IMPACT OF SALINIZATION ON RICE PRODUCTION AND FARMERS' ADAPTATION PREFERENCES: A CASE IN THUA THIEN HUE PROVINCE, VIETNAM

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Thi Huyen Trang Dam

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Abstract

The overall objective of this study is to analyze the impact of saltwater intrusion on rice cultivation at different salinity levels in the north central coastal region of Vietnam and to examine possible solutions. It explores how changes in the rice cultivar options within the study area can help to reduce these impacts and investigates possible solutions and their perception by farmers to help farmers to assess their situation and policy makers to develop and support appropriate practical solutions.

The study employed a combination of quantitative and qualitative research methods to quantify salinity impact on rice and investigate possible solutions as well as farmers' references. Primary data were collected from four different coastal communes in two districts (Quang Dien and Phu Vang) by using pretested questionnaires to personally interview 268 farms/households. In the first article, the study investigated impacts of salinity on mean and variability of rice yields in four communes of Thua Thien Hue Province and looked at possible changes in the portfolio of rice cultivars, which would offer farmers the potential to increase yields and decrease yield variability simultaneously. The Just and Pope (1978, 1979) regression model was used to analyze the marginal effects of the independent variables on mean yield-yield variance and portfolio analysis to examine the existence of alternative rice varietal portfolios that may increase production under different salinity classes. In the second article, we evaluated the impact of saltwater intrusion on the productivity and technical efficiency (TE) of rice farms in the study area using the stochastic frontier (SF) production function. Contrasting to existing studies, this research analyzed season-differentiated impact of soil salinity (as measured by electrical conductivity (EC)).

Salt tolerant rice varieties can secure yields as long as salinity levels are moderate but are inappropriate once salinity becomes severe. Rice farmers are well aware that converting rice fields to aquaculture or vegetable farming could provide higher returns than low rice yields or even leaving the fields fallow. This led to the conduct of third methodological approach that generated information about rice farmers' preferences and motivations for choosing among the portfolio of locally feasible adaptive and transformative options using a choice experiment (CE). The respondents' adoption outcomes at different salinity levels were also simulated.

The results showed that salinity has negative impact on rice yields, contributes to an increase in variability of yields and reduces rice technical efficiency depending on rice varieties. Rice farmers can benefit and improve rice performance from revised portfolios of existing varieties at initial salinity levels. The results of this study also reflect a broad path of agricultural adaptations that can contribute to the wellbeing of coastal dwellers facing formidable challenges, including seasonal weather variation, increasing salinity, legal restrictions and market issues in transforming to alternative farming systems. The choice experiment revealed that decisions of the majority of rice farmers near the lagoon areas in the Thua Thien-Hue Province are driven primarily by opportunities to earn a higher margin (return) and those they are currently averse to risks, higher investments, and higher efforts. In areas with higher salinity levels, waiving the legal restriction on the conversion of rice area to aquaculture ponds could help farmers to cope with the issue. The predicted adoption rates for salt-tolerant rice varieties are more than 38% when legal restrictions on land conversion are not waived. In case land conversion is allowed, 40% would adopt aquaculture options, 18% would grow vegetables and 2.1% fruits which could be improved by market interventions and introduction of salt-tolerant fruits or vegetables. These modelled changes in cultivation would offset the salinity impacts on income.

The study additionally indicates the need for increased investment in rice breeding for salinity tolerance, market development for alternative crops, the introduction of risk offset mechanisms and a planned shift to transformative alternatives like aquaculture. The study calls for a balanced effort for adaptive and transformative options for rice farmers, infrastructural options preventing salinity intrusion as well as enhanced global mitigation efforts to reduce possible rise in sea levels and limiting salinity intrusion. The study also documents an innovative approach for bridging the knowledge gap to guide policymakers on ways to promote adaptation or transformation measures in any coastal region around the world.

Keywords: Salinity intrusion impacts, rice production, coastal central Vietnam, farmers' preferences, adaptation to increasing salinisation.

Kurzfassung

Übergeordnetes Ziel dieser Studie ist es, die Auswirkungen von Salzwassereinbrüchen auf den Reisanbau bei unterschiedlichen Salzgehalten in der nördlichen zentralen Küstenregion Vietnams zu analysieren und mögliche Lösungen zu untersuchen. Sie untersucht, wie Veränderungen bei der Reissortenwahl innerhalb des Untersuchungsgebietes dazu beitragen können, diese Auswirkungen zu verringern, und untersucht mögliche Lösungen und deren Wahrnehmung durch die Bauern, um den Bauern bei der Beurteilung ihrer Situation und den politischen Entscheidungsträgern bei der Entwicklung und Unterstützung geeigneter praktischer Lösungen zu helfen.

Bei der Studie wurde eine Kombination aus quantitativen und qualitativen Forschungsmethoden eingesetzt, um die Auswirkungen des Salzgehalts auf den Reis zu quantifizieren und mögliche Lösungen sowie die Referenzen der Landwirte zu untersuchen. Die Primärdaten wurden in vier verschiedenen Küstengemeinden in zwei Distrikten (Quang Dien und Phu Vang) erhoben, indem 268 Bauernhöfe/Haushalte mittels vorgetesteter Fragebögen persönlich befragt wurden. Im ersten Artikel untersuchte die Studie die Auswirkungen des Salzgehalts auf den Mittelwert und die Variabilität der Reiserträge in vier Gemeinden der Provinz Thua Thien Hue und untersuchte mögliche Veränderungen im Portfolio der Reissorten, die den Landwirten das Potenzial bieten würden, die Erträge zu steigern und gleichzeitig die Ertragsvariabilität zu verringern. Das Regressionsmodell von Just und Pope (1978, 1979) wurde zur Analyse der marginalen Auswirkungen der unabhängigen Variablen auf die mittlere Ertragsvarianz und zur Portfolioanalyse verwendet, um die Existenz alternativer Reissortenportfolios zu untersuchen, die die Produktion unter verschiedenen Salzgehaltsklassen steigern können. Im zweiten Artikel bewerteten wir die Auswirkungen eines Salzwassereinbruchs auf die Produktivität und technische Effizienz (TE) der Reisfarmen im Untersuchungsgebiet unter Verwendung der „stochastic frontier“ (SF) Produktionsfunktion. Im Gegensatz zu bestehenden Studien analysierte diese Studie den jahreszeitlich differenzierten Einfluss des Salzgehalts des Bodens (gemessen anhand der elektrischen Leitfähigkeit (EC)).

