3.2 cm) than summer (8.6 ±5.6 cm) in all the 3 research sites (Fig. 2.6). Low water depth in mid Apr were due to midseason drainage. High precipitation in summer generally increased water depth.

GH and GT fragile fields had deeper water depth than GH and GT ordinary fields in March and/or late April to May (Fig. 2.6a) as well as in September and October (Fig. 2.6b). In ND, water depth was generally deeper in ordinary fields than fragile group (Table 2.3).

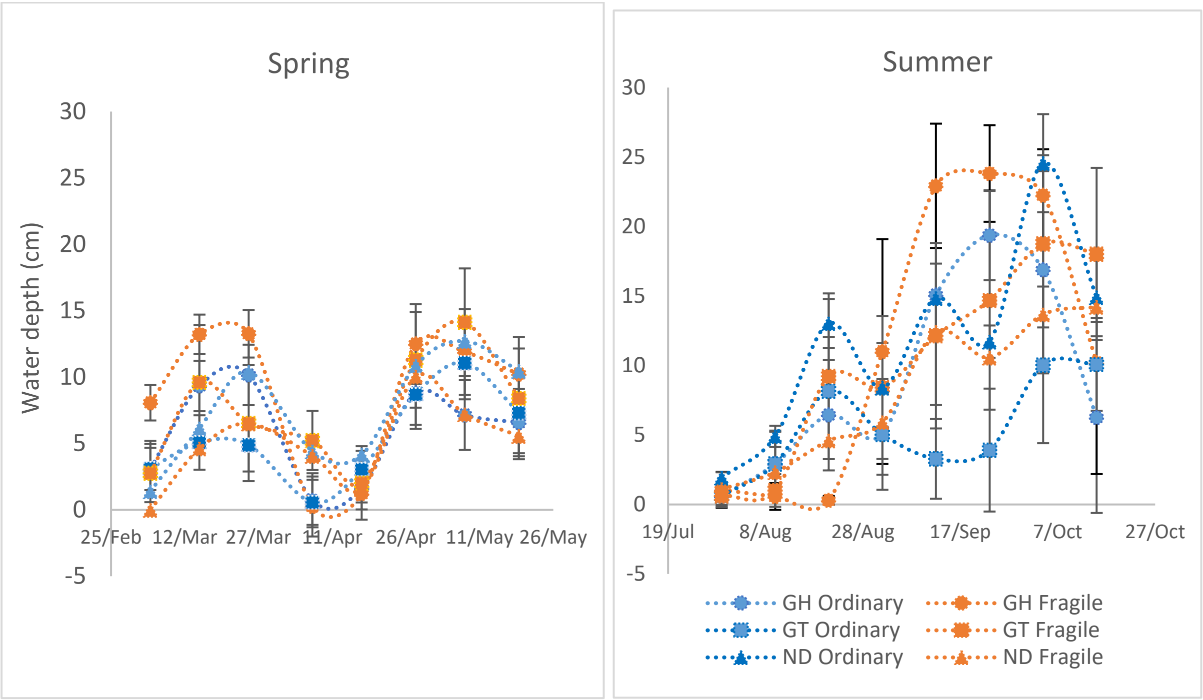

Figure 2.6 Dynamism of water depth of 2 field type in 3 sites over rice plant developing duration. Each data shows as average value of for whole cropping season in 3 years.

2.3.3.3 Soil properties

Concentrations of Na^+ and Cl^- in ND were significantly higher, while pH_{KCl} was lower (5.2) compared with GT (5.8) and GH (6.3) due to high concentration of SO_4^{2-} (Table 2.4). Sand proportion in ND (27%) was higher than GT (24.9%) and GH (24.3%). ND soil had higher OC, total N and available K_2O than those in GT and GH.

Soil in fragile group was characterized by saltier, sandier and less fertile than ordinary group. Fragile group had higher Na^+ (2.05 meq/100g) and higher sand proportion (28.7 %) than those in ordinary groups (1.79 meq/100g and 22.3 % respectively). Fragile group also had significantly lower OC, total N, total P, CEC and available P_2O_5 in compared with ordinary group (Table 2.4).

Table 2.4. Soil field properties varied in 3 sites and field group. Samplings were on 2015 Dec and 2017 Oct. Samples were collected at 0-15 cm depth at 5 positions each field by crossing line. P_2O_{5av}, K_2O_{av} *means* P_2O_5 *and* K_2O *available concentration. ANOVA results to test impact of Site and Field group on soil property: ***,**, ns, means significant at level 0.01 level 0.05 and no significant; respectively*

		pH_{KCl}	OC	N	P_2O_5	K_2O	$P_2O_{5\ av}$	$K_2O_{\ av}$	Cl^-	SO_4^{2-}	Na^+	CEC	clay	silty	sandy
			%				mg/100g		%		meq/100g		%		
Main effects	**Site (Si)**	***	***	***	ns	***	***	***	***	***	***	***	***	ns	ns
	GH	6.19	1.69	0.15	0.16	2.29	59.1	11.7	0.06	0.03	1.69	13.2	19.0	56.7	24.3
	GT	5.82	1.87	0.17	0.17	2.36	42.1	14.5	0.07	0.02	1.76	15.8	17.8	57.3	24.9
	ND	5.23	1.94	0.18	0.17	2.28	49.8	26.5	0.11	0.08	2.31	14.2	15.1	57.6	27.4
	Field group (F)	**	***	***	***	ns	***	ns	ns	***	**	***	**	***	***
	Ordinary	5.85	1.97	0.18	0.18	2.31	56.0	16.9	0.08	0.04	1.79	15.3	18.3	59.3	22.3
	Fragile	5.64	1.70	0.15	0.16	2.31	44.6	18.2	0.08	0.05	2.05	13.5	16.2	55.1	28.7
Interaction	**SixF**	ns	***	***	***	***	ns	**	ns	***	ns	ns	*	ns	ns
GH	Ordinary	6.41	2.10	0.19	0.19	2.33	66.0	12.5	0.06	0.03	1.51	14.6	20.8	58.7	20.4
	Fragile	5.98	1.29	0.12	0.14	2.25	52.2	10.9	0.06	0.03	1.87	11.9	17.1	54.7	28.2
GT	Ordinary	5.95	1.88	0.18	0.17	2.41	46.3	12.8	0.07	0.02	1.57	16.7	19.8	59.4	20.9
	Fragile	5.68	1.85	0.17	0.17	2.30	37.8	16.3	0.07	0.02	1.96	15.0	15.8	55.3	29.0
ND	Ordinary	5.21	1.92	0.18	0.17	2.19	55.7	25.3	0.10	0.06	2.29	14.7	14.4	59.9	25.7
	Fragile	5.25	1.96	0.18	0.17	2.36	43.9	27.6	0.12	0.11	2.33	13.7	15.7	55.3	29.0

2.3.4 **Variety choice in response to environment**

Variety using in the research sites were categorized into 4 groups named short inbred, long inbred, hybrid and local variety based on their main characteristic as described in Table 2.5. Short inbred varieties have high quality but low yield. Long inbred with high quality and high yield potential therefore was the most preferred by farmer. However, both inbred variety groups were not good at adapting with problematic soil (salty or waterlogged), consequently were limitedly distributed only in ordinary fields (Fig. 2.7). In spring, hybrid varieties were dominated in fragile fields to secure grain yield in saline condition. In ND, where saline problem most severe, hybrid was distributed in both fragile and ordinary group. In summer, local photosensitive varieties (mainly Nep Cao) were dominated in fragile fields to secure grain yield in flooding prone condition (Fig. 2.7).

Table 2.5: Varieties and grouping varieties in the research sites.

Variety group	Variety name*	Duration of developing in spring season (days)**	Duration of developing in summer season (days)**	Characteristics	Farmer preference ***
Short inbred	**Bac Thom 7,** TBR225, Thien Uu 8	120-130	100-105	Early mature, low yield, high quality. Not well develop in salty and flooding condition with low stature	2rd
Long inbred	**BC 15**, Nep 97	130-140	105-115	Late mature, high yield, average quality. Not well develop in salty and flooding condition	1st
Hybrid	**C uu da he No 1, Nhi uu 838**, Bac uu 903, Thai Xuyen 111, CRN 36, GS 9	125-140	105-115	Late mature, high yield, low quality. Well adapt in salty and flooding condition with high stature	4th
Local variety	**Nep Cao**, Nep Thau Dau,	-	130 – 140	Photosensitive, only being cultivated in summer. Very late mature. Low to average yield, very high quality. Well adapt in flooding condition with high stature	3nd

: popular varieties in the research area shown in bold; **: based on information from the seed producer; *: order of farmer preference of this variety group without any restricted of environment 1st- the most preference; 4th – the least preference*

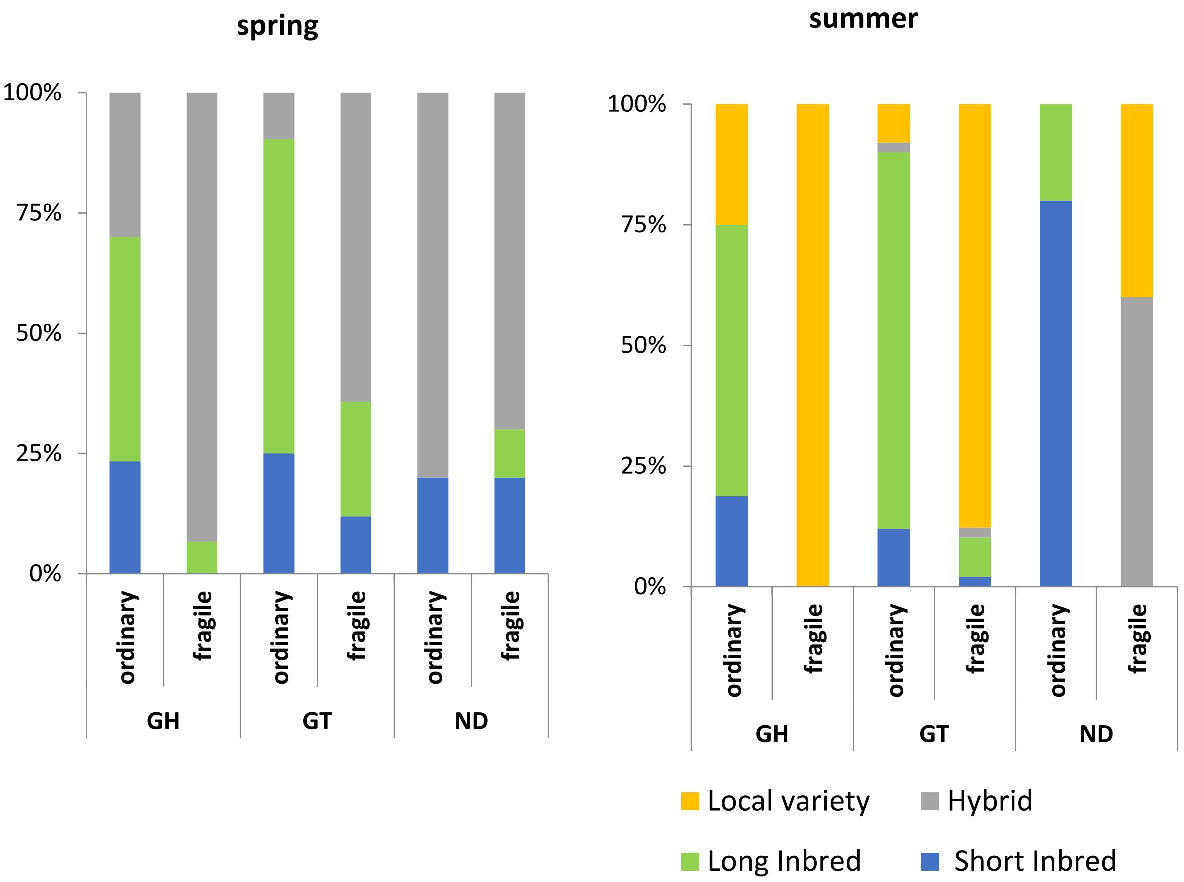

Figure 2.7 Percentages of rice variety groups (short maturing inbred, long maturing inbred, hybrid varieties, and local photoperiod sensitive variety) at different field locations in 3 sites for spring rice (a) and summer rice (b). Data shows as average percentage in 3 years.

2.3.5 **Fertilizer application in response to environment**

2.3.5.1 Fertilizer application variation

N fertilizer application rate among sites were highest in GT, followed by GH then ND (

Table 2.6). Among field groups, N fertilizer application rate were significantly higher in ordinary than in fragile fields (214 vs.187 kg/ha respectively). The N dose gap between ordinary and fragile fields were enhanced in summer (44 kg/ha in summer vs. 10 kg/ha in spring) as was detected as significant interaction between season and field group. The N dose gap between ordinary and field group were biggest in the ND site, where ordinary fields were applied 215 kg N/ha while fragile fields were just 124 kg N/ha.

Phosphorous fertilizer application rate was higher in GH (68 kg/ha) than ND (54 kg/ha), and there was a significant interaction among year, season and field group (Table 2.7). Potassium fertilizer application rate was much lower in ND (14 kg/ha) than GH (42 kg/ha) and GT (54 kg/ha) (Table 2.8). There was an interaction effect between site and field group on potassium application rate.

2.3.5.2 Environmental factors effected on fertilizer dose

N dose were negative corelated with salinity in water and with Na^+, Cl^- content in soil. N dose, meanwhile, positively corelated with soil's CEC in both spring and summer. P and K doses, however, have no strong correlation with environment factors (Table 2.9). Salinity significantly impacted on N application rate on both spring and summer. Ordinary fields with lower salinity tend to have higher application rate (Fig. 2.8)

Table 2.6 ANOVA results show variation in site, season, field group and their interactions effects on N fertilizer application rate variation.

***, **, * means significant effect at the 0.01, 0.05 and 0.1 level respectively

	N fertilizer (kg/ha)	
Main effects		
Year (Y)ns		
2015	195	
2016	205	
2017	207	
Site (Si)***		
GH	192	
GT	219	
ND	185	
Season (Se)***		
Spring	218	
Summer	185	
Field Group (F)***		
Ordinary	214	
Fragile	187	
SexF***	Spring	Summer
Ordinary	223	205
Fragile	213	161
Si x Se x F**	Spring	Summer
GH		
Ordinary	220	187
Fragile	211	153
GT		
Ordinary	251	218
Fragile	224	183
ND		
Ordinary	187	215
Fragile	182	124
Other interactions	YxSe***, SexF***, SixSexF*, YxSixSe*	

Table 2.7 ANOVA results show variation in site, season, field group and their interactions effects on P fertilizer application rate variation

***, **, * means significant effect at the 0.01, 0.05 and 0.1 level respectively

	P_2O_5 fertilizer (kg/ha)	
Main effects		
Year (Y) ns		
2015	58	
2016	69	
2017	56	
Site (Si) *		
GH	68	
GT	58	
ND	54	
Season (Se) ns		
Spring	63	
Summer	60	
Field Group (F) ns		
Ordinary	62	
Fragile	60	
Interactive effects		
Y x Se x F**	Spring	Summer
2015		
Ordinary	68	63
Fragile	50	54
2016		
Ordinary	65	67
Fragile	83	61
2017		
Ordinary	57	47
Fragile	57	63

Table 2.8 ANOVA results show variation in site, season, field group and their interactions effects on K fertilizer application rate variation

***, **, * means significant effect at the 0.01, 0.05 and 0.1 level respectively

	K_2O fertilizer (kg/ha)		
Main effects			
Year (Y) ***			
2015	28		
2016	40		
2017	63		
Site (Si) ***			
GH	54		
GT	42		
ND	14		
Season (Se) *			
Spring	36		
Summer	47		
Field Group (F) ns			
Ordinary	42		
Fragile	40		
Interactive effects			
Si x F**	GH	GT	ND
Ordinary	64	35	13
Fragile	45	49	15
Other interactions	YxSe**		

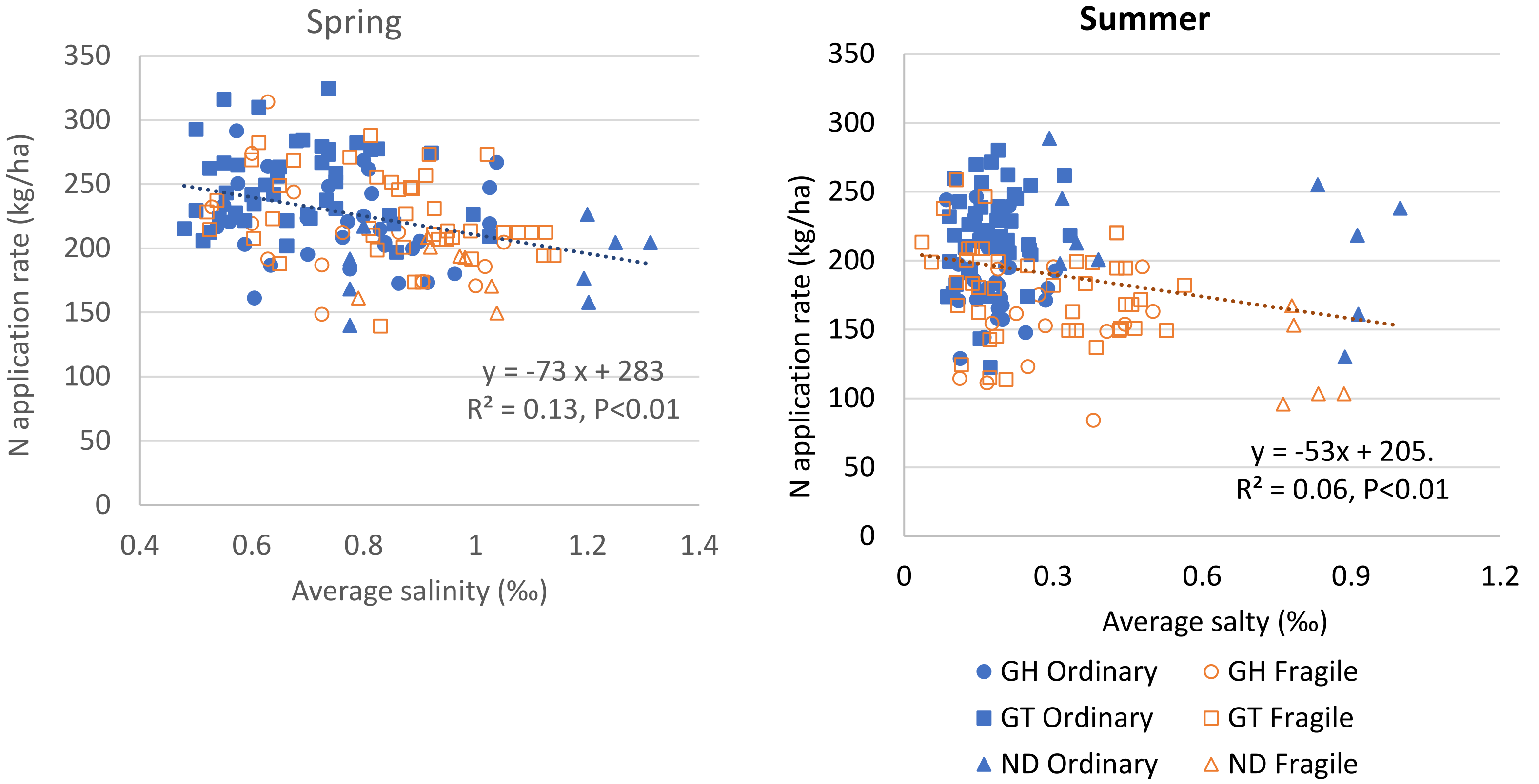

Figure 2.8 Salinity significantly impacted on N application rate on both spring and summer. Ordinary fields tend to have lower salinity and higher application rate

Table 2.9. Correlation coefficients between environmental parameters (salinity, water depth, soil field properties) and N, P, K fertilizer application rate.

Fertilizer	crop season	N	Average water salinity (‰)	Average water depth (cm)	pH_{KCl}	**OC**	**N**	**P_2O_5**	**K_2O**	**$P_2O_{5\ av}$**	**K_2O_{av}**	**Cl^-**	**SO_4^{2-}**	**Na^+**	**CEC**	**silky**	**sandy**
						%				**mg/100g**		**%**		**meq/100g**		**%**	
N (kg/ha)	spring	147	-.36***	-0.1	0.0	0.0	0.1	0.1	.31***	-.29***	-0.1	-.31***	-.17**	-.33***	.26***	.21**	-.18**
	summer	149	-.25***	-.39***	0.0	0.14*	.25***	0.1	0.14*	-0.1	0.0	-.21***	0.0	-.26***	.29***	0.1	-0.1
P_2O_5 (kg/ha)	spring	147	0.0	0.1	0.0	0.0	-0.1	-0.1	.21**	0.0	-0.1	0.0	0.0	0.0	-0.1	.18**	0.0
	summer	149	-0.1	0.0	0.1	-0.15*	-0.1	0.0	0.1	-0.1	0.1	-0.1	-0.1	-0.1	-0.15*	0.1	-.17**
K_2O (kg/ha)	spring	147	0.0	-0.1	0.1	.21**	.21**	.21**	0.0	-0.1	0.0	-0.1	-0.1	-0.1	0.1	0.0	-0.1
	summer	149	-.17**	0.0	0.1	0.14*	.167*	0.0	0.0	0.0	-.23***	-0.16*	-.19**	0.0	-0.1	0.0	-0.1

*,**, ***; significant at 0.1, 0.05 and 0.01, respectively (2-tailed).

2.3.6 **Grain yield variation**

2.3.6.1 Grain yield gaps at 2 yield levels: site level and micro level

GY sample from 3 site, 63 fields, in 3 years showed great variation at site level, regardless year nor season, with ND site at 472 g/m^2, GH site 619 g/m^2 and GT site 662 g/m^2 in average (Table 2.10). Site GY performant was significant in the interaction with year: GY in ND site tend to reduce over year from 2015 (448 g/m^2) to 2017 (0 g/m^2 - unable to cultivate) while GY in GT and GH site was increased from 588 g/m^2 (GT-2015) to 683 g/m^2 (GT-2016) and 714 g/m^2 (GT-2017). Site GY were significant in the interaction with season, ranging from 257 in ND in summer to 917 g/m^2 in GT in spring.