Salztolerante Reissorten können Erträge sichern, solange der Salzgehalt moderat ist, sind aber ungeeignet, wenn der Salzgehalt stark ansteigt. Reisbauern sind sich sehr wohl bewusst, dass die Umstellung von Reisfeldern auf Aquakultur oder Gemüseanbau höhere Erträge bringen könnte als niedrige Reiserträge oder sogar das Brachliegenlassen der Felder. Dies führte zur Durchführung eines dritten methodischen Ansatzes, der Informationen über die Präferenzen der Reisbauern und ihre Beweggründe für die Wahl aus dem Portfolio der lokal durchführbaren adaptiven und transformativen Optionen mit Hilfe eines Auswahlexperiments (choice experiment, CE) generierten. Die Adoptionsergebnisse der Befragten bei verschiedenen Salzgehaltsstufen wurden ebenfalls simuliert.

Die Ergebnisse zeigten, dass der Salzgehalt negative Auswirkungen auf die Reiserträge hat, zu einer Erhöhung der Variabilität der Erträge beiträgt und die technische Effizienz des Reises je nach Reissorte verringert. Die Reisbauern können von überarbeiteten Portfolios bestehender Sorten auf den anfänglichen Salzgehaltsniveaus profitieren und die Reiserträge verbessern. Die Ergebnisse dieser Studie spiegeln auch einen breiten Pfad landwirtschaftlicher Anpassungen wider, die zum Wohlergehen der Küstenbewohner beitragen können, die bei der Umstellung auf alternative Anbausysteme vor gewaltigen Herausforderungen stehen, darunter jahreszeitliche Wetterschwankungen, zunehmender Salzgehalt, rechtliche Einschränkungen und Marktprobleme. Das Choice-Experiment hat gezeigt, dass die Entscheidungen der Mehrheit der Reisbauern in der Nähe der Lagunengebiete in der Provinz Thua Thien-Hue in erster Linie von der Möglichkeit getrieben werden, eine höhere Gewinnspanne (Rendite) zu erzielen, und dass sie derzeit Risiken, höheren Investitionen und größeren Anstrengungen gegenüber abgeneigt sind. In Gebieten mit höherem Salzgehalt könnte die Aufhebung der gesetzlichen Beschränkung der Umwandlung von Reisanbauflächen in Aquakulturteiche den Bauern helfen, mit dem Problem fertig zu werden. Die vorausgesagten Adoptionsraten für salztolerante Reissorten liegen bei über 38%, wenn die gesetzlichen Beschränkungen der Landumwandlung nicht aufgehoben werden. Falls die Landumwandlung erlaubt wird, würden 40% die Aquakulturoptionen wählen, 18% würden Gemüse und 2,1% Obst anbauen, was durch Marktinterventionen und die Einführung salztoleranter Obst- oder Gemüsesorten verbessert werden könnte. Diese modellierten Veränderungen im Anbau würden die Auswirkungen des Salzgehalts auf das Einkommen ausgleichen.

Die Studie weist zudem auf die Notwendigkeit höherer Investitionen in die Reiszüchtung zur Salzgehalttoleranz, die Marktentwicklung für alternative Kulturen, die Einführung von Risikoausgleichsmechanismen und eine geplante Umstellung auf transformative Alternativen wie die Aquakultur hin. Die Studie fordert eine ausgewogene Anstrengung für adaptive und transformative Optionen für Reisbauern, infrastrukturelle Optionen zur Verhinderung des Salzwassereinbruchs sowie verstärkte globale Bemühungen zur Eindämmung des möglichen Anstiegs des Meeresspiegels und zur Begrenzung des Salzwassereinbruchs. Die Studie dokumentiert auch einen innovativen Ansatz zur Überbrückung der Wissenslücke, der Entscheidungsträgern als Orientierungshilfe für die Förderung von Anpassungs- oder Transformationsmaßnahmen in allen Küstenregionen der Welt dienen soll.

Schlüsselbegriffe: Auswirkungen der Versalzung von Küstengebieten, Reisanbau, Küstengebiete Zentralvietnams, Präferenzen der Bauern, Anpassung an zunehmende Versalzung.

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List of abbreviations

CE	Choice experiments
CISA	Carolinas Integrated Sciences and Assessments
CLRRI	Cuu Long Delta Rice Research Institute
DARD-TTH	Department of Agriculture and Rural Development in Thua Thien Hue Province
DEA	Data Envelopment analysis
dS/m	DeciSiemens/meter, the internationally accepted unit of electrical conductivity
EaO	Experts and officials
EC	Electrical conductivity
FAO	Food and Agriculture Organization
FTE	Full time equivalent
GFDRR	Global Facility for Disaster Reduction and Recovery
GM	Gross Margin
GML	Generalized mixed logit
GSR	Green Super Rice
ILO	International Labour Organization
IPCC	Intergovernmental panel on climate change
IPM	Integrated pest management
IPPC	Intergovernmental Panel on Climate Change
ITC	International Trade Centre
J-P	Just and Pope
MLE	Maximum likelihood estimation
MONRE	Ministry of Natural Resources and Environment UNDP
MRD	Mekong River Delta
No.	Number
RP	Random parameter
RPL	Random parameter logit
RRD	Red River Delta
RRI	Responsible Research and Innovation
SAS	Statistical Analysis System
SF	Stochastic frontier
SFA	Stochastic frontier analysis
SPF	The stochastic production frontier
ST	Salt-tolerant
TE	Technical efficiency
UNDP	United Nations Development Programmer
USD	U.S. dollar
USSLS	United States Salinity Laboratory Staff
VAAS	Vietnam Academy of Agricultural Sciences
VND	Vietnam Dong – Vietnam currency
WTP	Willingness to pay

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1 Research background

1.1 Introduction

Salinity intrusion is a natural disaster which is caused by the complex hydrological regime leading to penetration of salt water into the interior through estuaries (60). Salinity ingress causes increase in soil salinity, especially when the farmers irrigate their land with slightly saline surface water at the beginning of the low flow period (2). Currently, soil salinisation is considered to be one of the most serious problems threatening food security worldwide.

One of the major challenges for global agriculture is to meet the food demand of the current population and the expected additional 2.3 billion people by 2050 (28). Future expansion of arable lands faces erratic environmental conditions and abiotic stress (24; 28; 29; 13). One of the abiotic stress factors that significantly impede global plant production is salinization (55). In particular, salinization of coastal areas is one of the greatest challenges for crop production in many countries. In this context, sea-level rise contributes significantly to the risk of saltwater intrusion into coastal areas (76; 66; 15). Soil salinity not only reduces agricultural productivity, but also has long-term impacts on the livelihood strategies of smallholders (34; 70). Rice (*Oryza sativa* L.) is an important crop that feeds more than half of the world’s population and is the most important source of employment and income for rural smallholders in many developing countries (35). Across Asian countries, rice is a staple food, and presently rice production is under serious stress by high salt levels in soil. Rice yield in salt-affected land is significantly reduced, with an estimated 30-50% yield loss annually (26). Therefore, soil salinization is considered as one of the major problems limiting rice production and subsequently leading to food insecurity problems.

In rural Vietnam, rice cultivation is the main source of income (in many cases, the primary or sole source) for more than 75% of poor households as well as for about 48% of non-poor households (79). According to the Ministry of Agriculture and Rural Development, Vietnam's agricultural and rural development strategy for the period of 2011-2020 is to establish rice as Vietnam's main export commodity alongside sufficient rice production to ensure food security. Salinity levels influence agricultural production in coastal areas of Vietnam, which are otherwise very fertile (47), thus disrupting an important part of the Vietnamese economy (67). In addition, the country is the second largest exporter of rice in the world, and changes in production levels could have major economic consequences on regional and global food security (76; 66).

Salinity intrusion significantly affected the rice cultivation in Thua Thien Hue province in north-central coastal region of Vietnam (51). This area is considered as an ideal case study region due to the significant impact of salinity intrusion on 2,500 ha of agricultural land adjacent to the Tam Giang Lagoon (the biggest lagoon in Southeast Asia an area of approx. 22,000 ha) (17). Along with aquaculture, rice farming is the main source of income of farmers in this region. Rice farmers around the lagoon are facing increasing difficulties of salinization due to the uneven distribution of water over the years. It is therefore most relevant to assess the impact of salinization on rice production in this area and investigate possible solutions and their perception by farmers. This will help farmers to assess their situation and policy makers to develop and support appropriate practical solutions.

Fields in Hue show a high variance in salinity levels that can vary largely at small distances. This complicates not only the determination of the salinity level and its impact but also the development and application of adaptation options. Therefore, a study at the level of agricultural households is necessary, taking into account the measured salinity of the associated rice fields. We used households' production information and salinity measurement of each rice plot to estimate the relationship between salinization and rice performance. As part of this thesis we examined agronomic and economic aspects of production risk and technical efficiency under dynamic salt-affected conditions. A combination of these analyses provided important estimations of variability and efficiency of rice production, under saline conditions. Given the importance of breeding and varieties in adapting to salinization, the rice variety-specific agronomic and economic effects were analyzed. The results have been published in two journal articles. The first article investigates the impacts of salinity on mean yield and yield variability of different rice varieties and recommends solutions resulting from rice varietal portfolios analysis. The second article analyzes variety-specific effects of saline water intrusion on the rice technical efficiency.

Breeding solutions in the context of increased salinization, however, are inappropriate once salinity becomes severe. Rice farmers are also well aware that converting rice cultivating land to aquaculture or vegetable farming could provide higher returns than low rice yields or leaving the fields fallow. This led to the conduct of a further study of choice experiments (CE) of rice farmers' preferences and motivations for choosing adaptation options that ranged from incremental alterations in farming practices to transformative adaptation to aquaculture. The goal of the third study was to provide a portfolio of adaptation options to increased salinity appropriate for the local conditions.

1.2 Research rationale

1.2.1 Need for impact assessment using farm household data along with salinity measurement in center coastal areas of Vietnam

The impact assessments using household data are useful to assess exposure, susceptibility and adaptive capacity of farming households to the increasing salinity. The analyses based on production information of rice producers in their field not only helps to understand the levels of salinity impact, but also provides information on the factors influencing the rice production and efficiency of production (23). This also supports the formulation of effective and efficient adaptation measures. Most of the previous studies on salinization effects on rice production in Vietnam concentrated predominantly on the Red River Delta (RRD) and the Vietnamese Mekong River Delta (MRD) or the whole country (62; 16).

So far limited studies are available on the impact of salinity intrusion on rice using primary data in Central Vietnam. The study of Pedroso et al. (2018)(62) is about the modelling of salinity impact on rice technical efficiency and the study of Nguyen et al. (2014) (57) is about soil salinity effects on rice production. Pedroso et al. (2018) (62) analyzed the technical efficiency of rice production and its determinants in Central Vietnam based on 113 households' data considering the different rice seasons. But they did not investigate salt distribution as well as its impacts on rice cultivation. Though Nguyen et al. (2014) (57) focused on effects of variability of soil salinity on rice yield using salinity measurement; they ignored other information on household production. Hence, this dissertation specifically studies the impacts of saline intrusion on rice production, and efficiency using farm household level data and measurement of salinity levels (EC) for each rice plots by considering different rice growing seasons.