GY variation were also observed significantly among field groups which was within-a-site, regardless year nor season, with 558 g/m^2 in fragile group and 649 g/m^2 in ordinary group in average (Table 2.10). GY of field group were significant in the interaction with site and year, ranged from 311 g/m^2 in fragile group in ND in 2015 to 755 g/m^2 in ordinary group in GT in 2017. The top 5% highest GY among ordinary fields were recorded at 1008 g/m^2 in spring and 711 g/m^2 in summer. The top 5% lowest GY among fragile fields were recorded at 375 g/m^2 in spring and 228 g/m^2 in summer.

Summer rice yields (470 g/m^2 in average) were significantly lower than spring rice yields (744 g/m^2 in average) (Table 2.10). This result showed the great impact of climate seasonal condition on GY. The GY in summer were lowered by the higher temperature, shortening rice duration and erratic changes of weather with strong sunlight and heavy rain. In summer, the gap in GY between field group (116 g/m^2) were more substantial than in spring (67 g/m^2).

Table 2.10 ANOVA of GY variation: Year, site, season and FG and its interactions were significantly contributed to GY variation. ND had lowest yield among 3 sites. Summer had lower yield than spring, fragile had lower yield than ordinary fields, especially in summer.

***, **, * means significant effect at the 0.01, 0.05 and 0.1 level

	Yield (g/m^2)		
Main effects			
Year (Y)***			
2015	545		
2016	628		
2017	673		
Site (Si)***			
GH	619		
GT	662		
ND	472		
Season (Se)***			
Spring	744		
Summer	470		
Field Group (F)***			
Ordinary	649		
Fragile	558		
Interactive effects			
SixF***	GH	GT	ND
Ordinary	645	719	553
Fragile	593	606	311
SexF**	Spring	Summer	
Ordinary	775	524	
Fragile	708	408	
Other interactions	YxSe***, YxSi***, YxSexSi***, SexSi*, YxSixF*		

2.3.6.2 Environmental factors affecting rice yield

Water salinity, summer water depth, soil salinity shows significant correlation to GY. Correlation analyses (Table 2.11) among yield and possible influencing environmental factors show high and significant correlations (r) between grain yield and average standing water salinity in both spring (r= -0.31, $P<0.01$) and summer rice crop (r= -0.61, $P<0.01$) (Fig. 2.9); standing water depth in summer rice (r= -0.48, $P<0.01$) while no clear effect on spring rice (Fig. 2.10). Soil factors related osmotic stress show strong negative effect on spring GY with Na^+ (r= -0.43, $P<0.01$) Cl^- (r=-0.6, $P<0.01$) and SO_4^{2-} (r=-0.31, P=0.01) and medium to low negative effects on summer. CEC and pH_{KCl} show positive corelated on GY. Total nutrients (OC, P_2O_5, K_2O and N) in the soil however have weak or not significant correlation with GY. Soil structure with higher clay have a positive correlation with GY in summer rice (r=0.36, $P<0.01$) but not spring rice. These correlations suggested that each of these factors might influence rice yield variation in the study area. However, there were also strong relationships among pairs of the related yield influencing factors, e.g. soil's Na^+ and K_2Oav (r= 0.71, $P<0.01$), pH_{KCl} and K_2O av (r= -0.46, $P<0.01$).

Table 2.11. Correlation between environmental parameters (salinity, water depth, soil field properties) and grain yield (GY) in the research sites. Data presented from 3 years, 3 sites and 2 field groups.

	n	Average water salinity (‰)	Average water depth (cm)	pH_{KCl}	OC	N	P_2O_5	K_2O	$P_2O_{5\ av}$	K_2O av	Cl^-	SO_4^{2-}	Na^+	CEC	clay	sandy
					%				mg/100g		%		meq/100g		%	
Spring GY	147	-0.31***	0.0	0.17**	-0.1	0.0	0.0	0.0	-0.37***	0.0	-0.60***	-0.31***	-0.43***	0.18**	0.0	0.0
Summer GY	149	-0.61***	-0.48***	0.33***	0.1	0.1	0.18**	0.29***	-0.31***	0.1	-0.43***	-0.17**	-0.43***	0.28***	0.36***	-0.32***

, *; significant at 0.05 and 0.01, respectively (2-tailed).

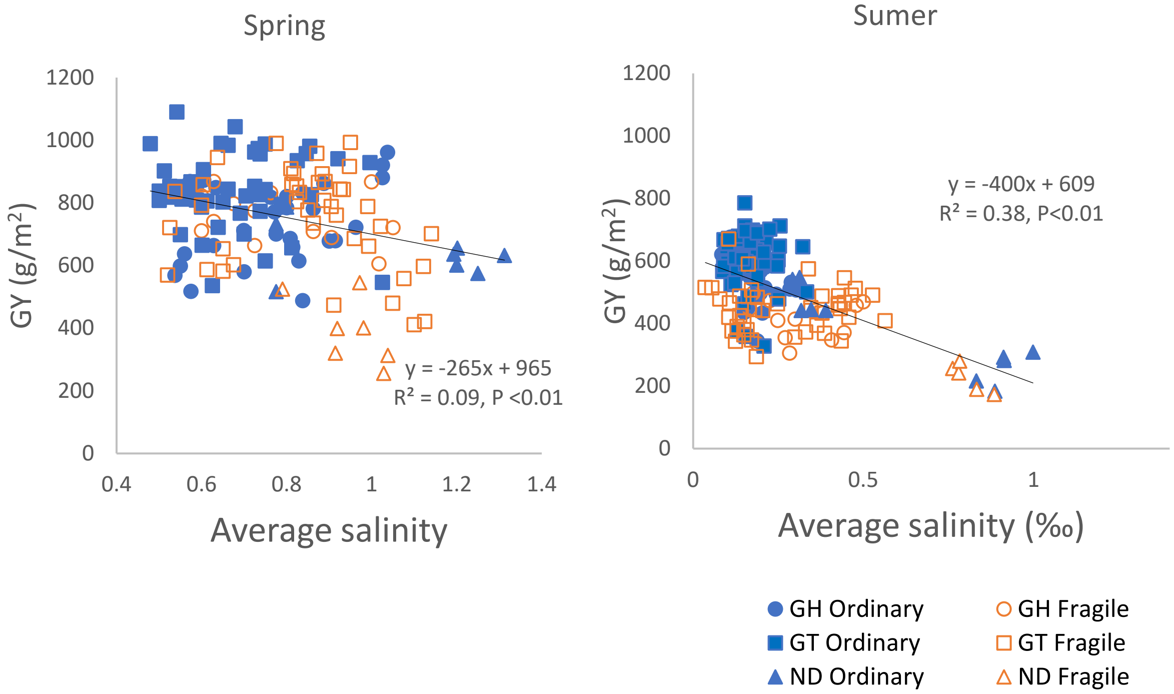

Figure 2.9 Salinity significantly reduced grain yield (GY) in both spring and summer. Ordinary fields tend to have lower salinity and higher GY

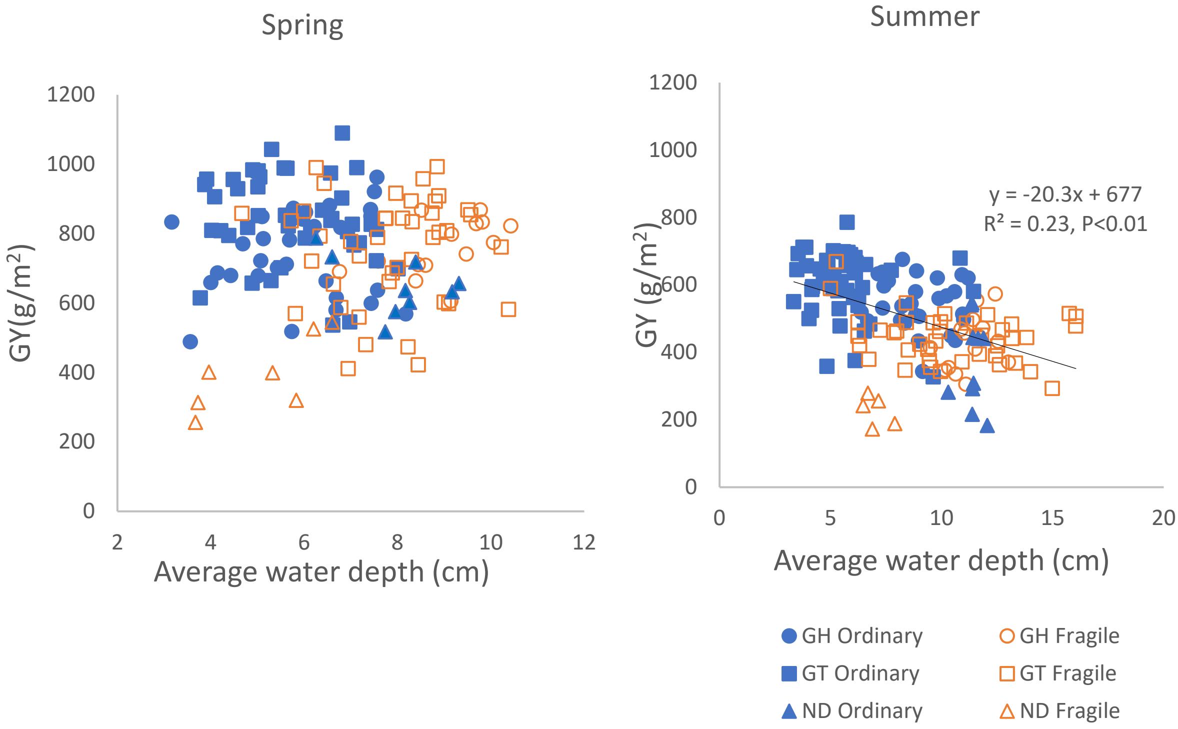

Figure 2.10. Water depth reduced grain yield (GY) not in spring but in summer. Water depth in fragile fields was deeper.

2.3.7 **Fertilizers and GY**

Only N have significant corelated with GY with r= 0.31 (spring) and 0.44 (summer) (Table 2.12, Fig. 2.11. There was no correlation between N, P and K dose with each other in both spring and summer but there is low correlation between N and P (r= 0.13, P<0.05) if checking whole year data set. (Table 2.12)

*Table 2.12 Correlations of N, P, K fertilizer application rate and grain yield (GY). *, ***; significant at P< 0.1 and 0.01, respectively*

Pearson Correlation	n	Grain yield	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
spring rice					
Grain yield	147	1			
N (kg/ha)		0.313***	1		
P_2O_5 (kg/ha)		0.0	0.16*	1	
K_2O (kg/ha)		.182*	0.1	0.0	1
summer rice					
Grain yield	149	1			
N (kg/ha)		0.436***	1		
P_2O_5 (kg/ha)		0.1	0.1	1	
K_2O (kg/ha)		0.1	0.1	-0.1	1

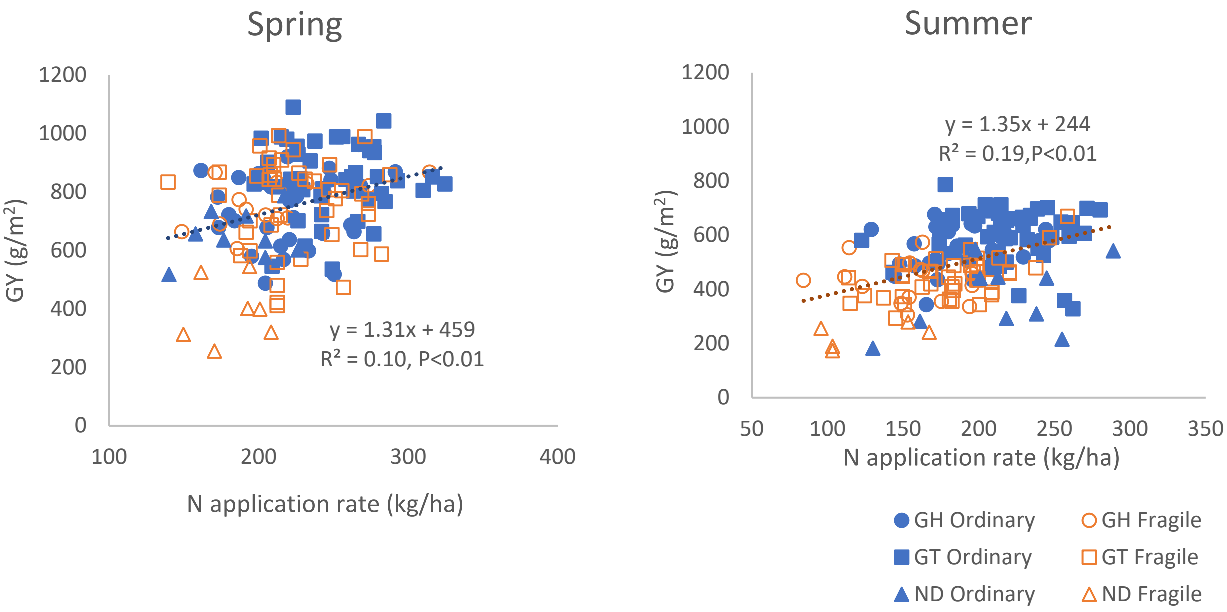

Figure 2.11 N application rate increased grain yield (GY) in both spring and summer. Ordinary fields tend to have higher N application rate and higher GY

2.4 Discussion

2.4.1 **Salinity intrusion effects among research sites in two estuaries.**

This study, for the first time, have compared 2 contrasting estuaries of RRD for their current extent of negative effects of salinity intrusion on rice production. We have clearly shown the severe reduction in yield by 184 g/m^2 in spring rice and 152 g/m^2 in summer rice and transformation of all the surveyed rice fields in ND to aquaculture by 2017, which were associated with salinity intrusion to Day estuary (12± 5.7‰ in January - the beginning of spring season at ND watergate) (Fig. 2.3ab), and also to the irrigation system (1.1± 0.3‰ in spring and 0.6± 0.3‰ in summer rice) (Fig. 2.4), and to the paddy soil (2.13 meq Na/100g) (Table 2.4). On the other hand negative effects of salinity intrusion at Balat estuary (7.7± 6.1‰ in January at Ngo Dong watergate) were milder on irrigation system (0.8± 0.3‰ in spring and 0.2 ± 0.2‰ in summer), on paddy soil (1.7 meq Na/100g) and only minor on rice production in the 2 sites (GT and GH). Dyke and water-gate system had helped to prevent salinity intrusion from the river into irrigation canals by operating water-gate. Water-gate only were opened to intake water when salinity lower than standard level at 1.97 dS/m (equivalent 1‰) which usually coincide with low tide, hence there was a large gap between salinity in the river water and in the canal. However, in fact the salinity higher than 1‰ occur frequently in ND canal but rarely in GH and GT. Firstly it was corresponding result of higher salinity in ND watergate than Ngo Dong watergate (Fig. 2.3); secondly, it was a consequence of the introduction of fresh aquaculture in Nam Dien, as encouraged by Vietnamese government policy, which required higher salinity water (Tho et al., 2008)**.** On the other hand in GH and GT, a small amount of seawater intruded into nearby the dyke field by leaking through dyke, seeping through sluices. Although the dyke system in the 2 estuaries in RRD protected the rice fields from salinity intrusion, this research provided an evidence that salinity still intruded into the field; suggesting that RRD rice were on risk of salinity intrusion more than what was known. In the previous research, salinity level of irrigation water measured in February 2005 in ND were lower at 0.9‰ and the salinity in the soil in the corresponding sampling time was much lower at 1.3 meq Na/100g (Dinh & Haruyama, 2006), compared with our findings in 2015-17 (Fig. 2.3, Table 2.4). Salinity threat might have been and is going to be escalated under the circumstance of climate change(Duc & Umeyama, 2011). When salinity intruded in the irrigation water excess to 1.97 dS/m (equivalent 1‰), it can cause significant negative impact on rice grain yield (Zeng & Shannon, 2000b). In this research, salinity excess 1‰ appeared in GH and GT field only for short period of the beginning of spring season with light stress but not in the rest of the year (Fig. 2.5) hence, rice plant could recover and achieved high yield. In ND, rice was affected by salinity at 1.2‰ during and after transplanting, then endured salinity stress until the most saline sensitive period of panicle initiation and booting stage. It threat to decreases the number of filled panicles, fertile panicle, weight of 1000 grains and percentage of fertile grains and the number of panicles (Falah, 2010; Rad et al., 2011; Zeng & Shannon, 2000; Asch et al., 2000).

The intensity of salinity intrusion in ND was much less severe than in MRD, where average salinity in the irrigation canal were recorded up to 14.4 ‰ during dry season in the areas near by the coastal line (Kotera et al., 2008). Lower topography and almost no dyke system make salinity isoline at 4 ‰ intruded up to 60-80 km inland in MRD (The Vietnam Academy for Water Resources, 2015). However, unlike ND where rice cultivation was stopped at irrigation salinity of 1‰, rice production in MRD was conducted even at salinity 5‰ with intensity of 0.9-1 crop per year with yield of ca. 4 – 4.5 t/ha (Kotera et al.,2008). This was a result of applying simultaneously adaptations such as shifting rice cropping seasons to avoid salinity stress, using salinity-resistant rice varieties in the area with salinity up to 4‰ and converting of rice mono-culture to rice-shrimp rotational farming system in the area with salinity above 4‰ (Nhanet al., 2012). This indicate rice production in saline prone fields in RRD can be more strengthened by adopting technical components such as stress resistant varieties from saline prone areas of MRD.

Transferring paddy rice into aquaculture as was observed in ND has emerged as a new trend in coastal area in RRD, but under different magnitude among estuaries. The aquaculture area has rapidly increased since 2000 after revision of the Land Law in 1998. The revision for the first time, has allowed farmers to convert low yielding paddy to other agricultural land use type such as garden or aquaculture, by getting permission from the local provincial governments (Marsh & MacAulay, 2002; World Bank, 2005). In 2002 the Government promulgated the resolution No.09/NQ-CP which further enhanced land-use transformation of low productive rice fields into aquaculture ponds (Nhuong et al., 2002). Fresh aquaculture area has increased as consequence of conversion from paddy fields in 4 coastal provinces (Hai Phong, Thai Binh, Ninh Binh, Nam Dinh) in RRD. Nam Dinh had the largest area of aquaculture ponds (2800 ha) transformed mainly from rice fields from 2008 to 2018 (Department of Agriculture and Rural Development (DARD) Nam Dinh, 2019). In Hai Phong province, 100 ha low-lying saline fields were converted into fresh aquaculture from 2005 to 2015 (DARD Hai Phong, 2016). In Thai Binh, 201 ha total rice field area were converted into aquaculture from 2010-2016 and 144 ha to be converted in 2017 – 2020 (DARD Thai Binh, 2017). In Ninh Binh province, 327 ha rice field in 2017 and 179 ha in 2018 were converted into aquaculture pond (DARD Ninh Binh, 2018). This massive transformation to aquacultural land use could prompt intake of saline water from the river to the irrigation system, which may negatively affect rice production. Proper control of transformation and water management would be needed by local government.

2.4.2 **Environmental characterization and farming adaptation in fragile field group**

We identified a group of fields under more fragile environmental conditions within the same sites in RRD, as defined by closer distance to dyke or aquaculture (or more distant to fresh irrigation water sources). This group, named as fragile field group had higher salinity (Fig. 2.4), deeper standing water (Fig. 2.6), more sandy and less fertile soils (Table 2.4), consequently causing lower GY (558 g/m^2) than ordinary fields (649 g/m^2) (Table 2.10). Spatial variability of irrigation water and soil properties such as soil nutrients (L. Nguyen et al., 2014; Ayoubi et al., 2012; Schmitter et al., 2010) and their consequent difference in yield within relatively small area (Lobell et al., 2007, 2009; Tittonell et al., 2008) have been frequently reported. Uniqueness of our study is to have disclosed heterogeneity of irrigated rice ecosystem in the coastal zone of RRD, as to point dyke-side fields that may be opt to salinity and/or submergence; they may have been historically cultivated for food production to cope with high population pressure of the region.

Farmers reduced N fertilizer application rate in fragile field group (Table 2.6), probably by reasoning higher risks of environmental hazard (Fig. 2.8) and lower response to nitrogen fertilizer with lower attainable yield (Fig. 2.11) in these fields. N fertilizer amount is often determined by farmers' goal of earning (Zhou et al., 2010; Abdoulaye et al., 2005), their target yield level, and expected yield gain from fertilization. High concentration of salts inhibits nitrification, resulting in accumulation of NH_4^+–N, leading to large losses via ammonia volatilization (Swarup, 1994). It was also inferred that saline soils reduced 25% of N, P, K use efficiency than non-saline soils in Pakistan (Mehdi, 2008).

Our study showed farmers chose specific varieties to fragile field group to address to salinity stress in spring and to flooding in summer (Fig. 2.7). Firstly, for spring rice, hybrid varieties such as C uu da he No 1, Nhi uu 838, were chosen in fragile fields at GH and GT as well as ordinary and fragile fields in ND. Hybrid varieties can express their vigor growth from vegetative stage under mild to moderate salinity stress in fragile fields to result in a high yield (708 g/m^2) (Fig. 2.9). Hybrid variety were reported as moderate to high resistant to abiotic stress such as salinity (Khush, 2009). A study about hybrid in RRD reported that it is more resistant to lodging than inbred rice, and suggested the idea of specific ecological conditions in hybrid evaluating (Vien & Nga, 2009). Secondly, for summer rice, a local landrace photoperiod sensitive and tall variety, Nep Cao (also known as Nep Cao Cay), was chosen. The names of this landrace hint at their morphological features with "Nep" means "glutinous" and "Cao" means "tall" ("Cay" means "plant"). Local landraces have been cultivated in low-lying land as an adaptation of farmer to waterlogging problem for many years in RRD (Nguyen et al., 2017; Kotera et al., 2005; Tuan & Dung, 1999; Seetisarn et al., 1993) or in MRD (Nhan et al., 2012). It is interesting to note that in rainfed lowland rice ecosystem where deep water logging is a problem, photoperiod sensitive long duration tall rice varieties had been using as an effective and traditional manner of farmers' local adaptation. These varieties typically had low yield potential but long duration (140 days), photoperiods-sensitive and tall (130-150 cm) with a rigid straw. These type of farmer adaptations are effective although consuming limited resource, valuable for rice extension, and needed further studies to better understand the mechanisms, scale up and magnify the efficiency.