1.2.2 Need for variety-specific assessment of yield and efficiency at various salinity levels

Short-term rice varieties are established as an efficient adaptation measure against climate stress and have been widely applied in Thua Thien-Hue region. Farmers in this region prefer to use traditional short-term varieties because of their high productivity, early harvest and also to avoid extreme climatic periods. However, in response to salinity, traditional varieties show low performance in moderate level of soil salinity. Rice breeders develop various short duration varieties that are tolerant or resistant to soil salinity. But very few rice farming households use salt-tolerant varieties despite their importance to salinity adaptation. Low productivity due to inappropriate rice varieties per plot decreases farmers' income. Therefore, the question rises in how far varieties being used in the study area are appropriate and effective, especially in the condition that the rice plots vary in salinity levels and in how far a rearrangement of suitable rice varieties for different rice plots could improve yield level and security of rice production as well as farm income. This dissertation therefore complements the studies focusing on breeding salt tolerant rice varieties and examining their yields in experimental field research (49; 59; 58).

1.2.3 Need for a study on farmers' adaptation behavior regarding different production options as a basis for adaptation policies.

The rice farmers in Thua Thien Hue province perceive the impacts of saline intrusion based on its frequency, intensity, timing, and effects on rice crops, and they have different ways to deal with salinity intrusion. In practice, the levels of saltwater intrusion might be difficult to observe and predict as they depend on yearly weather variations, the condition of the irrigation systems and ditches and the overall management of the lagoon. During dry season many rice plots are abandoned due to very high salinity levels. Government's policies and the projects focus only on stability of productivity and sustainable livelihood, but they give less focus on adaptive capacity of farmers (40). A few households choose adaptation options based on available inputs and changed farming practices at very low salinity levels. The adaptations based on local resources could be the important premise for sustainable rice production.

Understanding farmers' motivations, knowledge and attitudes is the key to improving farmers' adaptability and promoting sustainable production. Farmers are the agents undertaking as well as influencing the performance and the success of adaptive policies (39; Moon and Cocklin, 2011). The design and implementation of incentives, regulations or institutional reforms necessarily are based on farmers’ experiences and available local resources (Home et al., 2014). This helps in the effective implementation of adaptation policies and reduces wastage of resources. Improving the adaptive capacity of farmers should be given more importance in the development of policies to cope with increasing soil salinity (1). Given these challenges, different adaptation measures need to be developed and farmers’ preferences should be used as references for making adaptation policies. Therefore, we conducted choice experiments with farmers to examine their preferences with respect to crop choices under saline conditions. The choice experiments (CE) formulated options based on locally available resources. The results can support local authority’s policy decisions.

1.3 Overall objectives

The overall objective of this dissertation is to analyze the impact of saltwater intrusion on rice cultivation at different salinity levels and it also explores how changes in the rice cultivar options within the study area can help to reduce these impacts. In soils with high salinity levels which are no longer suitable for rice cultivation, more suitable adaptation strategies are called upon through examining farmers’ preference for different crop sequences and the factors affecting their preferences in the interaction with various levels of salinity. The dissertation consists of three specific sub-objectives that were addressed in three research articles. These objectives are as follows:

- To analyse the impact of salinity on variety-specific yield and variance and develop varietal recommendations regarding the portfolio of rice cultivars within the study area in order to optimise rice profit.
- To analyse the variety-specific effects of saline water intrusion on the technical efficiency of rice production.
- To investigate rice farmers’ preferences and motivations with respect to adaptation to increased salinity. Adaptation options may range from minor adaptation (varietal selections) to transformative adaptation (aquaculture).

1.4 Structure of the dissertation

This dissertation consists of five chapters.

Chapter one is an introductory chapter that gives readers background information related to the topic. It is continued with the problem statement, objectives of the study, research questions, and ends by describing the structure of this dissertation.

Chapter two provides information about the study area and data including the field surveys and salinity measurement. Two different rounds of surveys were conducted. In the first survey, I collected farm household level information on rice production including inputs-output and management data. Also, the soil salinity level of the surveyed rice farms was measured to allow for the examination of the interaction of salinity and yields. In the second survey I collected the information on farmers' preferences for adaptation strategies based on choice experiments.

Chapter three deals with the analytical framework consisting of different but complementary methodological approaches and it also substantiates their use for this dissertation.

Chapter four is the main body of this dissertation that presents our results in the form of three peer-reviewed published articles. Each article answers one of the research questions of this study.

- Article I examines the impacts of increasing salinity in rice production in terms of mean yield and yield variability and how their responses differ with respect to rice varieties. The second analysis is an optimised portfolio of rice varieties that combines profit-maximisation and minimisation of the impact of salinity.
- Article II analyses the economic efficiency through technical efficiency aspect of rice production. Subsequently the effect of salinisation on variety-specific rice production is also estimated. In addition to the role of inputs use, the importance of cultivar is emphasized in dealing with increasing salinity.
- Article III applied a CE approach to examine farmers' preference for different crop sequences and the factors affecting their preferences in the interaction with various levels of salinity. The article proposes appropriate adaptation measures to saltwater intrusion that are suitable for local conditions.

Chapter five contains the general conclusions drawn from the research and recommendations to farmers and policy makers regarding suitable adaptation measures to the increasing soil salinization in coastal center area of Vietnam. It also synthesized the main implications including limitations of the present study and outlook for the future research.

2 Study area and data collection

2.1 Study area

The study was conducted in the Thua Thien Hue province of Vietnam (figure 2.1). This is the central coastal province of Vietnam and it is constantly affected by climate change and resulting salinity issues. The province is characterized by a long coastline with 120 km of coastline, a lagoon system and a narrow delta, especially Tam Giang - Cau Hai lagoon system with an area of approx. 22,000 ha which is the largest in Southeast Asia (17). About 6,290 ha of Thua Thien Hue province has saline soils and they are of 2 types: high salinity soil (Hyper

Salic Fluvisols), low and medium salinity soil (Molli Salic Fluvisols) (73) which are mainly distributed in Phu Loc, Phu Vang, Huong Tra and Quang Dien districts.

Thua Thien Hue's climate has two distinct seasons in a year; viz: a hot dry season, and a cold and wet season along with many floods and storms. The rises in temperature and hot-dry Southwest wind in the dry season, the rainfall is erratic and highly concentrated during the rainy season. In particular, the dry season lasts from January to August every year, with droughts during March to April and July to August. The rainfall received during this period is only 20 % of the annual rainfall. While rice cropping calendar in Thua Thien Hue province includes the Summer-Autumn crop (starting from May and ending in early September) and Winter-Spring crop (starting from mid-December and harvesting at the end of next year April). The lack of irrigation in the dry season due to the persistent and prolonged drought increase salinization which leads to many difficulties in rice production in the province.

The rice-growing area (40,000 hectares) of the province is largely concentrated adjacent to Tam Giang lagoon and in low-lying plains of the districts of Phong Dien, Quang Dien, Huong Tra, Phu Vang and Huong Thuy located at elevations from -0.5 m to +3.0 m above sea level (15).

2.2 Data collection

Both primary and secondary data were collected to achieve the goals. Coordination with the agricultural cooperatives was important at all stages of our study, as they played an important role in our surveys by guiding and advising us, providing us with helpful information and contacting the farmers.

2.2.1 Primary data

The data collection on salinity measurement off each rice plot and the rice input, output and management data were collected in two waves. A data collection team was formed to collect the data. This team consisted of three researchers and four students from Hue university of Agriculture and Forestry. All members in the research team were familiar with field survey methodologies. In addition, the team was informed about the research objectives and data collection purposes as well as the tools used for data collection before the survey. The main author was involved in all stages of data collection especially during empirical primary data collection. Primary data collection included structured household surveys, managers of agricultural cooperatives and expert interviews. Expert interviews were also conducted without a structured questionnaire. Household surveys were focused on rice crop cultivation at individual plot level and the questionnaire was used for oral interviews with rice farmers.

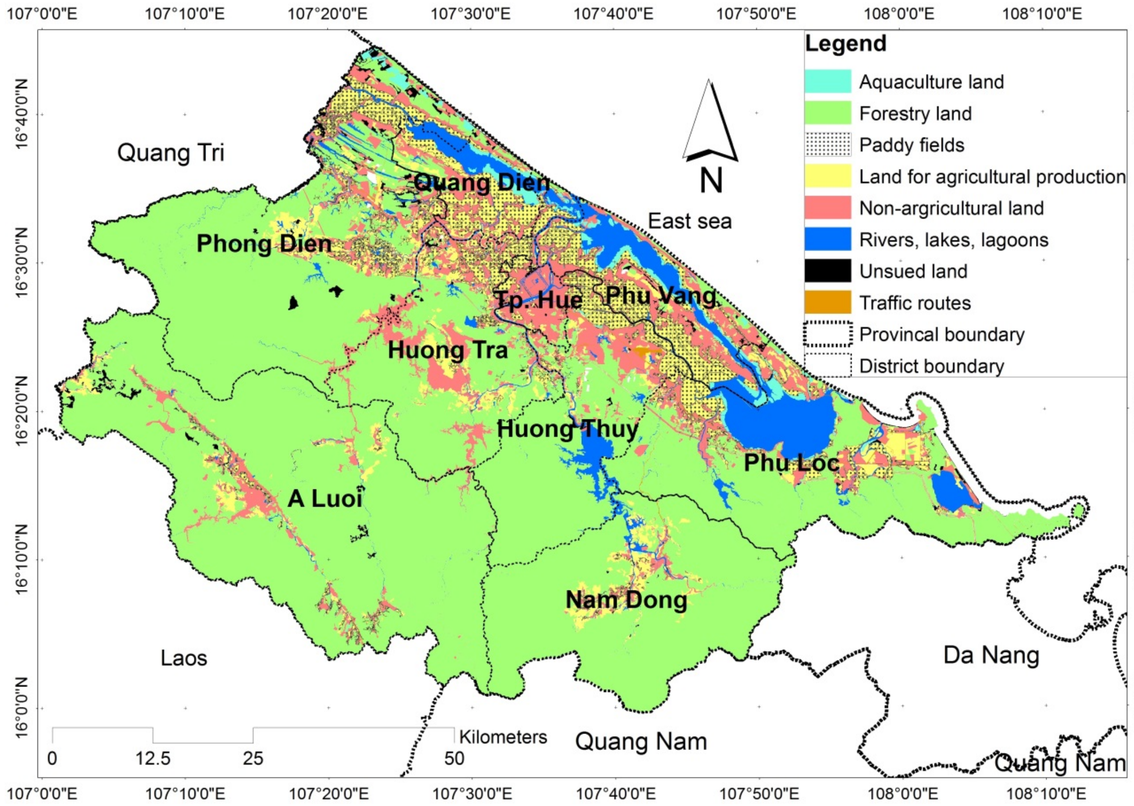

Figure 2.1: Land use map of Thua Thien Hue province (2015)

Source: Processed and translated from the land use map of Thua Thien-Hue province provided by the Department of Natural Resources and Environment (2015)

2.2.1.1 Interviews with experts and officials

Interviews with experts and officials (EaO) were conducted with project leaders, agricultural officials and local governmental staffs at province, district and commune level. The EaO interviews were conducted before, during and after the surveys with rice farmers. Face to face EaO interviews were conducted firstly at provincial level to get general understandings of socio-economic conditions and details of the salinity intrusion problem as well as historical coping and adaptation strategies in Thua Thien-Hue province. At district and commune levels, the information related to famers' characters, their vulnerability and adaptation to salinity intrusion were focused. Most appointments were made with certain governmental organization to get to right experts.