2.5 Conclusion

Nam Dien (ND) located nearby Day estuary characterized with higher salinity levels in the river, irrigation system and paddy fields compared with Giao Thien (GT) and Giao Huong (GH) sites at Balat estuary. Consequently, ND had significantly lower yield than GH and GT by 152 g/m^2 in summer rice and 184 g/m^2 in spring rice. The severe salinity intrusion stopped rice cultivation in ND by 2017. In the fields closer to the river dyke and other salt water source, characterized as fragile fields with less soil fertility, slightly higher salinity, and higher water depth in summer, farmers planted hybrid varieties in spring and tall local varieties in summer, and applied less N fertilizer, particularly in summer, resulting in lower yield (558 g/m^2) than the ordinary fields far to the river dyke with more favorable conditions (649 g/m^2). This is the first report to have demonstrated the differences of effects of salinity intrusion between estuaries and the small-scale environmental variability and site-specific farming adaptation for rice production in Red River Delta.

3 Chapter 3

On-farm manipulation of variety, water and N management to improve rice production in the coastal zone of the Red River Delta, Vietnam

3.1 Introduction

Extremely high dose of N fertilizer was used in rice production in the Red River Delta (RRD); in our survey in 2015-2017, N dose was at 218 kg/ha in spring and 185 kg/ha in summer (Table 2.5, Chapter 2), which were almost twice as large as the average dose in Asia at 117 kg/ha (on-farm survey data by Doberman et al, 2002) or 109 kg/ha (statistic data by FAOSTAT, 2017) . This large applied amount could result in a low nitrogen use efficiencies (NUEs) in the farmer fields, thus a potential of low production efficiency and negative impact on the environment in the RRD. However, the on-farm values of NUEs in RRD were limitedly documented. (Murtazaet al., 2014). We hypothesized N fertilizer application rate in RRD can be reduced without yield penalty. In order to prove this, we collected (1a) farm level N management and uptake data including zero fertilized plot in the RRD ; and (1b) designed experiments of yield response to N fertilizer application rates to make a quantitative assessment of current on-farm N management in RRD and a possible technical advises for improved NUEs.

Rice production in RRD has been threatened by salinity intrusion; high salinity was detected in one of the surveyed paddy fields and the irrigation canals along Day estuary, as well as in the estuary itslef, which led to serious yield reduction and termination of rice cultivation by 2017 (Chapter 2). Trinh et al., (2014) also reported over 12,000 ha of paddy fields affected by salinity intrusion in Nam Dinh province, accounting for 16 % of its paddy land with maximum salinity ranging from 1.2 ‰ to 3 ‰. The level of salinity in the irrigation canal in RRD (Chapter 2) ranged 0.5 ‰ -1.5 ‰ (for 2015-2017)…., which are lower than in MRD, ranged from 0.6 to 14.4 g/L (for 2003–2005; Kotera et al, 2008) . Salinity resistant varieties could be useful to mitigate the salinity stress, but no salinity resistant varieties were used by farmers in RRD (Chapter 2).

In the MRD, numbers of salinity resistant varieties were introduced such as OM 5464, OM5166, OM9921, MTL119 and MTL547 which were widely adopted by farmers and adapt successfully to salinity concentration up to 4 ‰ (Nhan et al. , 2012). For example, the variety OM8017 were cultivated in over 23.300 ha during 2003- 2014, OM5464 were cultivated in 100.000 ha during 2010 -2012 with average yield at 5.4 ton/ha (Hoa et al., 2016). In RRD, in contrast, little attention was paid to develop salinity resistant varieties, but alarmed by the increase in the salinity intrusion, the Vietnamese Government has recently launched several projects on breeding salinity resistant varieties targeted for RRD (Trần Thị et al., 2013). As a result, numbers of salinity resistant varieties had been developed such as M6, M2 and M14 by the Field Crop Research Institution in Vietnam since 2015. Nevertheless, these varieties were still not much disseminated to farmers. It is not clear whether new salinity resistant varieties perform well under the saline target fields in RRD, or farmers get interested in diversification rather than coping with moderate salinity condition by choosing resistant varieties. It is also unclear to find the technical guideline of local government extension to cope with salinity intrusion. We collected on-farm yield data of two newly developed salinity resistant varieties, M2 and M14, as compared with the conventional varieties, at multiple locations in multiple seasons in RRD.

Deep flooding did occur in some fields in RRD and it was associated with lower yield in Chapter 2. If shallower water management can be introduced by manipulation of irrigation and/or drainage, fresh water can be saved for other users. This would be practically helpful, considering the current trends of the reduction of freshwater for irrigation in RRD due to more seawater intrusion (Nguyen et al., 2017, Pham and Le, 2018). Alternate wet and dry irrigation technique is known to be able to reduce fresh water input (Lampayan et al., 2015), but this method may not be applicable in coastal paddy where the soil is saline either in the deep layer or in both deep and top layer (Dinh & Haruyama, 2006). Moreover, the frequent drainage water off the field in the alternate wet and dry irrigation can raise salts from deep soil layer to the surface by capillary (Hanson et al., 1999), hence could exacerbating the saline stress in surface soil. We hypothesis that shallower water management may be more applicable for the coastal zone in RRD, but its effectiveness could also depend on the salinity environments in the soil and irrigation water.

This study aimed to provide agronomic options for farmers to address concerns about over-fertilization and salinity intrusion and strengthen their rice production in RRD. (1) NUEs among farmer fields and yield response to different N fertilizer application rate were quantified in order to identify appropriate N fertilizer application rate. (2) Newly developed salinity resistant rice varieties and (3) shallow water depth irrigation management for water-saving were evaluated in multi-locations with different salinity across different seasons.

3.2 Methodology

3.2.1 **Research site and field selection**

The research was conducted in the three communes in the coastal zone of Red River Delta in Giao Thuy district, Nam Dinh province (Fig.3.1). Giao Huong commune (GH) is an upstream commune in Ba Lat estuary, less saline. Giao Thien commune (GT) is bordered with the coastal line in Ba Lat estuary. Nam Dien (ND) commune was reclaimed zone in Day estuary, exposed with saline water (either from the estuary or from brackish aquaculture) and being the most saline site among the three sites. To conduct the NUEs survey, 63 fields in total were selected in 3 communes, which were classified to 2 field groups namely save fields and at-risk fields. For more detail about the research site and farmer field selection, please refer the Chapter 2.

The list of research activities and taken-place locations were shown in Table 3.1

Table 3.1 Survey activity of the research

Season	No of the surveyed field	Commune	Data collection conducted
Summer 2015	63	GH, GT, ND	1. GY survey 2. N uptake in plant 3. The rate of N fertilizer applied
Spring 2017	48	GH, GT a	1. GY survey 2. N uptake in plant 3. The rate of N fertilizer applied 4. Indigenous soil N supply survey by 0 N plots
Summer 2017	48	GH, GT a	1. GY survey 2. N uptake in plant 3. The rate of N fertilizer applied 4. Indigenous soil N supply survey by 0 N plots

a: There was no survey conducted in ND in 2017 due to farmer rice field in ND were converted to aquaculture pond

3.2.2 **Survey on nitrogen use efficiencies.**

NUEs survey was conducted in the summer rice 2015, spring 2017 and summer rice 2017. Famers were interviewed by each crop season to collect information about fertilizer application rate and split. Grain yield was sampled in three quadrants of 1 m^2 for each field at maturity. Rice plant was sampled at harvest time to analyze N content in grain and straw separately to assess total N uptake of the rice plant. N were analysed by the Kjeldahl method.

In spring and summer rice 2017, zero fertilized plot of 1.5 m x 2 m encircled by a strong levee of 50 cm height and 20 cm width and covered by plastic was set at every 48 surveyed farmer fields. Grain yield without receipt N fertilizer was measured in order to assess indigenous soil N supply and to calculate parameters of NUEs.

In order to show NUEs, we calculated the PEP, RE, AE, PE uses the formulation by as bellowed:

PFP - Partial factor productivity of applied N (kg harvest product per kg N applied)

$$PFP = Y_N/F_N$$

AE = Agronomic efficiency of applied N (kg yield increase per kg N applied)

$$AE = (Y_N - Y_0)/F_N$$

RE = Crop recovery efficiency of applied N (kg increase in N uptake per kg N applied)

$$RE = (U_N - U_0)/F_N$$

PEN = Physiological efficiency of applied N (kg yield increase per kg increase in N uptake from fertilizer)

$$PE = (Y_N - Y_0)/(U_N - U_0)$$

Where F_N *– the amount of (fertilizer) N applied (kg/ ha)*

Y_N *– crop yield with applied N* (g/m^2)

Y_0 *– crop yield* (g/m^2) *in a control treatment with no N*

U_N *– total plant N uptake in aboveground biomass at maturity* (g/m^2) *in a plot that received N*

U_0 *– the total N uptake in aboveground biomass at maturity* (g/m^2) *in a plot that received no N*

The soil was sampled on Dec 2015 and Nov 2017 at the top layer (0-15 cm). Soil properties of 63 farmer fields on the survey were shown in Table 2.1

Table 3.2 Overview of the 3 trials (1. Salinity resistant varietal trial, 2. Shallower water depth irrigation trial, 3. N fertilizer response trial) with their experimental seasons, numbers, varieties, field location, and the treatments

Trial	Crop season	No of exp.	Variety	Location	Treatments
Salinity resistant variety (10 exp.)	2016 spring	3	M2, M14, BC15*	GH, GT*, ND	Salinity resistant varieties (M2, M14) vs conventional varieties (BC15, Cuu Dahe 1, Thien uu 8)
	2016 summer	3	M2, M14, BC15*	GH, GT, ND*	
	2017 spring	2	M2, M14, BC15	GH, GT	
	2017 summer	2	M2, M14, BC15	GH, GT	
Shallower water depth irrigation (10 exp.)	2016 spring	3	BT7	GH	Shallower water depth shallow (<5 cm) irrigation management (Ws) vs conventional irrigation management with deeper standing water (Wc).
			Cuu Dahe 1	GT	
			Nhi uu 838	ND	
	2016 summer	3	M2, M14, BC15	GH	
			M14, BC15	GT	
			M14, Thien uu 8	ND	
	2017 spring	2	BC15	GH, GT	
	2017 summer	2	BC15	GH, GT	
N fertilizer response (2 exp.)	2017 spring	1	BC15	GH	5 N application rates (0, 60, 120, 180, 240 kg/ha)
	2017 summer	1	BC15	GH	5 N application rates (0, 50, 100, 150, 200 kg/ha)

* Rice variety Cuu Da he no 1 in GT field in 2016 spring, Thien uu 8 in ND in 2016 summer were used instead of BC15.

Table 3.3 Soil properties of experiment fields in the research. ND was characterised with higher Na and Cl concentration than that in GH and GT.

Location	pHKCl	OC	N	P2O5	K2O	P av*	K av*	Cl -	SO42-	Na+	CEC	clay	silty	sandy
		%				mg/100g		%		meq/100g		%		
GH	6.4	2.1	0.2	0.2	2.3	30.4	9.1	0.05	0.04	1.4	15.2	18.5	61.2	20.3
GT	6.0	1.6	0.2	0.2	2.2	20.0	8.9	0.04	0.02	1.3	16.6	16.9	51.3	31.8
ND	5.2	1.9	0.2	0.2	2.2	25.5	21.3	0.10	0.06	2.3	13.8	15.0	61.2	23.8

*av – available

Weather conditions during the experimental period are shown in Fig. 2.2. Dry season with low average temperature (15 ºC) and low rainfall are from Nov to Apr, in which spring rice is cultivated. Rainy season with high average temperature (27 ºC) takes place from May to Oct, in which summer rice is cultivated. Thus, spring is characterized by a higher risk of salinity intrusion and lacking water for irrigation in compare with summer rice.

One farmer field was selected for each commune to conduct agronomic experiments

3.2.3 **Three research trials**

A series of experiments were conducted during the 2016–2017 spring and summer rice season (Table 3.1). In each commune, one farmer field was selected to conduct agronomy experiments trials

In each trial, farmers' conventional management other than the intended treatments were applied. Rice was transplanted at 15 days after sowing (spring) or 7 days after sowing (summer), 2-3 seedling per hill in GH, GT and 3-4 seedling per hill in ND at a density of 20 x 25 cm. N fertilizer application rate (217 ± 24 kg N/ha and 177 ± 63 kg N/ha for spring and summer rice, respectively)

Soil properties of the experiment fields in research sites were shown in Table 3.2. The soil in ND was much more saline than GH and GT with higher Na^+, Cl^- and SO_4^{2-}. According to these data, top layer soil in GH and GT were not saline soil since exchangeable sodium percentage (ESP-*calculated from percentage of soil exchangeable Na+ divided by CEC which is standpoint of soil containing sufficiently exchangeable sodium to adversely affect the growth of most crop plants when it more than 15%*) (Abrol et al., 1988) were 16.3% in ND, while only 11% and 12.8% in GT and GH (Table 3.2). However, it should be noted that even non-saline at surface soil, coastal soil in RRD are high saline potential due to saline in the deeper soil layer and underground water (Dinh & Haruyama, 2006); we refer as the less-saline commune.

Salinity resistant varietal trial conducted in three communes (GH, GT, ND) for the 2016 spring and summer growing crop (6 experiments) and conducted in two communes (GH, GT) for the 2016 spring and summer growing crop (4 experiments). There was no experiment in ND in 2017 due to all rice fields in ND were converted into aquaculture ponds. The treatments were two salinity resistant varieties (M2, M14) and farmer conventional varieties BC15. The rice variety Cuu Dahe 1 in the GT field in the 2016 spring, Thien Uu 8 in ND in 2016 summer were used instead of BC15C.

Shallower water depth irrigation trial conducted in three communes (GH, GT, ND) for 2016 spring and summer growing crop (6 experiments) and conducted in two communes (GH, GT) for 2016 spring and summer growing crop (4 experiments). There was no experiment in ND in 2017 due to farmer rice fields in ND were converted to aquaculture ponds. The treatment was two water levels: shallower water depth shallow (<5 cm) irrigation management (Ws) vs conventional irrigation management with deeper standing water (Wc).

N fertilizer response trial conducted in GH in spring and summer cropping seasons in 2017 (2 experiments). In the spring 2017, the five N application treatments were 0, 60, 120, 180, 240 kg/ha while in the summer 2017, five N application treatments were 0, 50, 100, 150, 200 kg/ha. The purpose of these two experiments was to draw N response curve in the target zone.

Data collection

Salinity concentration and standing water depth in the fields were measured 10 days interval from translating time to doughy grain stage by ATA0023-PAL-ES2 (Japan) salinity meter. Average of five readings in each measuring occasion was recorded for one field. Rice plant was harvested the above-ground parts by the sampling of 3 quadrats of approximately 1 m^2 for each field at the harvested time. Plant height and number of hills were measured after that were dried at 80°C under 72 hours to estimate total dry grain weight, dry grain straw and total biomass. Grain yield was calculated by adding 14% moisture to dry grain weight.

Salinity resistant variety M2 and M14

M2 is original from the breeding of Pokkali/PC6 by the Field Crop Research Institution in Hai Duong province, Vietnam. The variety development time is 130-135 days in spring rice, 100-105 days in summer rice. The main characteristics of this variety are: good in tillering, strong straw, small leave, long grain, total height 105-110 cm, flag leaf size 26.76 x 1.97 cm, panicle length 24.97cm. In the condition of salinity 3-5‰, M2 performance was: number grain per panicle is 160 ± 10; ineffective grain rate 10.2%; grain length 7.5mm; grain wide/length rate 3.95; 1000-grain weight 22.03 g; yield potential 5.5-6.0 t/ha.

M14 is original of the breeding of HHZ5-SAL10-DT1-DT1/AC5//AC5 by the Field Crop Research Institution in Hai Duong province, Vietnam. The variety development time 135-140 days in spring rice, 105-110 days in summer rice. The main characteristics are good in tillering, strong straw, small leave, long grain, total height 90-95 cm, flag leaf size 25.6 x 1.85 cm, panicle length 27.3 cm. In the condition of salinity 3-5‰, M14 performance was: number grain per panicle 171 ± 10; ineffective grain rate 11.0%; grain length 7.4mm; grain wide/length rate 4; 1000-grain weight 23.14 g; yield potential 6-6.5 t/ha.

Data were analyzed by ANOVA (SPSS 24), following by Turkey HSD multiple comparisons.

3.3 Results

3.3.1 **Survey on NUE of the farmer fields and N fertilizer response trial.**

NUE of the farmer fields

There was a high variation of indigenous N soil supply from 5.4 g/m^2 to 10.9 g/m^2 (average of 7.75 g/m^2) and nitrogen uptake in above-ground part of rice plant from 5.7 g/m^2 to 17.1 g/m^2 (average of 11.63 g/m$^{2)}$ (Fig.1). Literately, the N fertilizer application rate should be compensated to the gap between N demand (uptake of rice plant) and N supply from the soil. However, a high dose and large variation of N fertilizer (20 g/m^2) were applied to the fields, which consequently could lead to a low value and large variation of NUEs of farmer fields.

N uptake was higher in spring than in summer while soil N supplied were higher in summer than in spring (Table 3.9). N uptake was higher in GT than GH and ND; were higher in safe fields than at-risk fields, especially in summer. Similarly, soil N supply was higher in GT than GH; higher in safe fields than at-risk fields.

N recovery efficiency (RE), which were measured by g grain GY obtained per g N fertilizer applied, were higher in spring at 0.27 than summer at 0.23, particularly in at-risk fields (Table 3.9). Partial N factor productivity (PEP) was also affected by season, which was higher in spring than summer, particularly in the interaction with commune.

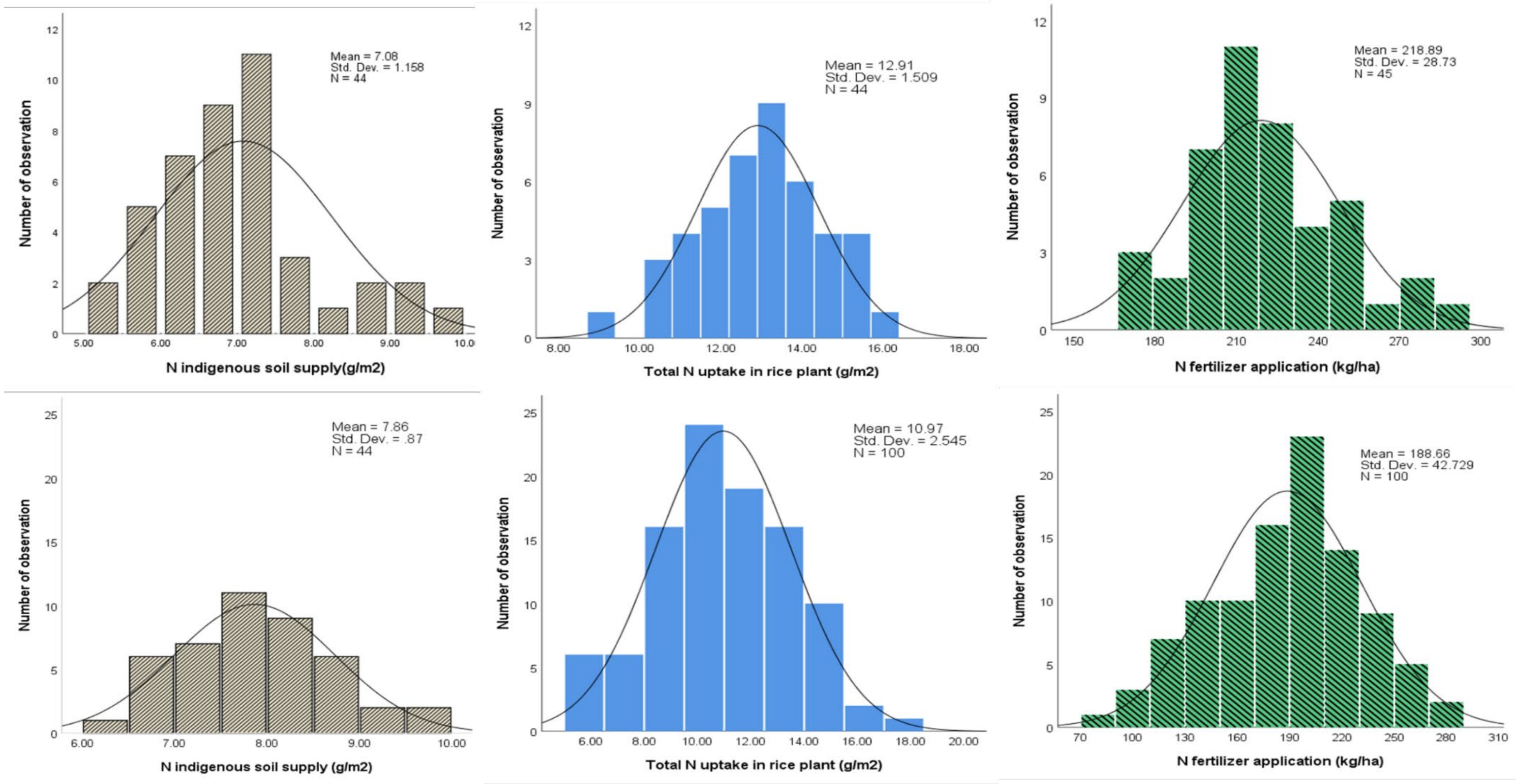

Figure 3.1 Variation in the N indigenous soil supply (plant N accumulation in on-farm plots that did not receive N fertilizer, g/m2), the plant N uptake in above-ground biomass at harvesting time (g/m2) and amount of N fertilizer applied in farmer field (g/m2) at the research site