2.2.1.2 Household survey

A total of 268 rice households were selected from four identified communes which are representatives for coastal rice zones of the two coastal districts of Thua Thien Hue province (Quang Dien districts includes Sia and Quang Thai communes, Phu Vang districts includes Vinh Thai and Vinh Ha communes). The selection of households was based on a systematic random sampling method with a pre-classification of households according to whether or not their fields had been affected by soil salinity. These groups of farmers were categorized by commune chairpersons and cooperative leaders, who could make the best reviewed estimation and give helpful information about their villagers. The 268 households were selected randomly from the list of rice farmers from agricultural cooperatives. Before the start of the interview process a check of eligibility of the interviewee was done to ensure that the selection criterion of rice cultivation experience and influence level to family productive decisions was met. However, in the absence of household heads due to unavoidable reasons, the interviewers collected the response from the persons who was taking decisions in their families. The survey was carried out in Vietnamese language and then translated to English. Details of the surveys conducted to collect data for different articles follow below.

A) Data collection for article I and article II (2016) – Impact assessment articles

The first round of household survey collected information related to household composition, consumption, crop management, yields of the winter-spring (January to May) crop and the summer-autumn (May to September) crop of 2016. The aims of both articles were to assess the impact of salinization on rice production in current cultivated conditions and the role of rice cultivars. Thus, questionnaires contain questions related to various socio-economic and demographic characteristics of household as well as information related to rice farming namely details of land, labor resources, rice varieties, other inputs, rice productivity, gross margin etc. The information was collected for both cooperatives and households sources and related to data of 873 rice plots with different cultivation.

B) Data collection for article III (2017) – Choice experiment article

The second household survey was conducted in the beginning of 2017 with participation of the same 268 rice farmers in the first survey. To investigate rice farmers' preferences and motivations for choosing adaptation options against saline water intrusion, a choice experimental setting was used. Each farmer was asked to imagine that their rice plots are affected by salinity intrusion and to choose their most preferred alternative from a set of crop sequences with characterized attributes. The various attributes were composed of different levels of returns and investment costs. In order to determine the suitable adaptation sequences as well as its attributes and levels, a pre-survey with the participation of both farmers and experts was carried out. The hypothetical crop choices were assumed to ensure local adaptability and suitability. Farmers got an introduction into the choice experiment, emphasizing also that there is no right or wrong in farmers' choices and they should make choices imagining that they are real.

2.2.1.3 **Salinity measurement**

One of the aims of the thesis was to assess the impact of different levels of salinity on rice production; therefore, levels of salinity at the farms under study were needed. The result from Thiruchelvam and Pathmarajah (1999) (72) indicates that significant yield reductions are noted once salinity level exceeds rice threshold electric conductivity (EC) level (in d/Sm). The relationship between EC and rice yield by Dobermann and Thomas (2000) (22) is presented in table below:

Table 2.1: Relationship between EC and rice yield

EC (dS/m)	Toxic level	Level of yield reduction for rice
<2	Suitable for rice cultivation	No yield reduction
>4	Slight toxicity	10-15%
>6	Medium toxicity	20-50%
>10	Strong toxicity	>50%

(Source: Dobermann and Thomas, 2000)

The characteristic of soil salinity is conventionally measured by EC of soil. The EC of soil samples of saline rice plots was measured in 2016 cooperation with the Department of Soil Science, Land Resources and Agricultural Environment Faculty of Hue University. Core samples of the soil were taken from composite topsoil, with sample layers of 5 cm and a subsurface layer at the depth of 20 cm. EC values of the soil samples were measured at a soil testing laboratory using the "EC 1:5 w/v" method. This method measures the EC of a solution consisting of one part air-dried soil as measured by weight (g) to five parts distilled water as measured by volume (ml), which is agitated and then allowed to settle.

2.2.2 Secondary data

The secondary data regarding the social-ecological system conditions and changes in the study area were collected from different secondary sources and organizations. Social, economic and environmental aspects data were mainly obtained from national statistical books and provincial/district statistical organizations. Annual reports from provincial, district, commune and village levels were collected from people committees and, agricultural cooperatives in the research site. Data related to salinity impacted areas, crop damages due to salinity intrusion and its risks to agricultural development process were also collected from the Department of Agriculture and Rural Development at province and district levels. Other relevant information related to salinization impacts and its consequences were collected from the official portals of agricultural agencies and offices.

3 Methods

This chapter explains the application of different methods to answer research questions (figure 5). The details of equations as well as assumption of each framework are represented in the results (Chapter 4).