Table 3.4 NUEs variability in the farmer field. ANOVA of effects of season, commune, field group and their interactions on variations in N uptake in rice plant, soil indigenous N supply, crop N recovery efficiency (RE) and partial N factor productivity (PFP)

	N uptake (g/m2)			N soil supply (g/m2)		PEP (g/g)			AE			RE (g/g)			PE (g/g)	
Main effect			Main effect		Main effects				Main effect		Main effets			Main effets		
Season (S)**			Season (S) **		Season (S)**				Season (S) **		Season (S)**			Season (S)**		
spring	12.8		spring	6.9	spring	40.2			spring	14.0	spring	0.27		spring	52.6	
summer	10.3		summer	7.8	summer	25.0			summer	4.0	summer	0.22		summer	19.1	
Commune (C)**			Commune (C)**		Commune (C)**				Commune (C)**		Commune (C)*			Commune (C)+		
GH	11.0		GH	7.0	GH	33.8 b			GH	8.2	GH	0.23		GH	35.1	
GT	12.4		GT	7.7	GT	33.8 b			GT	9.8	GT	0.26		GT	36.7	
ND	9.3		ND	-	ND	20.2 a			ND	-	ND	-		ND	-	
Fieldgroup (F) **			Field group (F) ns		Interaction effect				Field group (F) ns		Fieldgroup ns			Fieldgroup ns		
ordinary	12.2		ordinary	7.4	Sex C**	GH	GT	ND	ordinary	8.7	ordinary	0.25		ordinary	34.4	
fragile	10.2		fragile	7.2					fragile	9.3	fragile	0.24		fragile	37.5	
Interaction effect					spring	38.6	41.7	.a			Interaction effect			Interaction effect		
F x S**	ordinary	fragile			summer	29.0	25.9	20.2			S x F**	Spring	summer	S x F**	GH	GT
spring	12.5	12.8									Ordinary	0.25	0.25	Ordinary	33.9	41.0
summer	12.0	8.5									Fragile	0.29	0.19	Fragile	36.2	32.5
FxC**																
GH	11.7	10.3														
GT	12.6	12.2														
ND	12.5	6.1			Other interaction : S x C x F*											

*$P < 0.05$, **$P < 0.01$ by two-tailed *t*-test

(PFP - Partial factor productivity (kg harvest product per kg N applied: $PFP = GYn/Fn$); AE - Agronomic efficiency (kg yield increase per kg N applied; $AE = (Yn-Yo)/Fn$); RE = Crop recovery efficiency (kg increase in N uptake per kg N applied) ; $RE = (Un-Uo)/Fn$ and PE - Physiological efficiency (kg yield increase per kg increase in N uptake from fertilizer; $PE =(GYn-GYo)/(Un-Uo$

Table 3.5 Effected factors which have influenced the Nitrogen use efficiencies of farmer fields were not understood well in this research, but NUEs tended to be influenced by saline related factors such as water salinity, Na+ or Cl-. Data are shown as spring and summer rice 2017

Crop season	NUEs	Water deepth (cm)	Water salinity (‰)	pHKCl	OC	N	P2O5	K2O	P av*	K av*	Cl -	SO42-	Na+	CEC	clay	sandy	P2O5 fertilizer	K2O fertilizer
					%				mg/100g		%		meq/100g		%		kg/ha	
Spring (n=44)	PFP	0.1	-0.1	0.0	0.0	-0.1	0.0	-0.2	-0.2	0.2	-0.1	-0.2	0.2	0.2	-.365*	.331*	-0.2	-0.1
	AE	0.1	0.1	-0.2	0.0	0.0	0.0	0.0	-0.2	0.2	0.0	0.1	0.2	0.1	-0.2	0.1	-0.2	0.0
	RE	0.3	.402**	-0.1	0.1	0.1	0.0	0.0	-.382*	.606**	.420**	0.0	.592**	-0.1	-0.1	-0.1	-0.1	0.2
	PE	-0.2	-.420**	-0.1	-0.1	0.0	0.0	0.0	0.3	-.408**	-.459**	0.1	-.416**	0.2	-0.1	0.1	-0.2	-.358*
Summer (n=44)	PFP	0.1	-.251*	.310**	-0.1	-.218*	0.2	0.0	0.1	-0.2	-0.1	-.217*	-0.2	-0.1	0.2	-0.1	0.0	-0.1
	AE	-.341*	-0.1	0.0	0.1	0.1	0.2	0.3	0.0	0.0	0.1	0.2	0.0	.302*	0.2	-0.2	0.0	-0.2
	RE	-0.2	-0.2	-0.1	0.1	0.2	0.2	0.2	0.0	0.1	-0.1	0.3	0.0	.327*	0.1	-0.1	-0.2	-0.2
	PE	-0.2	0.0	0.1	0.0	0.0	0.1	0.1	0.0	-0.1	0.0	0.0	0.0	0.1	0.2	-0.3	0.3	-0.1

^{av} Available. *$P < 0.05$, **$P < 0.01$ by two-tailed *t*-test

(PFP - Partial factor productivity (kg harvest product per kg N applied: *PFP = GYn/Fn*); AE - Agronomic efficiency (kg yield increase per kg N applied*; AE = (Yn-Yo)/Fn*); RE = Crop recovery efficiency (kg increase in N uptake per kg N applied) *; RE = (Un-Uo)/Fn* and PE - Physiological efficiency (kg yield increase per kg increase in N uptake from fertilizer; *PE =(GYn-GYo)/(Un-Uo))*

N fertilizer response trial

In the N fertilizer response trial in spring 2017, the GY was not different in three levels of N fertilizer rate (12 g/m^2, 18 g/m^2 and 24 g/m^2) at 855 g/m^2, 901 g/m^2 and 920 g/m^2. Among these, N use efficiencies were highest at N level of 12 g/m^2 with crop recovery efficiency 0.26, agronomy efficiency 18 (g grain increased/g N applied, and physiological efficiency 93 (Table 3.10).

In the N fertilizer response trial in summer 2017, the GY was not different in three levels of N fertilizer rate (10 g/m^2, 15 g/m^2 and 20 g/m^2) at 653 g/m^2, 688 g/m^2 and 624 g/m^2. Among these, N use efficiencies were highest at N level of 10 g/m^2 with crop recovery efficiency 0.47, agronomy efficiency 17, and physiological efficiency 52.

Using experimental data, we draw the curse of N uptake and GY in response to the N fertilizer rate at the farmer field conditions to compare with the efficiencies of N use in farmer fields (Fig.2). Famer applied a high rate of N fertilizer application in both spring and summer. In spring, the high rate of fertilizer application was the reason of low NUE while in summer, high rate of fertilizer application, as well as low GY, achieved and low N uptake were the reasons of low NUEs at the research site.

Table 3.6 Grain yield, N uptake and N use efficiencies (crop recovery efficiency (RE), agronomic efficiency (AE), and physiological efficiency (PE) in 5 N fertilizer application rates in spring and summer rice 2017.

Crop	N applied (g/m^2)	GY (g/m^2)	N uptake (g/m^2)	PFP (g/g)	AE (g/g)	RE (g/g)	PE (g/g)
Spring 2017	0	640 a	7.4 a				
	6	761 b	8.7 a	127 a	20.2 a	0.22 ns	103 ns
	12	855 c	10.5 b	71 b	17.9 ab	0.26 ns	93 ns
	18	901 c	11.9 bc	50 c	14.5 ab	0.25 ns	75 ns
	24	920 c	12.9 c	38 d	11.7 a	0.23 ns	72 ns
Summer 2017	0	482 a	7.4 a				
	5	570 b	9.6 b	114 a	17.6 b	0.44 ns	71 c
	10	653 c	12.1 c	65 b	17.0 b	0.47 ns	52 b
	15	688 c	14.1 c	46 c	13.7 ab	0.45 ns	45 ab
	20	624 bc	14.0 c	31 d	7.1 a	0.33 ns	37 a

Mean with different alphabet shows the significant difference at 5% by Tukey HDS multiple range tests; ns is not significant

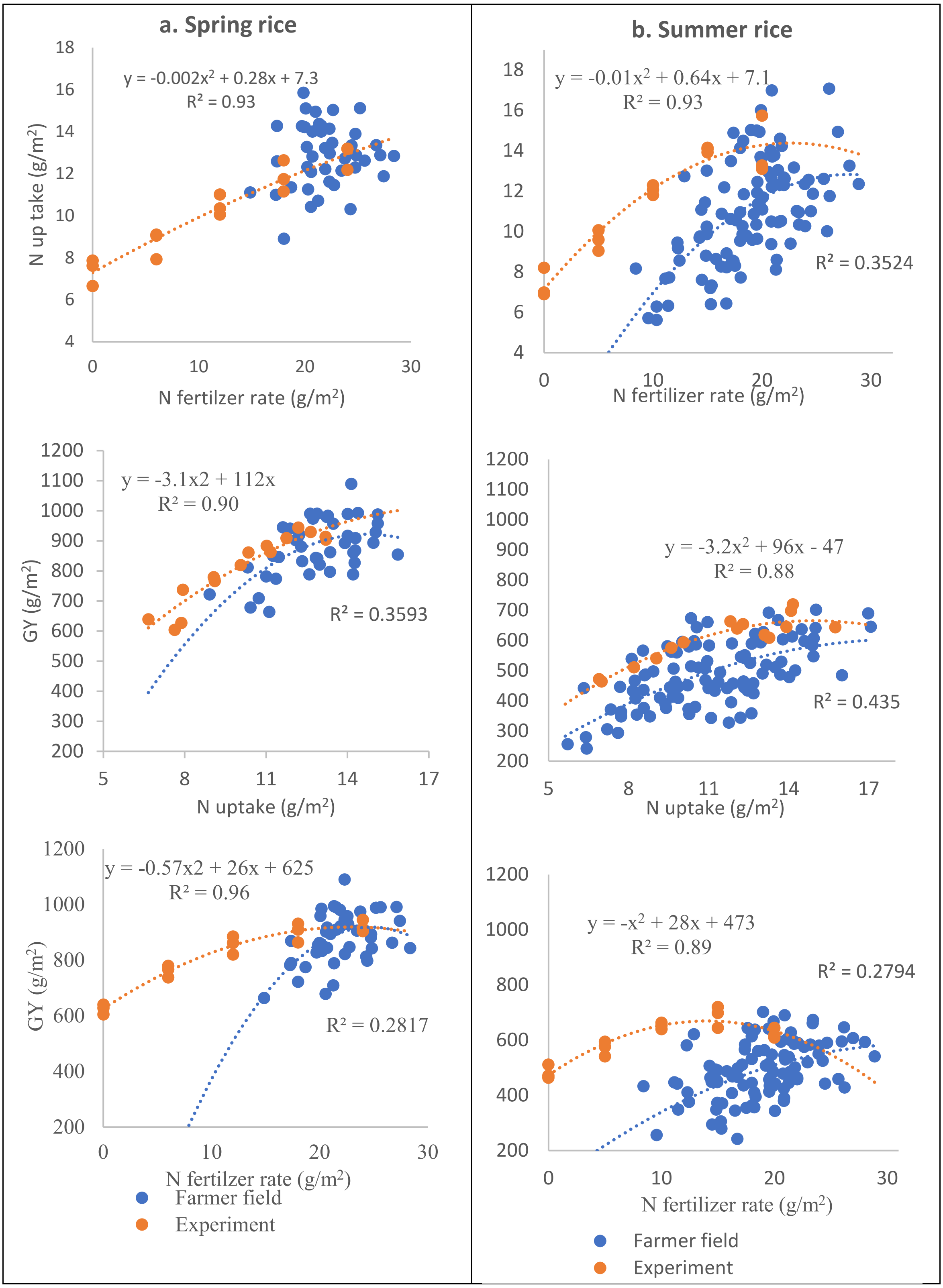

Figure 3.2 Relationships among N fertilizer application rate, N uptake and grain yield in the farmer field data and in the experimental data for (a) spring rice 2017 and (b) summer rice 2015 and 2017

3.3.2 **Salinity resistant varietal trial**

The interaction effect of commune and variety on GY were significant (Table 3.4). In the ND commune with high saline soil, M2 and M14 have higher yield compared to conventional varieties (529, 539 g/m^2 vs. 348 g/m^2) while in GH and GT commune with non-saline soil, M2 and M14 have lower yield (for example in GT 632, 618 g/m^2 vs. 751 g/m^2 respectively).

In spring rice, M2 and M14 have higher biomass than conventional rice in ND (978, 1020 g/m^2 vs. 892 g/m^2 while have lower biomass in GT (1092, 1217 g/m^2 vs. 1383 g/m^2 (Table 3.5); having higher HI than conventional variety in ND (0.5 vs. 0.4) while lower HI in GT (0.5 vs 0.54); having lower panicle number than conventional variety in ND (221, 220 panicle/m^2 vs 261 panicle/m^2 while lower plant height than conventional varieties (99cm, 106 cm vs. 114cm).

In summer, M2 and M14 gave higher biomass than safe variety in ND (487, 477 g/m^2 vs. 295 g/m^2) but not different in GT, GH (Table 3.5); having higher HI than conventional varieties in ND (0.47 vs. 0.43) while not significant in GT, GH (0.5 vs 0.54); having lower panicle number than conventional variety in ND (251, 275 panicle/m^2 vs 321 panicle/m^2) while lower in GT (223, 233 panicle/m^2 vs. 204 panicle/m^2); having lower plant height than conventional variety in ND (93cm, 91 cm vs. 89 cm) while lower in GT (102 cm, 100 cm vs. 108 cm)

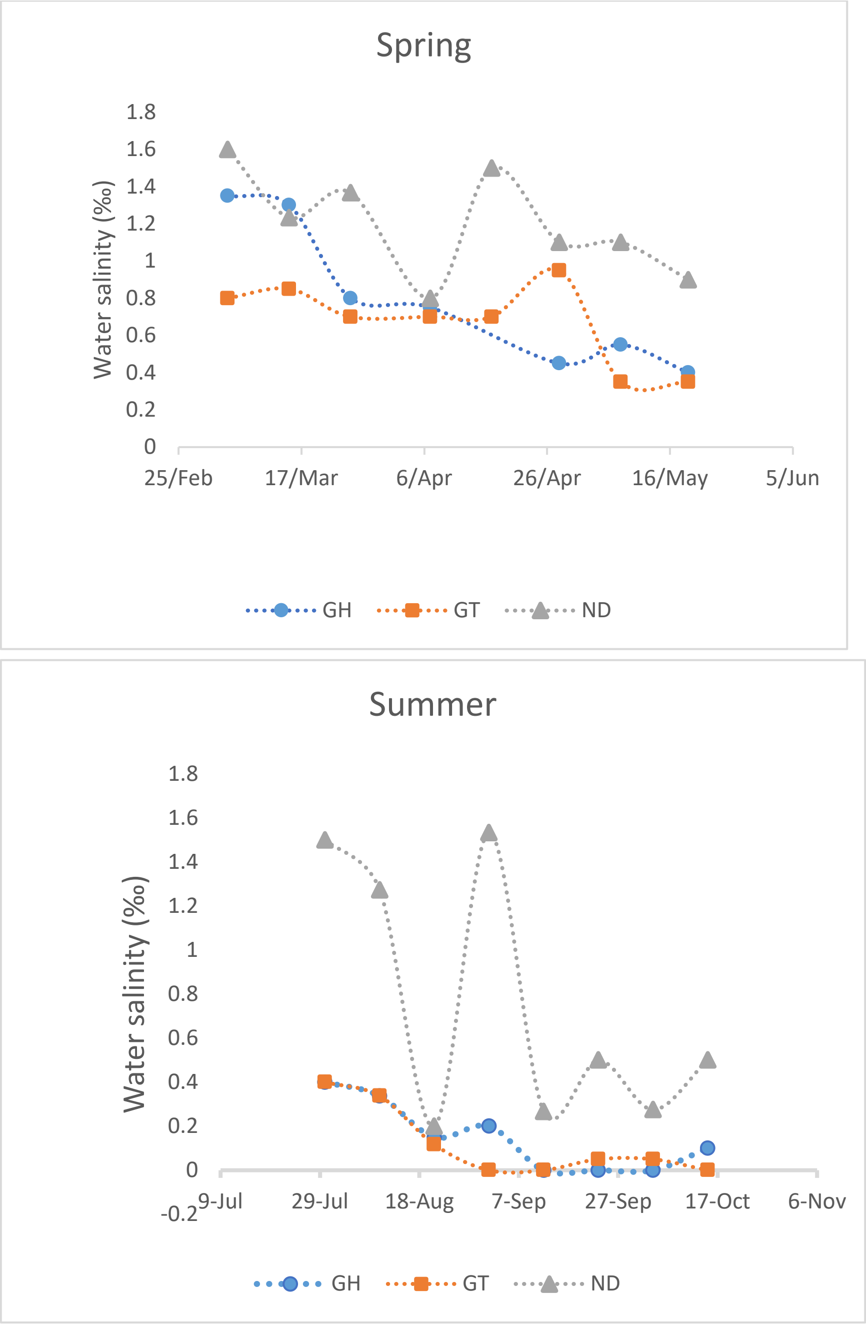

Figure 3.3 Dynamism of water salinity in the experiment fields in 3 sites over rice plant developing duration

Table 3.7 ANOVA of effects of year, commune, season, variety and their interactions on variations in GY. Salinity resistant varieties, M14 and M2, achieved a significantly higher yield than conventional varieties (Vc) in the most saline ND field, but their potential yield was lower.

Main effects	Yield (g/m2)	Se x Var **	Yield (g/m2)	C x Var**	Yield (g/m2)	Se x C x Var*		Yield (g/m2)
Year (Y)*		Spring		GH			M2	673
2016	608	M2	672	M2	635	spring, GH	M14	677
2017	645	M14	644	M14	635		Vc	747
Commune (C)**		Vc	728	Vc	686		M2	706
GH	652	Summer		GT		spring, GT	M14	637
GT	667	M2	557	M2	632		Vc	873
ND	475	M14	574	M14	618		M2	569
Season (Se)**		Vc	560	Vc	751	spring, ND	M14	592
spring	681			ND			Vc	401
summer	564			M2	522		M2	596
Variety (Var)				M14	539	summer, GH	M14	593
M2	615a			Vc	348		Vc	624
M14	609a						M2	559
Vc	644b					summer, GT	M14	600
							Vc	629
							M2	477
						summer, ND	M14	487
							Vc	295

***, * ANOVA significant at 0.01, 0.05 level. Mean with different alphabet shows significant difference at 5% by Tukey multiple range tests; ns is not significant*

Table 3.8 Grain yield and growth parameters of 2 salinity resistant varieties (M2 and M14) compared with conventional varieties (Vc-mostly BC15) in 3 farmer fields (GH, GT, ND) for spring and summer rice on average of 2016 and 2017

Season	Site	Average salinity ± SD (‰)	Treatments	Grain yield (g/m^2)	Biomass (g/m^2)	Plant height (cm)	HI	1000-grain weight (g)	Panicle number ($/m^2$)	Grain weight per panicle (g)
spring	**GH (n=2)**	0.81 ±1.4	M2	673 a	1082 a	105 ns	0.53 b	22 a	190 b	3.07 ns
			M14	677 a	1136 ab	107 ns	0.51 a	22 a	180 a	3.33 ns
			C	747 b	1292 b	109 ns	0.50 a	29 b	193 b	3.38 ns
	GT (n=2)	0.8 ± 1.5	M2	706 a	1217 a	106 a	0.50 a	22 ns	252 ns	2.46 a
			M14	637 a	1092 a	99 a	0.50 a	22 ns	221 ns	2.49 a
			C	873 b	1383 b	114 b	0.54 b	22 ns	191 ns	4.03 b
	ND (n=1)	1.23 ± 1.9	M2	569 b	978 b	99 ns	0.50 b	-	220 a	2.35 b
			M14	592 b	1020 b	100 ns	0.50 b	-	221 a	2.30 b
			C	401 a	892 a	103 ns	0.40 a	-	261 b	1.32 a
summer	**GH (n=2)**	0.1 ± 0.4	M2	596 ns	1053 a	104 a	0.49 ns	21 ns	250 ns	2.06 a
			M14	593 ns	1057 a	106 a	0.48 ns	20 ns	240 ns	2.14 a
			C	624 ns	1163 b	115 b	0.47 ns	22 ns	237 ns	2.28 b
	GT (n=2)	0.12 ±0.4	M2	559 ns	998 a	100 a	0.48 ns	21 a	233 b	2.07 a
			M14	600 ns	1084 a	102 a	0.48 ns	20 a	223 b	2.32 a
			C	629 ns	1172 b	108 b	0.46 ns	22 b	204 a	2.81 b
	ND (n=1)	0.9± 2.1	M2	477 b	880 b	91 b	0.47 b	-	275 a	1.50 b
			M14	487 b	883 b	93 b	0.47 b	-	251 a	1.67 b
			C	295 a	589 a	89 a	0.43 a	-	321 b	0.80 a

Mean with different alphabet shows significant difference at 5% by Tukey multiple range tests; ns is not significant.

3.3.3 **Shallower water depth irrigation trial**

The water level, commune, as well as the interaction between water level and commune shows significant effects on GY (Table 3.6). Shallower water depth was given a lower grain yield (646 g/m^2) than conventional irrigation (669 g/m^2). ND had lower GY than GH, GT. Saving water irrigation achieved no different grain yield than conventional irrigation in non-saline condition GH (667 g/m^2 vs 659 g/m^2), GT (699 g/m^2 vs. 729 g/m^2) but reduced grain yield in the saline ND field (496 g/m^2 vs. 574 g/m^2) (Table 3.7). There was no difference in GY between water treatments in the less-saline commune which were explained by the no different in biomass (both GH and GT); no different in HI and panicle number in GT commune, although shallower water depth slightly reduced HI and panicle number in GH. In contrast, in the saline commune ND, shallower water depth reduced biomass significantly (824 g/m^2 vs. 933 g/m^2), reduced plant height (88 cm vs. 93cm) and reduced the number of panicles per m^2 (246 vs. 286).

Effect of shallower water depth on GY was different in season (Table 3.8). In spring, shallower water depth had reduced 40% of water depth (4±1.3 cm vs. 6.4 ± 4.7 cm); resulted in a significant reduction in GY (737 g/m^2 vs 780 g/m^2). However, in summer shallower water depth had reduced 50% of water depth (4±1.4 cm vs. 8 ± 6.4 cm) with no significant reduction in GY (553 g/m^2 vs 558 g/m^2).

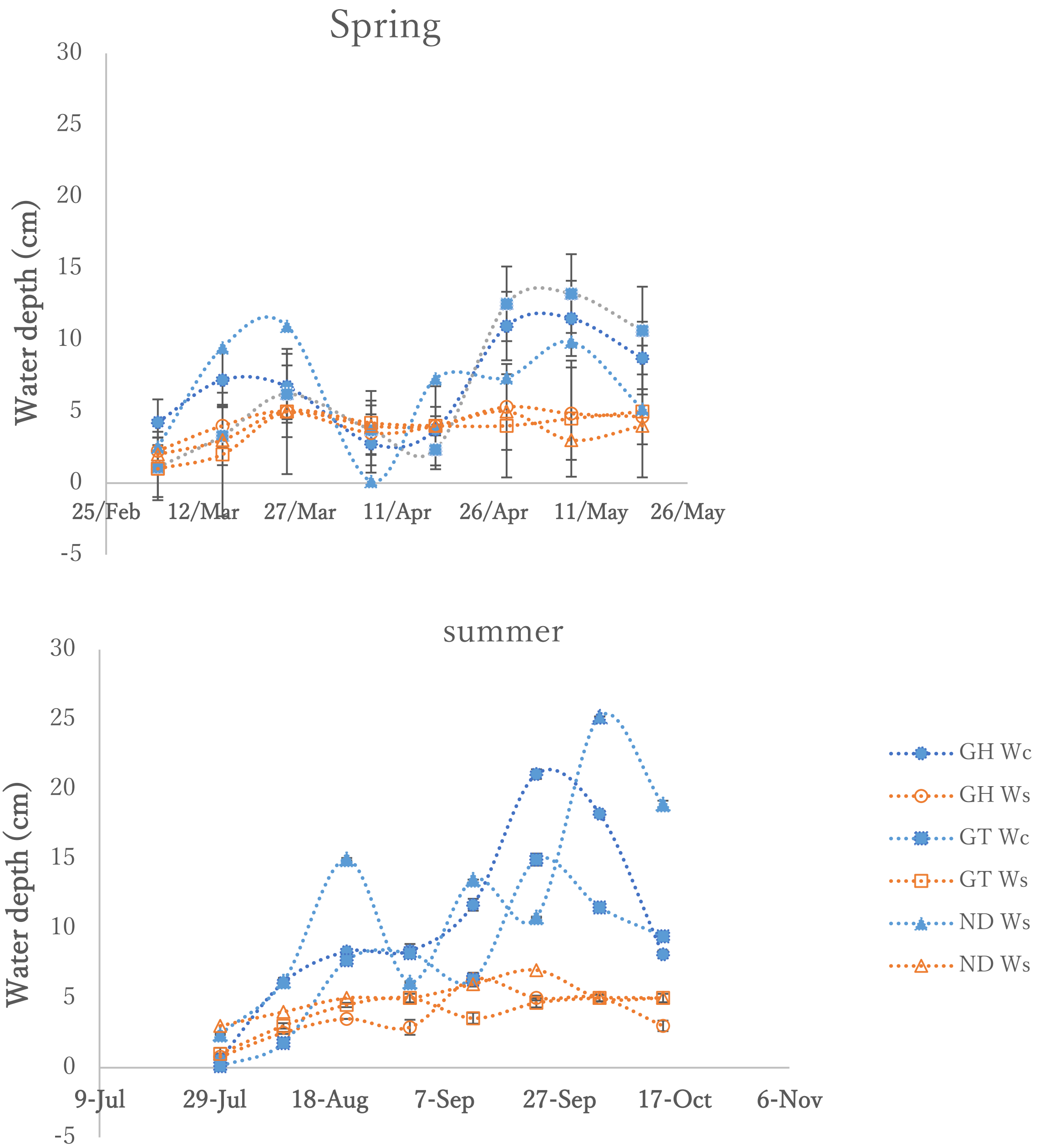

Figure 3.4 Dynamism of water depth in 2 water treatments (Wc-conventional irrigation and Ws shallow water depth irrigation) in 3 communes over rice plant developing duration

Table 3.9 ANOVA of effects of year, commune, season, water treatment and their interactions on variations in GY. Saving water irrigation achieved no different grain yield than conventional irrigation in non-saline condition GH, GT fields, but reduced grain yield in the saline ND field.

Main effects	Yield (g/m^2)	Se x W*	Yield (g/m^2)	C x W*	Yield (g/m^2)
Year *ns*		Spring		GH	
2016	631	Wc	780	Wc	640
2017	697	Ws	737	Ws	646
Commune (C)**		Summer		GT	
GH	663 b	Wc	558	Wc	710
GT	714 c	Ws	553	Ws	687
ND	534 a			ND	
Season (Se)**				Wc	511
Spring	758			Ws	496
Summer	557				
Water treatment (W)*					
conventional (Wc)	669				
shallower water depth (Ws)	646				

***, * ANOVA significant at 0.01, 0.05 level. Mean with different alphabet shows significant difference at 5% level by Tukey multiple range tests; ns is not significant*

Table 3.10 Grain yield and growth parameters of 2 water treatment in 3 communes. Data shows the average of 2016 and 2017

Site	Treatment	Water level ± SD (cm)	Grain yield (g/m2)	Biomass (g/m2)	HI	Plant height (cm)	1000-grain weight (g)	Panicle number (/m2)
GH (n=4)	Wc	7.2 ± 6.3	640 ns	1145 ns	0.48 *	111 *	25 ns	235 **
	Ws	4.0 ± 1.3	646	1099	0.51	106	25	220
GT (n=4)	Wc	6.3 ± 4.6	710 ns	1231 ns	0.49 ns	108 ns	22 ns	209 ns
	Ws	4.0 ± 1.6	687	1173	0.50	107	22	199
ND (n=2)	Wc	8.9 ± 5.9	511 **	933 **	0.46 ns	93 **		286 **
	Ws	4.6 ± 1.2	450	824	0.47	88		246

Table 3.11 Grain yield and growth parameters of 2 water treatment in spring and summer rice. Data shows the average of 2016 and 2017

Season	Treatment	Water level ± SD (cm)	Grain yield (g/m^2)	Biomass (g/m^2)	HI	Plant height (cm)	1000-grain weight (g)	Panicle number (/m2)
Spring (n=5)	Wc	6.4 ± 4.7	780 *	1297 ns	0.52 ns	109 ns	25.5 ns	219 ns
	Ws	4.2 ± 1.3	737	1238	0.51	107	25.2	221
Summer (n=5)	Wc	8.0 ± 6.4	558 ns	1038 ns	0.46 *	105 *	22.1 ns	247 **
	Ws	4.0 ± 1.4	553	971	0.49	100	21.5	216

3.4 Discussion

3.4.1 **Potential of reducing the rate of N application and increasing NUEs**

NUE of the farmer fields in all three research sites were low in general, particularly in summer crop at the saline site ND and saline at-risk field group (Table 3.9). For example, RE in summer (0.22) in at-risk fields (RE = 0.19) compared with the average value of 0.25; PFP in ND soil (24.4), in summer (17.9), in the at-risk field (20.4), compared with the average value of 30.7 (g/g). These results were explained by the effect of higher salinity in the irrigation water of ND and at-risk fields (Table 3.10 and Fig 3.2). Rice plants exposed to salt stress lower absorbed N due to antagonistic effects of Cl^- ions with $NO3^-$ ions (Aslam et al., 1992; Singh et al., 2013; Zayed et al., 2013) and the accumulation of Na+ and Cl- to toxic levels in the old leaves (Wang et al., 2012).

The results of N fertilizer application trial show that N fertilizer rate can be reduced without yield penalty in GH, GT (Table 3.10). The target ranges were 12-18 gN/m^2 and 10-15 gN/m^2 for spring and summer rice, respectively can maximize GY meanwhile achieved high values of PEP, AE and PE. Our results were in agreement with other studies on the optimum doses of N to maximize GY and NUEs in saline soil, such as in Bangladesh field experiment with 125 kg/ ha of N for saline soil at EC 6.2 dS/m (Haque et al., 2015); 150 mg N/kg soil at EC $\approx$ 6.0 dS/m, pot experiment (Murtaza et al., 2000); or 140.48 kg N /ha in the combination with 70.08 kg/ha of zinc sulfate for saline soil at 16.0 dS/m (Singh et al., 2013). The higher salinity in the soil, the higher N dose is required. Hence, consider the salinity of the field will be a good guide for farmers to adapt to the N fertilizer dose.

3.4.2 **Saline resistant varieties for salinity intrusion coastal fields**

The two variety M2, M14 had a significantly lower yield potential than conventional variety in non-saline condition (632 g/m^2, 618 g/m^2 vs 751 g/m^2 in GT) (Table 3.4). The lower yield potential was the consequence of lower biomass and HI in less-salinity stress GH, GT (Table 3.5). However, M2, M14 can achieve higher GY in the high saline-stress condition of ND. In ND, saline becomes more problem for rice, which reduce conventional GY to 401 g/m^2 in spring and g/m^2 295 in summer rice. It is documented that salinity in the irrigation water has a significant negative impact on GY of sensitive varieties when it excess to 1.97 dS/m (equivalent 1‰) (Zeng & Shannon, 2000) (Grattan et al., 2002). In such saline condition of ND, the salinity stress caused a serious loss in GY of Conventional variety at 348 g/m^2 while GY in M2, M14 were at 522 g/m^2, 539 g/m^2 respectively.

The performances of M2 M14 in saline field were derived from a lower reduction of M2 and M14 in both biomass (reduced by 135 g/m^2 144 g/m^2 between non-saline GH and saline field ND) and in HI (reduced by 0.01 vs 0.02 between non-saline GH and saline field ND), while there was a substantial reduction under saline ND field of Conventional variety in biomass (by 548 g/m^2) and in HI (by 0.09). Consequently, M2 and M14 in ND were obtained a higher biomass (929 g/m^2, 952 g/m^2), higher HI (0.49, 0.49) and higher panicle weight (1.92, 1.98 g/m^2) in comparison to that of Conventional variety (740 g/m^2; 0.41; 1.06 g/m^2 respectively) (Table 3.5). Interestingly, we found that panicle number in high salinity ND fields were higher than in less-saline fields of GH, GT in all three-variety treatment (291 vs. 214; 241 vs 220; 236 vs 210 for Conventional variety, M2, M14 respectively).

There were numerous study proved that salinity stress can seriously reduce the biomass, HI, number of filled panicles, fertile panicle, percentage of fertile grain in the susceptive variety (Falah, 2010)(Rad et al., 2011) (Zeng & Shannon, 2000)(Asch, Dingkuhn, & Dorffling, 2000), which support to our findings of GY reduction. Our result of the higher panicle number in ND fields than GH and GT fields could be explained by ND's farmers increased the transplanting seedling per hill in order to increase the survival rate of seeding under the saline stress. Nevertheless, unde the saline stress condition, panicle of Conventional variety could not elongate, caused grain infertile, thus grain weight per panicle (1.1 g/m^2) were much lower than in non-saline condition (3.4 g/m^2 in GT). The reason probably is under saline environment spikelet per panicle decline owing to spikelet malformation and degeneration (Yokoyama et al., 2002).

M2 and M14 were limited in grain quality. According to the varieties authors, M2 and M14 were average quality; agreed by farmers who claimed that M2 and M14 taste were much lower quality than conventional cultivars targeted for human eating such as BC 15, Bac Thom 7; but higher than current popular hybrid varieties which original from China. Hybrid varieties such as Nhi Uu 838, C Uu Da He no1, were considered slight resistant to salinity by local farmers (Trinh et al., 2014) and cultivated dominantly in spring at marginal, salinity-prone fields in the research site (chapter 2), mainly for purpose of animals food or sell at low price (Vien & Nga, 2009). Hence, the introduction of M2 and M14 to replace Chinese hybrid varieties will provide a wider adaptation choice for farmers at saline fields, such as in ND or in the at-risk field in GH, GT. Moreover, further improving quality of salinity resistant varieties are needed to increase farmer adoption.

3.4.3 **Shallower water depth irrigation for less saline coastal fields**

Keeping a thin water layer (<5cm) in the paddy field can reduce 35-50% water depth than conventional irrigation method (Table 3.7), hence significantly reduce the water use. Meanwhile, GY achieved of the two irrigation methods were different depend on research site (Table 3.6). In the less-saline sites, shallower water depth irrigation achieved a similar GY in GH (646 g/m^2 vs 640 g/m^2) and GT (678 g/m^2 vs 710 g/m^2) meanwhile a lower GY in saline field of ND site (450 g/m^2 vs 511 g/m^2) compared to conventional irrigation. Shallower water depth irrigation reduced panicle number in all three sites but increased HI in non-saline condition (Table 3.7). This result was explained by the requirement of higher water available in saline soil condition. Since salts in the soil move along with water, the distribution of salt in the soil is determined by the water flow through the soil, hence water depth. Firstly, water infiltrating downward into the soil, for instance, carries salt near the surface to a lower depth. The higher irrigation water depth, the larger the leaching fraction appears within the root zone (Hanson et al., 1999). Secondly, a high-water depth can dissolve and reduce the Na+ concentration in the soil. Phogat et al. (2010) reported that the grain production per unit evapotranspiration and water productivity in respect of total dry matter production was also significantly reduced when soil salinity increase, indicating that under saline condition, rice plant the require a higher water irrigation to cope/avoid the saline stress, thus saving water irrigation was unsuitable for high saline soil condition.

Effect of shallower water depth on GY was different by seasons with the GY reduction appear only in spring, when salinity stress was more severe while no GY reduction in summer, included in ND field (Table 3.8), owing to the high rainfall in summer (Fig. 2.2). It suggested that even in the saline area, saving irrigation water is possible without harmful of GY in summer crop.

Due to the reduction in water availability for irrigation (Nguyen et al., 2017), shallower water depth method is promising to reduce water use while maintaining GY for less-saline soil; but reduced GY in spring season in saline soil.

3.5 Conclusion

Salinity resistant varieties, M14 and M2, achieved a significantly higher yield than conventional varieties in the most saline ND field although their potential yield was lower in less-saline fields GH and GT.

Shallow water depth management (<5 cm) could maintain a similar level of yield as conventional depth management in less-saline fields (GH, GT), but resulted in significant yield reductions in more saline ND field.

Current rice production had problems of both over-fertilization and low efficiency, particularly in summer. The N fertilizer application rate can be reduced without much yield penalty; the target ranges were 12-18 g N/m^2 and 10-15 g N/m^2 for spring and summer rice, respectively.

4 Chapter 4 Effect of salinity on the economic efficiency of rice and aquaculture production in the coastal area of Red River Delta, Vietnam

4.1 Introduction

In Nam Dinh, a coastal province of Red River Delta (RRD), aquaculture production areas have been increasing from 9,500 ha in 1995 to 15,500 ha in 2017(General Statistic Office of Vietnam, 2018). The coastal aquaculture production in Nam Dinh had been developed mainly in (1) natural coastal wetland outside the dyke (brackish water), (2) salt fields inside the dyke (brackish or fresh-water), and (3) paddy fields inside the dykes (fresh-water), according to local authorities. The third type was recently increased due to the limited areas of coastal wetland and salt fields (Fig.1).

The acceleration of the land-use conversion came from several factors. Firstly, market demand for aquacultural products has been increasing (Nhuong et al., 2002). Secondly, the Government and local authorities legally facilitated aquacultural farming, especially with the promulgation of the revision of Land Law in 1998 and resolution No.09/NQ-CP issued on 15/6/2000, which for the first time allowed the transformation of rice/salt fields of low productivity into aquacultural fields (Nhuong et al., 2002). Report from the Ministry of Fisheries (MoFi, 2002) showed that shrimp farming area in Vietnam increased by 42.6 % in 2001 (478,800 ha) compared to 2000 (250,000 ha). Thirdly, aquaculture increased the income of farmers and created rural employment (Halwart et al., 2003). The total revenue of aquaculture in 2015 was 366 million VND/ha, which was 3.5 times higher than that of rice (Nam Dinh Statistics Office, 2016). Fourthly, salinity intrusion in RRD has been increasing, causing yield reduction in some coastal paddy fields (Duc & Umeyama, 2011)(Hien et al., 2010), Nguyen et al., 2017), as was observed in Chapter 2. The more severe salinity intrusion problem, the larger area of rice conversion to aquaculture were observed in MRD (Kotera et al., 2008). It is generally perceived that higher salinity in the irrigation canals would cause economic disadvantages for rice and give more incentive for farmers to change to aquaculture, but the quantitative information of the effects of salinity on the economic efficiency of each land-use type has not been studied in the RRD.

We hypothesize that the salinity level in irrigation canals determines the profit of each land-use type, consequently, determines the conversion from rice to aquaculture. Using the combination of field measurement and questionnaire survey methods, this research aims to estimate the relationship between the salinity and economic efficiency of rice production and aquacultural production. Based on the estimation, we will determine the salinity level where rice production profit equates with fish production profit.

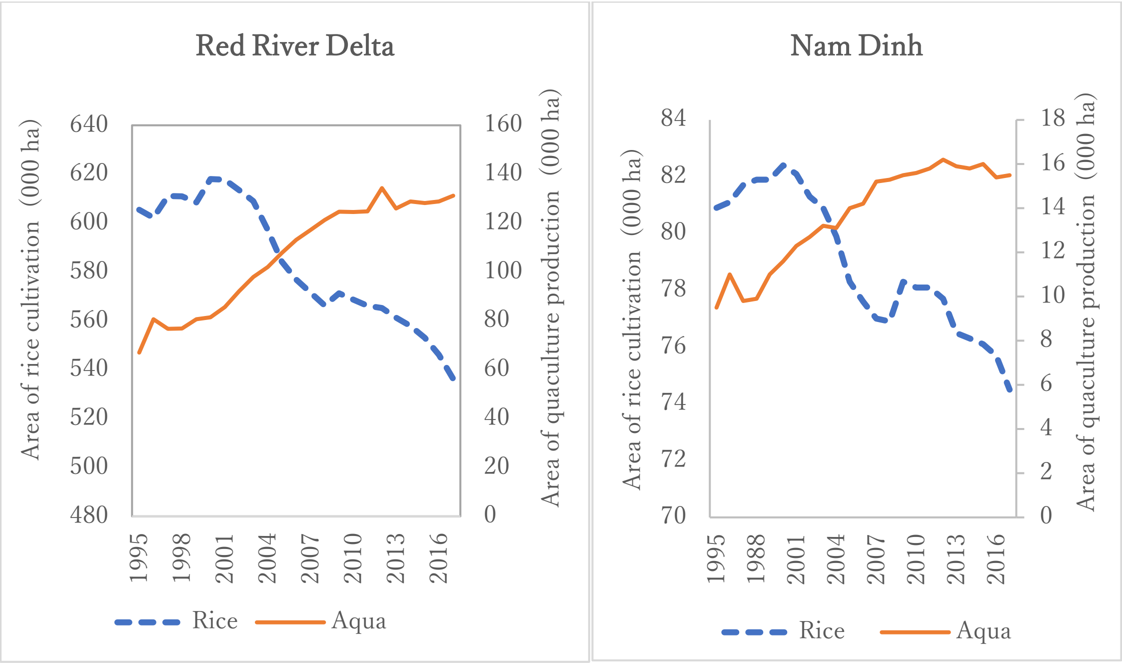

Figure 4.1 The increasing of aquaculture production area accompanied by the reducing of rice production area in Red River Delta (a) and in Nam Dinh province (b). (General Statistic Office of Vietnam, 2018)

4.2 Methodology

4.2.1 Study area

Nghia Hung district, Nam Dinh province, located in the south of the Red River flood plain on the East Sea. The weather in Nghia Hung is primarily a tropical monsoon climate with an annual average temperature of 24°C. December and January are the months with the coldest climate (16-17°C) whereas the hottest month is July, with a mean temperature of 30oC. Nghia Hung has a medium humidity level of 85% with a total annual rainfall of 1,800 mm, concentrated between May and October. This coastal region is wave-dominated and affected by salinity intrusion. The population is about 180,000 (in 2015) with a population density of 694 per square km (in 2015) which is typical of the Red River Delta. The coastal district is the boundary by 2 large river estuaries: Ninh Co (Ninh Co river) and Day (Day river); with 12 km long coastal line and severely affected by frequent storms, as the livelihoods of people are primarily dependent on 16,761 ha agricultural land of rice cultivation, aquaculture and salt making. There are three soil types in NH: sandy soil, alkaline soil and alluvial soil.

In order to protect the district of salinity intrusion and flooding, a dyke and sluice system along to the sea and the river with average height of 6-7 m were built date back to the 11th century, were frequently reinforced but there were five major dyke-building operations have been carried out between 1892-1900, 1934-1939, 1957-1962, 1962-1971 and 1975-1980. It showed that the dyke played a critical role in the historic development of the area, especially the role to protect rice production. However, rice cultivation in some communes which nearer the estuaries still had been facing with salinity intrusion which currently is increasing.