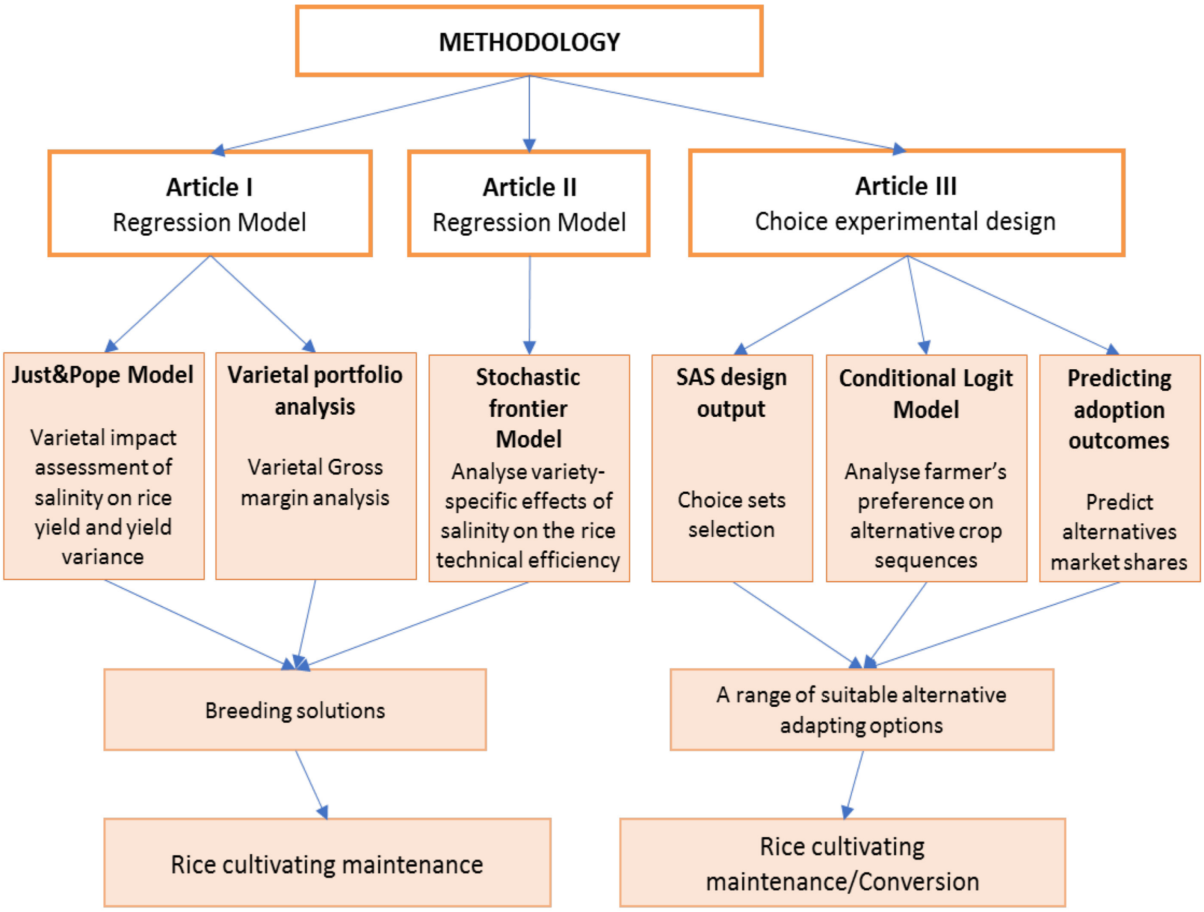

Figure 3.1: Conceptual frame of various methods used in the study

3.1 Application of regression models (Article I and article II)

The analysis of residuals plays an important role in validating the regression model. There are two generally separate analytic frameworks which plays central importance in residuals analysis from a production model's deterministic portion. First is risk analysis in a Just-Pope (1978, 1979) (44)(45) framework and the second framework is inefficiency analysis in a stochastic frontier framework (3; 7; 52).

Risk analysis in a Just-Pope (1978, 1979) (44) (45) framework involves recovering the residuals and using them to investigate the marginal effects of inputs on production risk, or noise (43). Just-Pope framework requires a specification in which there are no a priori restrictions on the marginal risk effects so that an input to production could be either risk-increasing or risk-decreasing (42). In contrast, technical inefficiency in a stochastic frontier framework specifies the residuals with both a two-sided white noise component and an inefficiency component (43).

Risk analysis and technical inefficiency analysis are two integral aspects of producers' technology decisions (42). The combination of these two analyses in the study provides more credible estimates of rice production efficiency. In addition, Just-Pope framework and stochastic frontier framework have no antagonism. The Just-Pope framework requires specification of no a-priori restrictions on the marginal risk effects so that an input to production could be either risk increasing or risk decreasing. There are no restrictions on the marginal inefficiency effects so that an input could be either efficiency increasing or decreasing in stochastic frontier framework. Fact is that the stochastic frontier model is consistent with the Just-Pope model and they complement and improve mutually in analyzing economic efficiency.

In my thesis therefore, I applied both frameworks to estimate the determinants of productivity, variability and efficiency of rice farming in the context of increasing salinization. To assess the salinity impact on rice production's aspects, in both frameworks, salinity is determined as an important factor in rice production. Different salinity levels are distinguished, from a slight impact to a serious impact. Because of breeding importance to rice production in salinity mitigation, we also considered rice varietal input into regression models. These analyses set the stage for finding suitable rice varieties for different salinity classes.

Article I

Consequently, in article I (15) presenting rice variance aspect, firstly we applied the Just and Pope Framework to demonstrate that salinity has a negative impact on rice production sustainability and that current varieties used by rice farmers are not suitable with the equations below:

$$Y_i = f(Z_i;\ \alpha) + \varepsilon_i \qquad (1)$$

(1) is the mean yield function, to understand the variety-wise differences in salinity impacts in terms of yield, ε_i is an error term and is explicit for heteroskedastic errors, allowing an estimation of variance effects.

$$\varepsilon_i = h(X_i;\ \gamma) + E_i \qquad (2)$$

Is the equation explaining the impact of explanatory variables, including salinity, on the variability of yields, while E_i is a random error term.

With E_i expressed as $E_i \sim N(0,\ \sigma_v^2)$

where Y_i is the yield; Z_i and X_i are vectors of explanatory variables, including set of the inputs of fertilisers, pesticides, machinery, and EC levels; $i = 1, 2, \ldots n$; α and γ are the corresponding parameters of the functions.