4.2.2 **Site selection**

The two communes where rice production and aquaculture co-exist were selected for conducting the research. The first commune was Rang Dong (RD), located about 5 km from the Day estuary, with a serious problem of salinization (Fig. 4.2). The total natural land in this commune is 1,331 ha, of which 470 ha is rice production which has the problem of salinization and flooding and 537 ha is aquaculture. In RD, aquaculture was included both brackish water and freshwater types due to high salinity concentration. The second commune, Nghia Binh (NB), located further inland than RD commune at ca. 6 km from Ninh Co estuary. Salinity level in irrigation systemin NB was often lower than RD. The total natural land in NB was 815 ha, of which 350 ha is rice production and 196 ha are aquaculture which was only freshwater type (Nam Dinh statistical office, 2016).
Two communes were divided into 6 zones by the local land-use plan as shown in Table 4.1.

Figure 4.2 Location of Day estuary and Ninh Co estuary of the Red River Delta where 2 studied communes were selected (a); Rang Dong (RD) commune divided into 3 subregions (zone) with difference in salinity condition and land-use pattern (b); Nghia Binh (NB) commune divided into 3 zones with difference in salinity condition and land-use pattern (c).

4.2.3 **Data collection**

Firstly, field measurements of irrigation salinity level were conducted 5 times at the beginning of spring cropping season (2 Feb, 7 March, 10 Apr 2017) and at the beginning of summer cropping season (20 July and 25 Aug 2017). Salinity level (‰) were measured by WQC24 in every main irrigation canal at the water inlet of each field/pond.

Secondly, a questionnaire survey was conducted in August 2017 to collect the information about their rice and aquaculture field characteristics (size, relative elevation, location); cultivation’s input and output; during the period of August 2016 to July 2017; household demography; and socio-economic status of the household. Randomly chosen 311 households (HH) 473 rice fields and 572 aquaculture ponds.

4.2.4 **Analytical methods**

Economic profit of either rice or aquaculture farming land-use type was observed only among the adopters. Income and profit of each land use type were estimated separately.

For rice farming:

Purchased input (1) = Seed price x seed amount + fertilizer price x fertilizer amount + herbicide cost + cost of other chemicals + wage x man-days of hired labour + machine rental cost + land rental cost + agriculture service cost.

Output (1) = Market price of production x rice production

Income = Output – Purchased input

Profit = Income – cost of own input

Cost of own input (2) = wage x man-days of family labour + cost of own machine + cost of own land

Note: (1) Purchased input and Output of spring rice and summer rice were calculated separately and then summed up for a year value. (2) own input is the inputs owned by a farmer. We assume that the owner cost is the same as the rental machine and rental land

For aquaculture farming:

Purchased Input for fish /shrimp= seed price x amount of seed purchased in a year + feed price x amount of feed purchased in a year + cost of chemicals purchased + wage x man-days of hired labour + electricity cost + equipment/ machine maintenance cost + pond rental cost + loan interest cost + agriculture service cost

Purchased Input for garden = sum value of seed for garden + sum value of chemical input + wage x man-days of hired labour

Output sales (1) = average of fish/shrimp price x sum amount of output for each type of fish/shrimp + garden production price x output amount of each garden production

Income = Output sales (in a year) – Purchased Input for fish/shrimp (in a year) - Input paid for the garden (in a year)

Profit = Income (in a year) - cost of own input (in a year)

Cost of own input (2) = wage x man-days of family labour + cost of own pump/machine + cost of own land

Note: $^{(1)}$ Since self-consumption takes minor share, we assume all the production is sold. $^{(2)}$ We assume that the cost is the same as the rental pump/machine and rental pond

To test the hypothesis, this research used multiple linear regression to describe the relationship between a possible explanatory variable with profit, including average salinity in the irrigation system. However, factors explaining can be different for a given land-use type, although some factors can explain the profit of both land-use type, so regression analysis was run for each land-use type separately. Because of the subordination and the contribution of unobserved factor into the profit, it is necessary to avoid the exogenous variable to include in the model.

$$\text{Rice profit (VND/ha/year)} = a_1{*}x_1 + a_2{*}x_2 + \ldots\ldots + an{*}x_n + b$$

The explanatory variables for land-use profit were described in Table 4.2 and Table 4.3. The included variables for close examination in this study consist of field characteristics, zone dummy variable, production characteristic and household social characteristics.

Field characteristic variables of in rice farming were average salinity concentration (‰), relative plot height and farm size (representing by field plot size). Meanwhile, for aquaculture, field characteristic variables included average salinity concentration (‰), farm size (pond area and garden area), and time of cultivation.

Production characteristic variables might affect rice farm profit were the market price of seed, price of fertilizer and price of sale rice. In another hand, for aquaculture farming, they were number of annual pond production (fish/shrimp), number of annual garden production, price of pond production sale.

Household characteristics variables for both land-use types were the household size (representing by the total number of households working-age-members), household head's age, household head's sex, number of household head's schooling and the participation of training or extension

Table 4.1 Descriptive statistic of the explanatory variable for rice farming profit

n = 473 (plot)	Description	Mean	SD	Minimum	Maximum
HH head age	Years	52.4	10.12	28	92
HH head education	Completed year of schooling	7.03	2.77	0	15
Number of working-age adult in HH	HH member who ages from 16-70	2.4	0.8	0	5
Average salinity	Salinity concentration in the direct irrigation canal (%o)	0.4	0.2	0.1	1.3
Plot size	m^2	1828	1104	180	10000
Average seed price	Market price of seed in summer and spring (000'vnd / kg)	15.66	8.917	6	61
Average market paddy rice price	Markets price of rice product in summer and spring (000'vnd / kg)	7.71	0.566	6	9
HH head sex = Men	Dummy (men = 1; women = 0)	0.89	0.32	0	1
HH head sex = Women	Dummy (men =0; women= 1)	0.11	0.32	0	1
zone = "NB1".	Dummy (NB1 = 1; others = 0)	0.16	0.37	0	1
zone = "NB2".	Dummy (NB2 = 1; others = 0)	0.28	0.45	0	1
zone = "NB3".	Dummy (NB3 = 1; others = 0)	0.14	0.35	0	1
zone = "RD1".	Dummy (RD1 = 1; others = 0)	0.19	0.4	0	1
zone = "RD2".	Dummy (RD2 = 1; others = 0)	0.22	0.41	0	1
Relative plot height = flooding prone.	Dummy (flooding prone = 1; medium = 0; high= 0)	0.27	0.45	0	1
Relative plot height = medium	Dummy (flooding prone = 0; medium = 1; high= 0)	0.49	0.5	0	1
Relative plot height = high	Dummy (flooding prone = 0; medium = 0; high=1)	0.24	0.43	0	1

Table 4.2 Descriptive statistic of the explanatory variable for aquaculture farming profit

n = 66 (HH)	Description	Mean	Std. Deviation	Minimum	Maximum
HH head age (year)	years	50.1	9.9	26	64

HH head education (year)	Completed year of schooling	6.6	3.2	0	16
Number of working-age member in HH	HH member who age from 16-70	2.4	0.7	1	5
Average salinity	Measured at direct irrigation canal (%o)	1.3	0.7	0.62	3.82
Pond areas (m2)	m^2	3968	4083	720	23700
Garden area (m2)	m^2	1256	1115	0	6100
Time of cultivation (years)	years	7.0	4.5	0	26
Number aquaculture crop per annum		3.0	1.5	1	10
Price of pond product	(000VND/kg)	81.8	53.8	24	269
Sex HH head = Women	Dummy (1-men; 2 women)	0.0	0.2	0	1
Participation training or extension = Yes	Dummy (1-Yes; 2 -No)	0.53	0.5	0	1
Participation training or extension = No	Dummy (1-Yes; 2 -No)	0.47	0.5	0	1
Zone = "NB3".	Dummy (1-NB3; 2 -RD2)	0.48	0.5	0	1
Zone = "RD2".	Dummy (1-NB3; 2 -RD2)	0.52	0.5	0	1
Loan = No	Dummy (0-No, 1-Yes)	0.47	0.5	0	1
Loan = Yes	Dummy (0 -No, 1-Yes)	0.53	0.5	0	1

4.3 Results

4.3.1 **Characters of rice production in the 5 zones**

RD commune was characterized with higher salinity (0.6 ‰) especially in the zone RD2 with low relative plot height (0.7‰) (Table 4.3). As a consequent, GY in RD2 zone (9.5 t/ha) was lower than RD1 (10.3 t/ha). NB commune was characterized with lower salinity (0.25 ‰) than RD although salinity also higher in the zone NB3 with low relative plot height (0.4‰) compare to NB1, NB2 (0.2 ‰). GY in NB3 (8.9 t/ha) was lower in NB1 and NB2 (10.4 t/ha).

Plot size in RD (2244 m^2) was higher than NB (1533m^2) (Table 4.3). Farmers in RD invested a higher purchased input (1975 USD/ha/year) than in NB (1596 USD/ha/year) (Table 4.4) which explained by higher rented labour due to larger fields size and paid high land renting fee while renting fee of farmers in NB was neglectable. The difference is the land renting fee were because the farmer in RD cultivated in rented land while NB farmer cultivated in their own land (data were not shown). Larger field size in RD however, reduced labour significantly compared with NB, (104 vs134 manday/ha/year). As a result, farmers in RD had a significantly higher profit (511 USD/ha/year), after subtracting the value of own cost of HH labour and own land renting cost from the income value) compare to the farmers in NB (169 USD/ha/year).

4.3.2 **Multiple linear regression model of rice profit**

Multiple linear regression model has satisfactorily explained the relationship between explanatory variables and rice profit with a coefficient of determination (R^2 = 0.35).

Salinity showed a significantly negative impact on rice farming profit with the highest standardized coefficient (0.53) among studying influent variables (Table 4.5). Rice plots with a larger size and located in RD1, RD2 zone have a higher profit. Plots located at flooding prone were provided lower profit. Fertilizer price caused a negative impact while sale rice price caused a positive impact on final profit. Increasing in HH head age and education increased rice profit, probably due to their experience and cultivation knowledge.

By using the average value of all influent variable from the results of regression analysis, excepting for salinity, we were able to estimate the relationships between salinity and rice profit in the model (1)

$$Rice\ profit\ (USD/ha/year) = -1364 * Average\ salinity\ + 909 \quad (\mathbf{1})$$

Table 4.3 Household characteristic and paddy field characteristic of rice farming in 5 research zones

zone	n	HH head age	HH head education (year)	Number of working-age members in HH	Relative plot height	Average salinity. (%o)	Plot size (m2)
NB1	75	55.9	7.4	1.9	2.4	0.2	1799
NB2	134	56.0	6.8	2.0	1.9	0.2	1517
NB3	68	53.7	7.3	2.2	1.3	0.4	1274
RD1	92	48.4	7.0	2.5	2.4	0.5	2250
RD2	104	47.9	6.9	2.5	1.9	0.7	2239
Average	473	52.4	7.0	2.2	2.0	0.4	1828

Table 4.4 Economic characteristic of rice farming in the research zone. Data are shown as the net value from rice plot as well as the value calculated per ha of land. All the data were shown by per year unit.

	zone	NB1	NB2	NB3	RD1	RD2	Average
	(n)	*(75)*	*(134)*	*(68)*	*(92)*	*(104)*	*(473)*
Net HH value	HH Plot purchased input (USD)	295	236	195	453	430	324
	HH Output (USD)	647	524	399	789	751	627
	Plot HH income (USD)	352	287	204	335	321	302
	Cost of own HH input (USD)	293	243	182	183	208	223
	HH Plot profit (USD)	59	45	22	152	113	80
	Income per labour (USD/manday)	16	15	12	17	13	15
Value calculated per ha of land use	Yeild (t/ha)	10.8	10.2	8.9	10.3	9.5	10.0
	HH Labor input (manday/ ha)	132	134	135	97	109	121
	Purchased input (USD/ha)	1652	1585	1535	1998	1944	1748
	Output (USD/ha)	3617	3477	3127	3481	3338	3419
	Cost of own input per ha (USD/ha)	1715	1696	1507	871	984	1355
	Income (USD/ha)	1965	1893	1593	1483	1394	1672
	Profit (USD/ha)	251	172	85	613	410	310

(1) Income (the return value farmer earned) = Output - Purchased Input ; (2) Cost of own HH input is input which farmer did not need to pay for, included HH labour and value of own land could earn if use for renting; (3)Profit = Income - Cost of own input

Table 4.5 Regression analysis results of rice farming profit, salinity shown significant negative impact,

	Unstandardized Coefficients				
Model R^2 =0.353, $p < 0.01$	B	Std. Error	Standardized Coefficients	t	Sig.
(Constant)	-40458	9374		-4.316	0.000
HH head age (year)	126	56	0.094	2.242	0.025
HH head education (year)	332	194	0.068	1.715	0.087
Number of working age members in HH	-297	649	-0.018	-0.458	0.647
Average salinity (%o)	**-30281**	**3555**	**-0.530**	**-8.519**	**0.000**
Plot size (m2)	3.05	0.50	0.249	6.068	0.000
Fertilizer price(000`VND/kg)	-1185	423	-0.110	-2.805	0.005
Seed price (000`VND/kg)	-46	63	-0.030	-0.725	0.469
Average market paddy rice price (000`VND/kg)	6030	1030	0.252	5.852	0.000
Sex of HH - head = Women	-2747	1669	-0.065	-1.646	0.100
zone = "NB1".	423	1689	0.011	0.250	0.803
zone = "NB3".	5537	1952	0.144	2.836	0.005
zone = "RD1".	16816	1974	0.492	8.519	0.000
zone = "RD2".	17224	2234	0.527	7.710	0.000
Relative plot height = 1.0.	-3286	1443	-0.108	-2.277	0.023
Relative plot height = 3.0.	1155	1360	0.036	0.849	0.396
a. Dependent Variable: Profit (USD/ha/year)					

4.3.3 Salinity impacts on inputs, grain yield, the output of rice farming

In order to understand the negative impact of salinity on profit, we analysed the impact of salinity on the components of profit. Firstly, salinity positively correlated with the total purchased input ($r=0.29$, $p<0.01$). Salinity reduced fertilizer cost ($r= -0.15$, $p<0.01$) due to low response of rice plant to fertilizer application; reducing HH labour input ($r= -0.18$, $p<0.01$) probably due to low expected GY (Table 4.6). However, salinity increased hired labour cost ($r=0.16$, $p< 0.01$) which was taken a large proportion of total input, probably due to the increase the possibility of re-transplanting in the field under saline stress; increasing the renting machines cost ($r=0.08$, $p<0.1$); increasing the seed cost ($r=0.09$, $p<0.05$) due to requiring more seedling for transplanting, as well as due to higher price of hybrid seed which can moderate adapt to salinity. In addition, in saline fields which usually sunken and far to the residential house, the hired labour cost and rental machine price were more expensive due to harder work. Secondly, salinity reduced rice grain yield ($r=0.49$, $p<0.01$) and reduced final output ($r=0.39$, $p<0.01$) (Table4.6 and Fig 4.3).

Table 4.6 Correlation coefficient shown that salinity increased input and reduce output of rice farming

n= 473	Fertilizer purchased (USD/ha)	Herbicide and pesticide (USD/ha)	Seed cost (USD/ha)	Rented labor (000'VND/ha)	Rented machine (USD/ha)	HH Labor input (manday/ ha)	Purchased input (USD/ha)	Yeild (t/ha)	Output (USD/ha)
Mean	476	314	71	81	427	122	1748	9.98	3419
Correlation	-.149**	.066	.090*	.164**	0.085^{+}	-.179**	.287**	-.493**	-.393**

+, *, **. Correlation is significant at 0.1, 0.05, 0.01 respectively

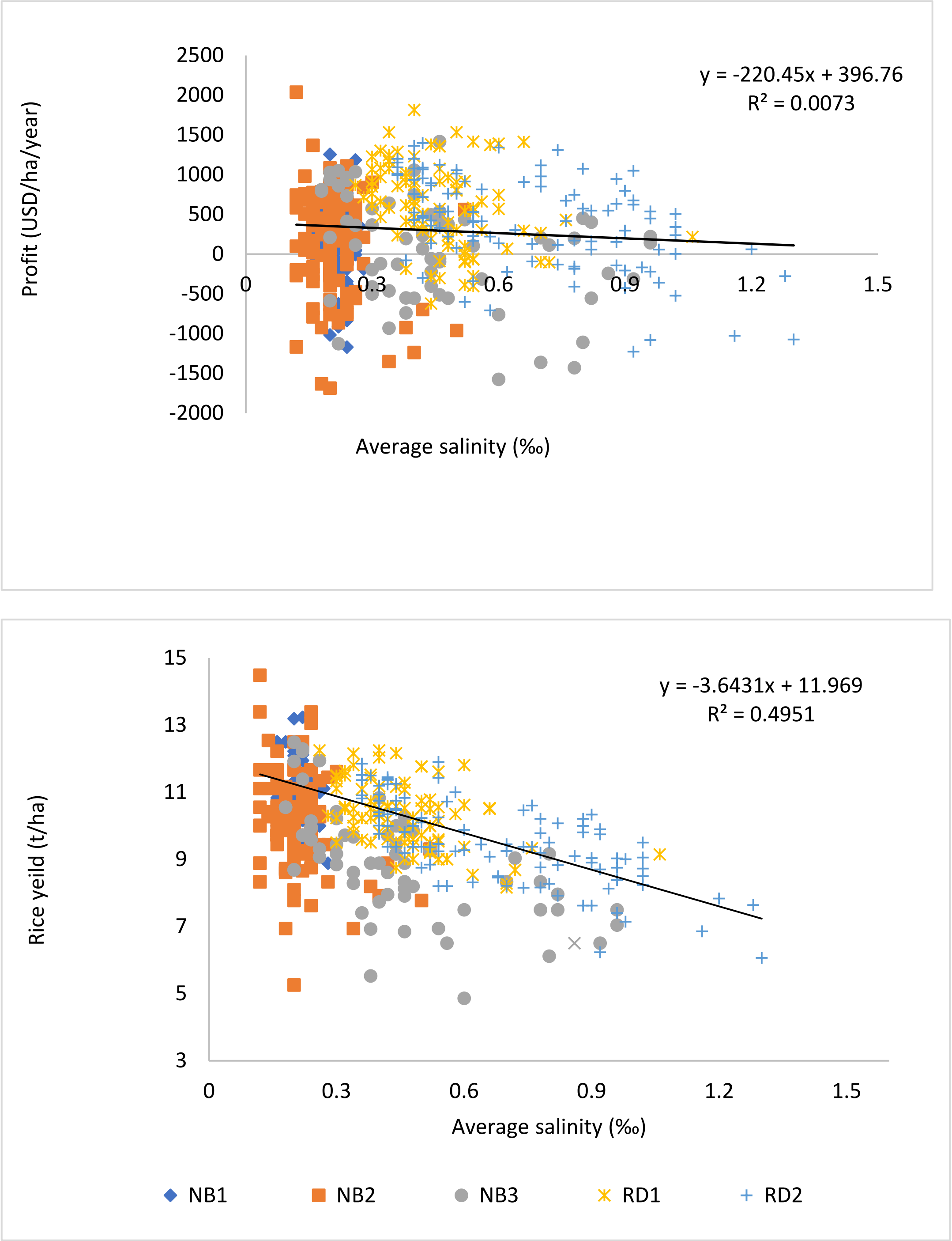

Figure 4.3 Negative impact of salinity on rice yield and profit

4.3.4 **Characters of aquaculture in the man-day zones**

Salinity was significantly lower in NB3 (0.9‰) compare to RD2 (2.6‰) and particularly RD3 (15.2‰) due to the irrigation system in RD3 were managed to cultivate brackish aquaculture (Table 4.7). The difference in the type of cultivation also lead to neglectable garden size in brackish water zone RD3 (59m2 in 4772 total farms are), because of high salinization; meanwhile, in the freshwater zone, gardening used a considerable part of farm size with 20% farm area in RD2 and 32% farm area in NB3. Time of cultivation was longer in RD (9.7 years) compare to in NB3 (5.8 years).

Input purchased in brackish water aquaculture RD3 (15621 USD/ha/year) were much higher than in fresh-water aquaculture RD2 (13135 USD/ha/year) and NB3 (10674 USD/ha/year) (Table 4.8), partially due to higher pond area, which required a higher input per ha of land than gardening, and partially due to the character of brackish water aquaculture in the study site, mainly cultivating Song and for-eye fish which have higher value than the fresh-water aquaculture. As a result of the higher revenue, RD3 create higher income (4597 USD/ha/year) and finally smaller negative profit (-76 USD/ha/year) in compare with RD2 (1462 USD/ha/year and – 2541 USD/ha/year respectively) and with NB3 (4022 and -998 respectively). The extremely low value of income and profit in RD2 were explained by the suddenly drop by 40% of the price of Dieu Hong fish in 2016, which is one of the main fish of fresh-water aquaculture zone.

4.3.5 **Multiple linear regression model of aquaculture profit**

Multiple linear regression model has satisfactorily explained the relationship between explanatory variables and aquaculture profit with a coefficient of determination (R2 = 0.53) (Table 4.9). Salinity showed no significant effect on aquaculture farming profit (Table 4.9 & Fig.4.4) while the time of cultivation and HH head education shown significant effects. Increasing cultivation time which usually related to increasing of pollution mug and disease accumulation in the pond, reduced aquaculture profit significantly. Increasing HH head education shown the increase in profit.

By using the average value of time of cultivation and HH head education, we were able to estimate the relationships between salinity and rice profit as a constant equation in the model (2)

$$Aquaculture\, profit\ =\ 240\ (USD/ha/year)\quad (\mathbf{1})$$

The regression lines which presents the relationship of each land-use types with salinity concentration according to model (1) and (2) were met at the salinity of 0.5‰ (Fig.4-5). At this point, rice farming profit equates with aquaculture farming profit while at salinity higher than 0.5 ‰, aquaculture can provide a higher profit than rice farming

Table 4.7 Household characteristic and land field characteristic of aquaculture farming in 3 research zones

zone	n	Average salinity	Number of ponds	Pond areas (m2)	Garden area (m2)	Time of cultivation (years)	Construction cost and equipment purchased (USD)
NB3	32.0	0.9	2.1	2368	1125	6	1158
RD2	36.0	2.6	3.6	5351	1330	9	3663
RD3	69.0	15.2	3.4	4703	59	10	3845
Total	137.0	8.6	3.1	4328	642	9	3169

Table 4.8 Economic characteristic of aquaculture farming in the research zone. Data shows as the net value from rice plot as well as the value calculated per ha of land

	zone *(n)*	NB3 *(32)*	RD2 *(36)*	RD3 *(69)*	Average *(137)*
Net HH value	Amount of the harvest in total (kg)	1491	3382	1411	1948
	Output (USD)	4134	11014	9062	8424
	HH input (USD)	3520	10038	6958	6964
	HH income (1) (USD)	1336	1543	2118	1784
	Own input cost (USD)	1568	1782	1780	1731
	HH profit (3) (USD)	-232	-239	340	54
Value calculated per ha of land-use	HH labor (manday/ha)	536	410	551	511
	Purchased input (USD/ha)	10674	13135	15621	13812
	Income (1) (USD/ha)	4022	1462	4597	3639
	Own input cost (2) (USD/ha)	5020	3691	4706	4512
	Profit (3) (USD/ha)	-998	-2541	-76	-939
	Income per HH labor (USD/manday)	10.3	8.8	9.7	9.6

(1) Income (the return value farmer earned) = Output - Purchased Input ; (2) Cost of own HH input is input which farmer did not need to pay for, included HH labour and value of own land could earn if use for renting; (3)Profit = Income - Cost of own input

Table 4.9 Regression analysis results of aquaculture profit

	Unstandardized Coefficients		Standardized		
n = 66 (HH) R2= 0.53, p < 0.01	B	Std. Error	Coefficients	t	Sig.
(Constant)	-97955	199219		-0.492	0.626
HH head age	2422	2468	0.147	0.982	0.333
HH head education (year)	14465	6925	0.313	2.089	0.044
Number of working-age member in HH	-34577	31554	-0.149	-1.096	0.281
Average salinity	**34737**	**45895**	**0.134**	**0.757**	**0.454**
Pond areas (m2)	4.8	18.2	0.048	0.263	0.794
Garden area (m2)	-6.2	26.9	-0.033	-0.231	0.819
Time of cultivation (years)	-12241	5255	-0.360	-2.329	0.026
Number of pond production (per annum)	-23027	22511	-0.155	-1.023	0.314
Price of production ('000VND/kg)	560	538	0.154	1.040	0.306
Number of crop production (per annum)	-2012	25024	-0.011	-0.080	0.936
Dummy variable indicating Zone = "RD2".	1082	56176	0.003	0.019	0.985
Dummy variable indicating HH head sex = women	-146469	107540	-0.187	-1.362	0.182
Dummy variable indicating Participation training or extension = No	-3889	43343	-0.012	-0.090	0.929

Table 4.10 Salinity had a positive correlation with pond input but no correlation with income from pond and garden cultivating, consequently, no correlation with total household profit.

	Pond input (USD/ha/year)	Pond income (1) (USD/ha/year)	Garden input (USD/ha/year)	Garden income (1) (USD/ha/year)	HH labour (Manday/ha)	Total Income (1) (USD/ha/year)	Profit (3) (USD/ha/year)
Mean	15281	1693	1186	1659	467	3352	-1837
Pearson Correlation	.370**	-.030	-0.16	0.00	-0.07	0.08	0.02

(1) Income (the return value farmer earned) = Output - Purchased Input ; (2) Cost of own HH input is input which farmer did not need to pay for, included HH labour and value of own land could earn if use for renting; (3)Profit = Income - Cost of own input

4.3.6 **Characterized two land-use types in the research area**

HH head of aquaculture farm was significantly younger (49±12 year) than HH head of rice farm (53±10 year) (Table 4.10a). Aquaculture fields located in higher salinity area (9±8 ‰) and have a larger size (4970± 3658 m^2) than rice fields. They required higher HH labour (496±362 manday/ha), higher purchased input (14,011 USD/ha/year) and provided higher income (3,592 USD/ha/year) than rice farming (Table 4.10b). However, coastal aquaculture had significantly lower economic efficiency with a lower profit at 109 USD/ha/year) and a lower income per HH labour (9.5±24 USD/manday) compared with rice (436 USD/ha/year; 14.4±5.8 USD/manday, respectively). The reason is the low level of mechanization of aquaculture cultivation in this local area, while rice cultivation was wildly used machine to replay manual work such as in the land preparation and harvesting; consequently, aquaculture requires a higher cost of own-input (4512 USD/ha/year) than rice (1355 USD/ha/year).

Table 4.11. Compare household head social characteristics, land characteristics and economic efficiency between two land-use types by (a) HH net value and (b) value calculated per ha of land-use

a. HH net value

Landuse type		HH head Age	HH head education	Max salinity (%o)	Average sal (%o)	Field area (m2)	HH labour input (manday/year)	HH Purchased input (USD/year)	HH income (USD/year)	Income per HH labour USD/manday)	HH Profit (USD/year)
Rice	n=225	53±10	6.9±3	0.7±0.4	0.4±0.2	3843±2559	42±25	673±506	627±472	14.4±5.8	165±307
Aqua	n= 137	49±12	7.3±3	11±10	9±8	4970± 3658	190±101	6870±7778	1761±4238	9.5±24	53±4227
Significant		***	ns	***	***	***	***	***	***	***	ns

b. Value calculated per ha of land-use.

Land-use type		Labour input of HH (manday/ ha/year)	Purchased Input (USD/ha/year)	Output (USD/ha/year)	Income (1) (USD/ha/year)	Cost of own input (2) (USD/ha/year)	Profit (3) (USD/ha/year)
Rice	n=225	122	1,775	3,429	1,655	1,355	436
Aqua	n= 137	496	14,011	17,603	3,592	4,512	109

(1) Income (the return value farmer earned) = Output - Purchased Input ; (2) Cost of own HH input is input which farmer did not need to pay for, included HH labour and value of own land could earn if use for renting; (3)Profit = Income - Cost of own input

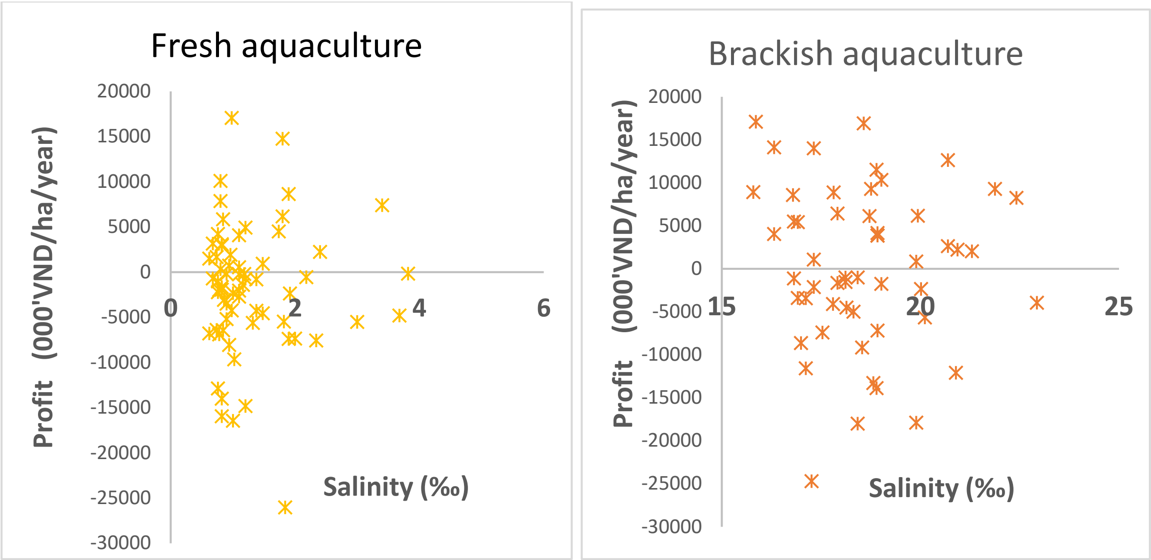

Figure 4.4 Salinity did not have effect on both brackish and fresh water aquaculture profit

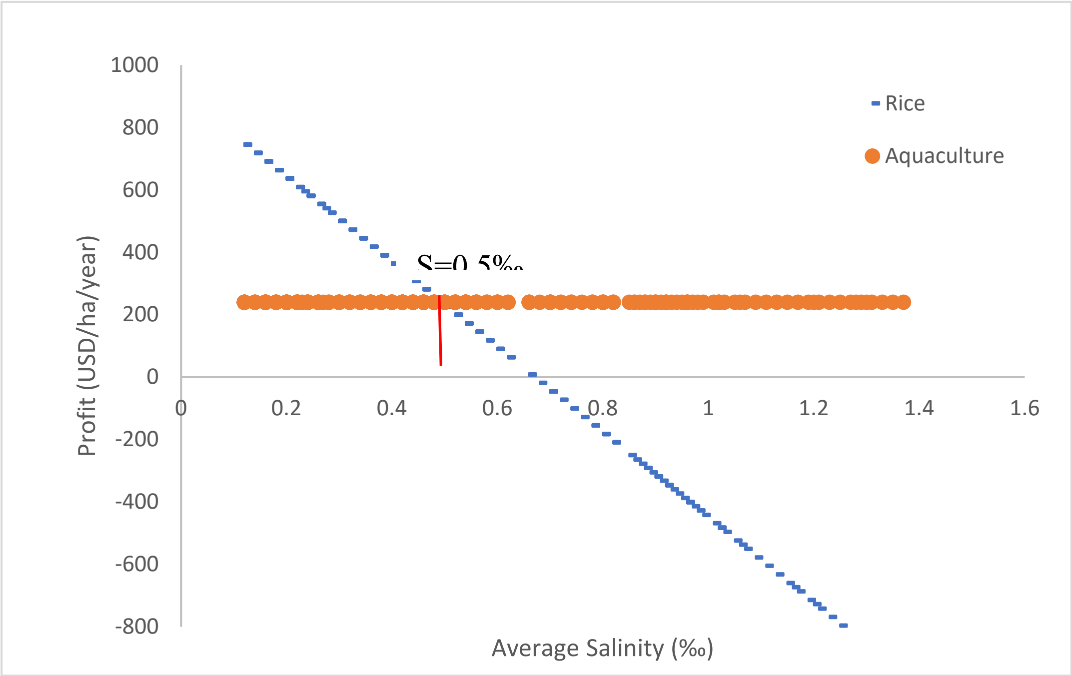

Figure 4.5 The salinity level where rice farming profit equates with aquaculture farming profit is at S=0.5‰. At salinity higher than 0.5 ‰, aquaculture can provide a higher profit than rice farming

4.4 Discussion

4.4.1 **Salinity impact on economic efficiency between 2 land-use types.**

Impact of salinity was clearly shown as negative on rice farming profit (Table 4.5) whereas unclear on marine aquaculture profit (Table 4.9). Increasing salinity caused higher purchased input for rice farming, reduced grain yield and output, hence reduced farmer income and profit (Table 4.6). Salinity stress caused reduced survived rate of rice seedling (Zeng & Shannon, 2000); reduced nitrogen use efficiency (Singh, Pal, & Sharma, 2013), as well harmed reproductive development (Hussain et al., 2018). Negative impacts of salinity on rice grain yield and profit were also recorded in elsewhere such as Gang delta (Rabbani, Rahman, & Mainuddin, 2013) and Mekong River Delta (Tuong et al., 2003) (Khai, Dang, & Yabe, 2018). On the other hand, salinity had no significant correlation with aquaculture farming input, output or profit in the research area (Table 4.10). The results were explained by aquaculture farmers would choose different aquaculture creatures to adapt to the large variation of salinity while rice farmer can limitedly adapt to high salinity. Moreover, as the most dominant aquaculture creature here, food conversion efficiency, body weight and body length of white leg shrimp were evidently independent with salinity concentration (JAYASANKAR et al., 2009) (Zhang, Zhang, Li, & Gao, 2009). Our results were contradicting with the local perception of farmers that higher salinity facilitated aquaculture farming profit. This perception might be derived from their observation of lower white-leg shrimp survive rate under low salinity condition (Zhang et al., 2009)(Maicá, de Borba, Martins, & Wasielesky, 2014); or/and from the geographical co-location of salinity intrusion and shrimp farming. Our results have clarified the rumour.

Our results show that in the field/area with average salinity at 0.5‰ (maximum 1.3‰), aquaculture and rice can create an equal profit (Fig. 4.5). It proved that aquaculture could be a good adaptation in the condition of high salinity (>0.5‰), intern of economic aspect. In fact, high salinity was the driving for rice field conversion to aquaculture in many coastal areas in the world, but there is no universal threshold to determine in which salinity conversion should be taken place. Our research has estimated this threshold. However, a careful application of the threshold average salinity value is needed since there would be diverse types of dynamism of salinity with different intensity, duration and timing, and sensitivity to salinity levels would be varied depending on rice varieties and developmental stage of the rice plant.

4.4.2 **Rice or aquaculture farming?**

The research demonstrated the attractive features of marine aquaculture to provide farmers with higher income (3592 ± 7672 USD/ha/year vs 1655 ± 581 USD/ha/year) and employment opportunity (496 ± 362 vs 122 ± 37 manday/ha) (Table 4.11b) in compare with rice. However, the profit turned out to be higher in rice (436 ± 541 USD/ha/year) at the average salinity level of 0.4 ± 0.2‰ than aquaculture 109 ± 7853 USD/ha/year) at the average salinity level of 9 ± 8 ‰. Nguyen also reported shrimp created 8 times higher in return money for local people in Ba Lat estuary (T. T. N. Nguyen, Tran, Ho, Burny, & Lebailly, 2019). In the situation of high rural immigration to urban (in 2009, 6.7 million internal migrants) due to low income and lacking employment in the rural area (Kabeer & Van Anh, 2002; Kim Anh, Hoang Vu, Bonfoh, & Schelling, 2012), virtually, aquaculture will be much more attractive than rice. Generating income and employment and making unproductive, marginal land (high salty) productive were well-recognised functions of aquaculture in rural development in over the world (Halwart et al., 2003). The aquaculture will be even more promising than rice since there was no correlation between aquaculture profit and salinity (discuss in section 4.4.1), hence there is possible to develop in-land aquaculture even at the distance 370 km from the coastline by using techniques called "closed systems" which were adopted widely in Thailand (Flaherty & Vandergeest, 1998), China and Ecuador (Boyd, 2002). Without proper administration from authorities, farmers would prefer brackish water aquaculture, even in low-salinity, freshwater area. Rice, on the other hand, can achieve higher profit under low-salinity conditions (discuss in section 4.4.1), and importantly, more sustainable with more stable income and profit in compare with marine aquaculture (discuss below). But with low labour and income-generating, rice would be not preferred by local farmers. From the viewpoint of economic efficiency, the rice cultivation should be promoted in the low-salinity condition. Then, the problem here is the way to provide non-farm and off-farm employment for rice farmer during their unworking time, which were proved that played critical role on increase household income and poverty alleviation (Haggblade, Hazell, & Reardon, 2010; Lanjouw & Shariff, 2004).

Another important aspect was drawn in our results were the low economic sustainability of aquaculture in compare with rice, indicating by the large range in aquaculture income and profit (Table 4.11). The first reason for highly fluctuated aquaculture profit was highly relying on market price, which is un-predicted and fluctuated (Neiland, Soley, Varley, & Whitmarsh, 2001). The negative value of aquaculture in RD 2, and NB 3 also mainly a result of the sudden dropped of Red Tilapia market price to 25,000 VND/kg from 40,000 VND/kg in the previous years. The second reason was the high risk of disease and production failure (Alam, Pokrant, Yakupitiyage, & Phillips, 2007). Thirdly were the unbalance of ecology and environment pollution caused an increase in the production input (Hossain, Uddin, & Fakhruddin, 2013). There were examples of aquaculture systematically collapsing in Thailand, Taiwan, Mekong River Delta. Unsustainability explained for the negative correlation between shrimp cultivation and average farmer income reported by Haider & Hossain, (2013) and a positive correlation between shrimp and poverty reported by Johnson et al. (2016). Rice farming, in contrast, is more sustainable which has existed and being the main livelihood for local people for hundreds of years.

Finally, we provided an overall comparison between the characteristics of rice and aquaculture farming. Aquaculture required a bigger amount of capital investments than rice, included (1) the money for setup farming (digging pond or purchased ponds and equipment) (3169 USD per household, table 4.7) and (2) the flowed capital for purchased inputs (14,011 USD/ha/year) than rice farming investments for purchased input only at 1775 USD/ha/year in average (Table 4.11). Not every farmer can be afforded or managed to access to this large amount of capital. Aquaculture required relatively a larger field size (4970 m^2 included both pond and garden, table 4.7), which not necessary by rice (1828 m^2, Table 4.3). This is because marine aquaculture farming needs a number of ponds (3.1 ponds per farm, Table 4.7) with different functions (settling ponds, rearing ponds for a different stage of productions) in order to operate normally.

These three economic aspects, thus, besides environmental and social aspects, need to be considered carefully by the farmers as well as by policymakers in the making decision for rice or aquaculture.

4.4.3 **Fresh aquaculture or brackish aquaculture?**

Brackish water aquaculture generated higher income (4597 USD/ha/year in RD3) and finally produced smaller negative profit (-76 USD/ha/year in RD3) in comparison with fresh-water aquaculture in RD2 (1462 USD/ha/year and – 2541 USD/ha/year respectively) and fresh-water aquaculture in NB3 (4022 and -998 respectively) (Table 4.8). This is the evidence to explain why farmers often prefer to brackish aquaculture rather than fresh aquaculture. Brackish aquaculture in RD3 requires high average salinity (15.2 ‰) while fresh aquaculture can operate under low salinity water (less than 5‰) with an average of 2.6 ‰ (in RD2) and 0.9 ‰ (in NB3) (Table 4.7). For example, we observed some farmers in NB3 and many in RD2 where only fresh aquaculture was allowed to be cultivated; in order to cultivate the brackish fish name Four-eyed sleeper, pumped the salty water into their pond to raised salinity level to 10 - 15‰ during the time of settling and maintain at about 7‰ during the rest of cultivation time. They shared tube to lead brackish water up to 4 km distance from the brackish water area. Stimulated by higher benefit, brackish aquaculture might be spread further inland by farmers. The develop of brackish aquaculture could seriously load the high salty water into in-side dyke fields, contaminate irrigation canal, and harm rice cultivation. A study in Mekong River delta reported that rice farmers losses from salinization were included the direct rice yield loss associated with salinized soil, and the risk associated in delaying the planting date in order to flush the soil that could shift the crop into less favourable weather time in a year; which is when accounted for, made the rice monoculture systems performance as well as, if not better, than the shrimp-based (Tran, 1996). Consider the impact of salinity is negative in rice profit, while no correlation with aquaculture profit (discuss section 4.4.1) strictly manage brackish aquaculture boundary by local government is needed urgently.

4.5 Conclusion

Aquaculture generated a much higher income (3592 ± 7672 USD/ha/year) and employment (496 ± 362 manday/ha) than rice (1655 ± 581 USD/ha/year; 122 ± 37 manday/ha). However, the profit turned out to be higher in rice (436 ± 541 USD/ha/year) at the average salinity level of 0.4 ± 0.2‰ than aquaculture 109 ± 7853 USD/ha/year) at the average salinity level of 9 ± 8 ‰. Salinity reduced rice profit and being the most determining factor (with highest Standardized Coefficients) of rice profit meanwhile had no impact on the profit of freshwater marine aquaculture. At average salinity 0.5‰, rice and aquaculture profit were equal, while at higher salinity (>0.5‰) aquaculture proved a higher profit and could be a successful adaptation to the harmful impact of salinity on rice. Brackish aquaculture brings higher profit than fresh aquaculture; rationally, the farmers will likely prefer brackish aquaculture than fresh aquaculture. Hence, without proper control of the government, brackish aquaculture might spread further inland and seriously harm rice production

5 Chapter 5 General discussion

5.1 Salinity intrusion and adaptations on rice production in RRD

Salinity intrusion in RRD was spatially and seasonally variated, although all RRD was protected by the river and sea dyke systems and sluice (Chapter 2). The effect of seasonal rainfall pattern (Fig 2.1) caused higher salinity intrusion in spring ( ) than in summer ( ) (Table 2.5). There are 8 estuaries of Red River systems and its branches which under different salinity intrusion intensity in the river water. In the 4 main estuaries, the 5 psu (5 ‰) of mid-tide water were distributed at the distance of ca. 32 km from Ninh Co estuary, 20 km from of Tra Ly estuary, 17 km from Ba Lat estuary, 18 km from Day estuary) according to computed results from observation on Jan 2006 (Duc & Umeyama, 2011). Using 2 estuaries as a case study, we have drawn the contracting picture of the spatial variation in salinity intrusion effect on rice production. Salinity in paddy fields in Day estuary (1.1± 0.3‰ in spring and 0.6± 0.3‰ in summer rice) was higher than in Ba Lat estuary (0.8± 0.3‰ in spring and 0.2 ± 0.2‰ in summer), which caused by the difference in the water river and irrigation management. In ND commune - Day estuary water was intake directly through the nearby, Nam Dien water gate which characterized by higher salinity water (12± 5.7 ‰ in January), thus saline stress happens frequently in the year. In GH and GT communes - Ba Lat estuary, water was intake through a further upstream, Ngo Dong gate which characterized by lower salinity water (7.7± 6.1‰ in January), thus saline stress only happened at the beginning of the season (Fig.). In addition, in ND, rice and aquaculture were practised parallelly inside the dyke, hence higher salinity water may be due to the preference of aquaculture farmers were intake, compare with GH and GT where only rice was cultivated inside the dyke. Consequently, GY in ND were reduced by 152 g/m^2 in summer rice and 184 g/m^2 in spring rice. compare to that in GH and GT. The severe salinity intrusion caused rice cultivation discontinuous in ND site while no or litter impact in GH and GT. The variation of salinity intrusion effects on rice production should be taken into account in the regional planning of the government, especially, under the light of climate change, the reconsideration and proper strategies for rice development to adapt salinity intrusion impacts are urgently needed.

Within a site, we demonstrated that GY was variated at field group level due to its location to dyke, aquaculture or main drainage canal, which led to the difference in soil properties, water availability. Salinity was higher in fields near to the dyke or aquaculture area called at-risk fields (0.60) than in the others called save fields (0.54). At-risk fields, in addition, were characterised by less soil fertility, higher sand content and higher water depth in the summer, resulting a lower yield (558 g/m^2) than the save fields (649 g/m^2). As adaptations, in at-risk fields, farmers planted hybrid varieties in spring and tall local varieties in summer; and given smaller amounts of N fertilizer application particularly in summer. Such the small-scale variations were happened in over the RRD, not only in the coastal fields. Kono and Tuan (1995) reported that water condition was closely related to micro-topography and was the main factor determined rice production in Red River Delta, including land preparation, rice yield and labour productivity.

However, farmer adaption was limited, we conducted a series of on-farm trials experiments to explore the possibilities to improve the rice production in RRD (Chapter 3). Firstly, in variety choosing, hybrid varieties were only resistant to salinity under the low salinity Ba Lat's at-risk fields, while were severely damaged in high saline ND fields. Moreover, hybrid although can achieve a satisfactory GY under low saline concentration but have smaller gross margin than long inbred (0.22 vs 0.42 in safe fields; 0.22 vs 0.3 in at-risk fields, Table 2.8) due to its low quality (Table 2.6). We test the two new, average-quality varieties M2, M14, which can resist salinity up to 3-5‰. Although had a significantly lower yield potential than conventional variety in non-saline condition (632 g/m2, 618 g/m2 vs 751 g/m2 in safe fields in GT) (Table 3.4), the two variety M2, M14 achieved higher GY in high saline-stress condition of ND at 522 g/m2, 539 g/m2 compared with conventional variety at 348 g/m2.

Although farmer changed N fertilizer dose to adapt with salinity variation and variety change as discussed in chapter 2, N management in farmer fields were still both over-use and low efficiency. N fertilizer dose was high at 218 kg/ha in spring and 185 kg/ha in summer. NUEs were low in general and spatial variated. For example, N recovery efficiency (RE, measured by g grain GY obtained per g N fertilizer applied) were average at 0.25 in compare with Asia rice at 0.31 (Dobermann & Cassman, 2002); RE was higher in spring at 0.27, lower summer at 0.22, particularly in at-risk fields (0.19) (Table 3.9). Our results of N fertilizer application trials shown that N fertilizer rate can be reduced without yield penalty in GH, GT (Chapter 3, Table 3.10). The optimal dose of N fertilizer was 120-180 kg/ha and 100-150 kg/ha for spring and summer rice, respectively which GY were maximized meanwhile achieved high values of PEP, AE and PE.

Finally, we test the salinity impact on the economic efficiency of rice production and aquaculture production, given the sharp, current land-use conversion in RRD from rice to aquaculture (Chapter 4). We explored the potential of aquaculture as an adaptation of rice under the impact of salinity intrusion in the regards of cost-benefit analysing. We combined salinity field measurement and a questionnaire survey of 311 households who own 473 rice fields and 572 aquaculture ponds. Aquaculture generated a much higher income (80 ± 176 VND/ha) and employment (496 manday/ha) than rice (37 ± 27 VND/ha; 122 manday/ha). However, the profit turned out to be higher in rice (6.2 ± 12.9 mVND/ha) at the average salinity level of 0.4 ± 0.2‰ than aquaculture (-20.8 ± 182 mVND/ha) at the average salinity level of 9 ± 8 ‰. Increasing in salinity reduced rice profit meanwhile, have no impact on the profit of freshwater marine aquaculture. When average salinity was higher than 0.5‰, aquaculture profit remained stable while rice farming profit became lower; suggesting that above salinity 0.5‰, aquaculture could be a successful adaptation to the harmful impact of salinity on rice while lower than that point rice production was more profitable for the farmer.

5.2 Rice technology and dissemination to improve the efficiency of rice production in RRD

Possible innovation to optimised production efficiency

The coastal area of RRD was affected by seawater intrusion, salinity threatens the continuation of rice production. The coastal province Nam Dinh has over 38,000 hectares affected by salinity intrusion, accounting for 23 % of its natural land, mainly distributed in the coastal districts (Giao Thuy, Hai Hau, Nghia Hung) with salinity ranging from 1.2 to 3 ‰, and in some years even over 4 ‰) (M. Van Trinh et al., 2014). Higher salinity tended to result in significant lower GY, especially using the currently available, salinity sensitive varieties; however, the management can play an important role to adapt and alleviate salinity stress. Currently, farmers in the coastal area in RRD use Chinese hybrid such as Nhi Uu 838, C Uu Da He no 1 to adapt with salinity stress (Fig. 2.6) but their adaptation capability were limited. Under the slight saline condition of at-risk fields in GH, GT (Ba Lat estuary) they can achieve high yield () but not successful growth under the higher saline condition of ND (). Some farmers in ND have to abundant their fields, while many of them convert rice field to aquaculture. A set of salinity resistant varieties was needed for diversifying farmer choices. For example, in our experiment, M2 and M14 can increase GY in ND from 348 g/m2 to 522, 539 g/m2 (Chapter 3).

Rice production in RRD was also facing flooding/inundation in the summer due to its low elevation. World Bank (1995) estimated that more than 50% of the RRD area is less than 2 meters above sea level which is highly at risk of flooding. Our survey identified that higher water depth in summer led to lower grain yield in the marginal at-risk fields and required farmer use a different variety to cope with (chapter 2). In the research site, farmers used a local variety, Nep Cao, which successfully adapted with high water depth by its tall and strong straw. The success case study of Nep Cao should be considered to magnify and adopt in other flooding prone parts of RRD.

Dissemination of these innovated varieties either salinity resistant or submergence resistant, however, highly depend on its quality, and market value (cited). There was many examples of farmer rejection of new resistant variety due to its low quality ( ) or difficult to sell in the local market system. The average quality of M2 and M14 in comparison to poor quality of hybrid is an advantage to hybrid but still, need further improvement. Thai Xuyen 111 as an observed example in the research site, which was proposed by local authority recently. This new Chinese hybrid was introduced as good at salinity resistant (up to 2.5 ppt), high yield potential (Trinh, 2014); nevertheless, its adoption by farmers was low after several years of introducing. We observed only one farmer in GT has tried but stop cultivating in the next season. His reasons for stopping cultivation were the high price of seed (1.5 times higher than other Chinese varieties, 4 times higher than inbred varieties), not be bought by the local middleman, and the taste is not as good as his preference. The case of Nep Cao, although with high quality but the lacking support of market system might be constraints for its larger-scale adoption.

Another prevailing problem of rice production in RRD was high dose (218 kg/ha in spring and 185 kg/ha in summer, Table 2.5) and low efficiency of N fertilizer (RE, measured by g increased in N uptake per g N fertilizer applied, were 0.27 in spring and 0.22 in summer). Excess N fertilizer not only increased the production cost, but also lead to large N losses in the form of ammonia volatilization and N leaching into groundwater and lakes (Zhu & Chen, 2002), as well as soil acidification, which consequently resulted in declines in agricultural productivity (Guo et al., 2010). Our results from N trials indicated N dose can be reduced to 120-180 kg/ha for spring and 100-150 kg/ha for summer rice; suggesting a possible reduction by 20-45% of N fertilizer input, which accounts for 27% in total of rice purchased input according to our survey (Table 4.6).

An innovated technology was studied in this research was water-saving irrigation trial to deal with the reduction in water irrigation. Keeping a thin water layer resulted in a 40% lower water depth in the less-saline area without sacrificed GY. However, saving water in the high saline condition were not effective, partly because of the saline stress caused by the salty water itself. These results suggested in the upstream fields, where salinity is not a problem, there is a high possibility to reduce water use for rice. Irrigation contributed an important role in producing a high yield of rice in RRD. However, lacking water for irrigation are happening frequently at the beginning of the spring season, which could be escalated due to the increase in water demand of other economic sectors and impacts from climate change. Water resource in the Red River Systems basin generally was considered abundant but seasonally and spatially un-event distribution, for example, the south-western portion of the RRD could experience a critical situation of water resource crises (Luu et al., 2010). Thus, this saving irrigation method can be disseminated broadly without harm in grain yield, in the effort of improving the efficiency of rice production in RRD.

A larger scale of cultivation can significantly improve rice production efficiency. Using the case study of Rang Dong commune vs. Nghia Binh commune (chapter 4), we reveal that higher field size in RD (2250 m2) than NB (1500 m2) reduced labour and provided higher profit per ha of land-use (Table 4.4). The multiple regression analysis again has shown the positive coefficients of field size with profit (Table 4.5). A study estimated the efficiency of farm size in RRD estimated at 0.9, which means that in comparing to the 20% largest size farm (optimal scale), 80 % of farmer in RRD was cultivated at an inefficiency of 10%, which could be reduced by increasing the farm size (Hoang Linh, 2012). Increasing farm size sharply decreased N fertilizer used and increased GY in China (Ju, Gu, Wu, & Galloway, 2016).

To compare economic efficiency among cultivar type, we calculated gross margin for each type of variety group by the equations

$$Gross\ margin = \frac{output - input}{output}$$

Where $Output\ =\ yield\ x\ market\ price$

$$Input\ = seed + fertilizer + pesticide\ \&\ herbicised +\ renting\ marchine\ + labour$$

Gross margin is the ratio between profit and total output, given the assumption in that study is farmer sell all rice production from the field to obtain profit. Gross margin shows the relative competition between cultivar group regard of economic efficiency: higher gross margin means higher efficiency. At-risk fields tend to have lower gross margin in all cultivar groups in both spring and summer (0.29 vs 0.21) (Table 5.1). In spring, hybrid have smaller gross margin than long inbred (0.22 vs 0.42 in safe field; 0.22 vs 0.3 in at risk field). This is because hybrid have lower profit than long inbred and short inbred in safe field (358 USD/ha vs 935 USD/ha, 796 USD/ha). Interestingly, hybrid can maintain similar profit and gross margin in at-risk field in comparison with safe field; while both long inbred and short inbred were reduced significantly. The lower market price (0.225 USD/kg) make hybrid output were lower than other cultivar group although hybrid have achieved satisfactory yields in spring.

In summer, local cultivar gross margin were significantly higher than other cultivar group in both safe fields (0.31 vs 0.22, 0.13) and at-risk field (0.23 vs -1.04). The performance of local cultivar (mainly Nep Cao) were achieved from higher market price than other rice such as long inbred (0.362 USD/kg vs 0.256 USD/kg) due to its high quality. Hence although a lower GY

(428 USD/ha vs 630 USD/ha of long inbred in at-risk field), hybrid still bring satisfactory profit (eg. 237 USD/ha vs 338 USD/ha of long inbred in at-risk field) for farmer

Table 5.1 Inputs, output, profit and gross margin of cultivar groups were different between safe and at-risk fields. Amount and type of inputs (cultivar; amount and source of seed; fertilizer type and amount; pesticide; labour) was obtained by interviewing the field owners each season. The cost of each input and output value were estimated by multiple the amount to local market price which obtained from a separated survey on 310 household in Nghia Hung district

Field group	Cultivar group	N	Seed price (USD/kg)	Seed rate (kg/ha)	Seed (USD/ha)	Fertilizer (USD/ha)	Labor (USD/ha)	Pesticide (USD/ha)	Rental machine (USD/ha)	Total input (USD/ha)	Yield (ton/ha)	Price (USD/kg	Output (USD/ha)	Gross profit (USD/ha)	Gross margin (%)
spring		**147**			**117**	**272**	559	**137**	**196**	**1281**	**754**		**1823**	**543**	**0.3**
safe	Short inbred	13	1.41	55.5	78	271	559	137	196	1242 a	669 a	0.305	2037 b	796 b	0.39 b
	Long inbred	37	1.33	55.5	74	278	559	172	196	1279 a	862 b	0.256	2214 b	935 c	0.42 b
	Hybrid	34	3.53	41.6	147	278	559	120	196	1300 b	747 a	0.225	1658 a	358 a	0.22 a
at-risk	Short inbred	7	1.41	55.5	78	231	559	137	196	1202 a	452 a	0.305	1376 a	174 a	0.13 a
	Long inbred	5	1.33	55.5	74	318	559	172	196	1319 b	735 b	0.256	1886 b	568 c	0.30 c
	Hybrid	51	3.53	41.6	147	264	559	120	196	1286 b	744 b	0.225	1651 a	365 b	0.22 b
summer		**149**			**66**	**242**	513	**147**	**196**	**1185**	**500**		**1507**	**322**	**0.21**
safe	Short inbred	15	1.41	55.5	78	245	513	103	196	1136 a	429 a	0.305	1307 a	171 a	0.13 a
	Long inbred	59	1.33	55.5	74	256	513	155	196	1193 b	599 b	0.256	1537 b	345 b	0.22 b
	Hybrid	1	3.53	41.6	147	277	513	103	196	1236 -	628 -	0.225	1393 -	157 -	0.11 -
	Local cultivar	12	0.59	83.3	49	248	513	155	196	1207 b	488 a	0.362	1761 c	554 c	0.31 c
at-risk	Short inbred	1	1.41	55.5	78	220	513	103	196	1111 -	437 -	0.305	1331 -	220 -	0.17 -
	Long inbred	2	1.33	55.5	74	342	513	155	196	1279 c	630 c	0.256	1617 b	338 b	0.21 b
	Hybrid	4	3.53	41.6	147	154	513	103	196	1114 a	246 a	0.225	546 a	-568 a	-1.04 a
	Local cultivar	55	0.59	83.3	49	229	513	155	196	1187 b	428 b	0.362	1545 b	357 b	0.23 b

Different alphabet shows the significant different among cultivar groups at $p < 0.05$, - means statistical comparison was not applicable for this group due to the N= 1.

1 USD = 22650 VND

In briefs, there were numerous of innovated possibilities to increase the efficiency of rice production in RRD such as the ones discussed in this section, including replacing the new salinity resistant varieties, reducing N fertilizer dose, reducing water use for irrigation in non-salinity stress and scaling up the farm size. Using data is taken from Vietnam Household Living Standard Survey 2003-2004 which implemented by General Statistics Office of Vietnam, the technical inefficiency of rice farm in RRD at the current farm size operation, was estimated at 0.31 with input-oriented, suggesting that a farm can reduce its cost by 31 % to obtain a similar output (Hoang Linh, 2012). Taken the farm size efficiency into account, a further 10% input cost can be reduced.

Agricultural extension activities were played an important role on the introduction of new rice varieties and the dissemination of advanced technologies, which had been contributed significantly in the miracle achievements of rice development in RRD since agricultural de-collectivization on 1986. However, in order to cope with currents problems of rice production in RRD, agricultural extension is facing many difficulties and problems institutionally, methodologically and financially (De et al., 2005). Insufficient qualified staff (Hoang et al., 2006) (De et al., 2005) and poor coordination and management (Castella et al., 2006) are the major problems to limit the diffusion of innovations. Better institutional arrangements for comprehensive collaboration between the professional extension system and mass supporting organizations and research institutions will be the key issues. The top-down approach is still prevailing, although there were some positive signs that agricultural extension is becoming more farmer oriented, demand-driven and market-oriented (Poussard, 1999; Schad et al., 2013). This rigid approach may not appropriate for the spatial variation characteristics in RRD such as salinity intrusion both regional scale and small scale (chapter 2), soil properties and water availability (chapter 3). In addition, top-down extension limited the utilizing and diffusing farmer adaptations such as Nep Cao landrace (discussed in chapter 2), which was called "decentralization diffusion". Such type of innovation, in which originally selected /invented by farmers, then be put in the co-operation with scientist and development organization, and later disseminated broadly to farmers across the region, has been proven to be effective (Rogers, 2010; Fujisawa & Kobayashi, 2013; Hirota & Kobayashi, 2019). Therefore, a such further transition to bottom-up approach of agriculture extension were essential in order to increase the dissemination efficiency

5.3 Opportunity and weakness of aquaculture as an adaptation for salinity intrusion

In this study, the impact of salinity was clearly shown as negative also on rice farming profit (Chapter 4, Table 4.5). Increasing salinity caused higher purchased input for rice farming, reduced grain yield and output, hence reduced farmer income and profit (Table 4.6). Salinity stress reduced survived rate of rice seedling (Zeng & Shannon, 2000a), hence requiring for a re-translating; reducing nitrogen use efficiency (Singh et al., 2013), as well harmed reproductive development on rice plant (Hussain et al., 2018), which were expected to be more severe in the future due to the climate change. Under the higher salinity (i.e 0.5‰), marine aquaculture, both in freshwater and brackish water, were proven higher profitable. The results provide a scientific reference for land-use planning of government and farmers. It suggested without innovations to adapt and to improve production efficiency, rice fields should be transformed into fresh-water aquaculture, from the economic point of view. Even at low salinity level (<0.5‰) aquaculture still could be a considered option to generate income and employment for the rural area.

However, aquaculture involves in a supper higher risk than rice. Our survey data show the various risk sources which aquaculture farmer has been facing recently, (1) from market price fluctuation; (2) from production failure due to disease spread or water pollution, and (3) from a larger investment mostly come from bank loans. In the following part, we discuss about problems and solutions if transforming rice to aquaculture were selected. The first critical issue is reducing risks. Developing industry is one of the strategies which has been aware by governments recently. Nevertheless, the processing factory is still not available in the region yet. Improving the irrigation system with separating between irrigation and drainage system was important to better manage water quality. In fact, the drainage system in RRD was complex-using dual-purpose irrigation and drainage canals, hence, inadequately functioning (Ritzema et al., 2008). Avoiding ecological conflicts by spatial and irrigation separating between rice and aquaculture is needed. Recently, rice and fresh-water aquaculture in Nam Dinh, as well as in some other areas in RRD were co-cultivated at the same location and share the same irrigation system because both land-use types are categorized as fresh-water. This way of management can put aquaculture under the risk of pollution from crop protection chemical used for rice, moreover negative effect on rice production (discussed below). Better disease controlling also involves advanced technologies, providing training and agriculture extension services to farmers. Finally, support from the government in term of financial access with low interest are necessary. These comprehensive solutions should be applied synchronized to ensure sustainable development; therefore, a large-scale transformation from rice to aquaculture should be avoided before these preparations are ready.

Aquaculture caused environment problem, threaten its own sustainability as well as rice cultivation. Number of year pond-in-use positively increased pond preparation while negatively reduced aqua profit (chapter 4, Table 4.9), suggesting the impacts of pollution and disease accumulation over time in pond mug. Rice in sub-region where rice and aqua were cultivated parallelly NB3 have lower output and profit than NB1, NB3 (Table 4.4) suggesting that rice and aquaculture should be spatially separated. Freshwater aquaculture farming such as white-leg shrimp, even low salinity requires, still caused negative impact on rice cultivation. Similar results were reported in (Be, Dung, & Brennan, 1999; Tho et al., 2008).

We conducted an assessment the sustainability of transforming from rice to aquaculture using SWOT analysis. The method is to analyse the internal and external audit that draws attention, from a strategic perspective, to the critical strengths and weaknesses and the opportunities and threats facing of the farm which taking the transformation (Table 5.2).

Table 5.2 Assessing the sustainable transformation from rice to aquaculture

INTERNAL FACTORS	
STRENGTHS (+)	**WEAKNESSES (-)**
- The transformation could be a good adaptation to high salinity concentration, e.g above 0.5‰, particularly important under the light of climate change which expected to increase salinity intrusion. - Transformation generates higher income for farmers, with very high-income potential, especially if farmers can manage to better control diseases. - Generating higher employment for farmers, with very high employment-potential; particularly meaningful under the situation of rural unemployment. - Providing and diversifying nutrient sources for household.	-Aquaculture causes ecological unbalance, environmental pollution, and disease accumulation in the pond mug, which can reduce efficiency or damage the production. The larger scale of tranformation, the higher risk posibility appear due to the intension of risk source. -High labour requirement due to less possibility of mechanicalization incompare with rice. - Require huge money to facilities invent and money to operate the production while involving a high risk of failure. - Curent status of aquaculture has lower profit efficiency than rice, which is needed to be improved. - Since aquaculture is new to farmer, training and learning is critical in order to transform from rice to aquaculture. - Transformation can lead salinity intruded further into inland, causing ecological conflict directly with rice and other crops which require fresh water for irrigation

EXTERNAL FACTORS	
OPPORTUNITIES (+)	**THREATS (-)**
- The global market value of aquaculture is predicted significantly increase while that of rice increase at a slower rate. - New developed and modern aquaculture farming technique is available to reduce risk and increase production efficiency, while rice production almost reaches to the stagnancy stage. - Aquaculture was explitedly encouraged by the government through policies and investment in improving the irrigation system or processing industry. -	- Water quality for irrigation which aquaculture farming is particularly sensitive with is difficult to control and threaten by nearby industrial factories, rice farming and domestic water waste. - The global market price was fluctuated and tended to reduce gradually since the boom of global supply, which can directly threaten the success of aquaculture. - Threat from the change in government policy or international co-operation. - If aquaculture is failed due to external factors mentioned above, re-transformation to the rice-based system will be very costly, even impossible.

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