Also focus on aiming to examine the existence of alternative rice varietal portfolios that may increase production under different salinity classes, the optimisation of portfolios of cultivars under saline conditions was attempted. Thus, after applying the Just and Pope Framework, we applied varietal portfolio analysis in addition to address fitting varieties to study area with equation:

$$\text{Max}\ \pi = \sum_i^n x_i(P_i\, Y_i - C_i) \qquad (3)$$

Subject to

$\sum_{i}^{n} x_i \sigma_i^2 \leq \emptyset$ (4)

$\sum_{i}^{n} x_i = 1$ (5)

$x_i \geq 0$ (6)

Article II

Publication II (16) builds on the same database and reveals significant effects of salinity on rice efficiency and importance of salt-tolerant breeding. We used stochastic production function (SPF) that is consistent with the Just-Pope framework to estimate technical efficiency (TE)

$\mathrm{Ln}\ (Z_i) = \theta_0 + \sum_{i}^{n} \theta_i \mathrm{Ln}\ X_i + d_i D_{ij} + \varepsilon_i ,$ (1)

Where $\theta_0 + \sum_{i}^{n} \theta_i \mathrm{Ln}\ X_i + d_i D_{ij}$ forms the deterministic part of the function

and:

Z_i is the rice productivity of the ith household. X_i are the input factors including land area of rice plot (hectares); N, P and K fertilisers; pesticides; machinery; irrigation; hired labour; seasonal changes; EC (as a proxy for salinity effect). Ln stands for natural logarithmic transformation.

θ_i, d_i: vectors of unknown parameters to be estimated

D_{ij}: dummy variables where i represents different rice varieties, j has the value “1” or “0”.

If coefficients θ_i and $d_i > 0$, this means that an increase in inputs is expected to increase rice production.

ε_i is the error term, which is assumed to consist of statistical noise (v_i) and inefficiency (u_i)

$\varepsilon_i = v_i - u_i$ (2)

(u_i) technical inefficiency effects in the model where $u_i \geq 0$ and $i = 1, 2, \ldots, n$.

In other words, a zero value of u_i implies that the farm is completely efficient, while a high value of u_i implies a high degree of technical inefficiency. For v_i, a normal distribution with zero mean (N $(0, \sigma_v^2)$;) is assumed. The error term u_i captures inefficiency; it is distributed independently of v_i (exponential and half-normal distributions are tested), and satisfies the condition of $u_i \geq 0$.

The TE of the ith household (TE_i) is

TE_i = exp (-u_i) (3)

The TE scores are scaled between 0 and 100 in this study, where scores below 100 show inefficient production. The θ_i, d_i parameters and the efficiency scores (TE_i) were calculated using the Frontier Package of Stata 13.0. Subsequently, efficiency score of the rice farmers is modelled as a function of EC and cultivars in addition to farm inputs.

3.2 Application of Choice Experiments

Rice farmers are considered a key component in the evolution of rural sustainability. As Beckford (2002)(8) highlighted, farmers' views must be taken into account when accessing the usefulness of innovations; particularly those of small households who are heavily dependent on traditional rice production. Decision-making of rice farmers to adapt to salinization in the interaction with different salinity levels led me to choose choice experiments (CE) as a method to investigate possible farming activities, suited to local conditions other than rice production.

In the two first two published articles, I assumed that farmers opt to continue rice cultivation and therefore, breeding solutions are prior options to adapt to salinity levels. Once rice farming is not available in high salinity levels, the questions are: what are suitable conversion options and what are their risks and opportunities? How acceptable are these options to farmers? CE application answered these questions based on the given adapting scenarios and revealed farmer's behavior on each scenario. I investigated other suitable solutions based on learning from rice farmers how they have adapted to environmental changes, collecting experts' opinions, and analyzing the adapting trade-offs. Then I used CE to create a framework for assessing the behavior of rice farmers when adapting decisions.

One popular type of CE method used in many studies of climate change impact is willingness to pay (WTP) and its determinants in which respondents are asked for only one scenario. CE method has significant advantages over WTP studies and is a contingent valuation stated preference technique (68). CE is valuable in creating new datasets on behavioral studies that are being recognized for avoiding the large adoption gap and contributing to investment decisions (4). Recently, a number of studies have used CE to explore behavioral issues and factors that influence decision making (69; 6; 12; 21) including investment decisions (5and 4). Similarly, my study methodologically, presented hypothetical investment alternatives to farmers and examined how investment profitability, risk, and financial flexibility affect farmers' decisions.

Attributing characteristics of different farming activities are measured towards rice farmers' behavioral settings. Based on assumption of suitable adaptation options for rice farmers corresponding to every soil-salinity level, it is more interesting to look at the famers' preference in the interaction with different salinity levels (Figure 6). This permits characterizing multidimensional and preference-based valuation to estimate Costs - Benefits of alternative cultivations.

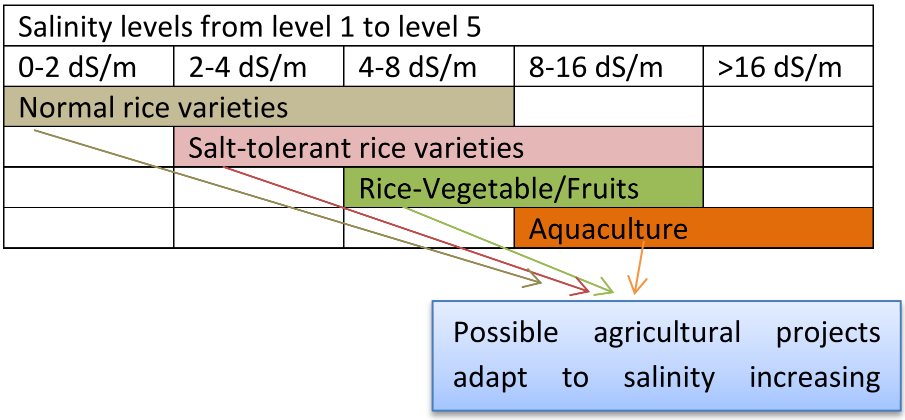

Figure 3.2: Alternative consequence options response to salinity levels

Depending on the objectives, the CE study basically has four phases including attributes and levels identification, experimental design, data collection and final statistical data analysis (see figure 7). In the first phase, once the salinity levels of different rice plots are recognized, adaptation choices including rice farming or shifting to other cultivations are characterized. The relevant attributes and their levels are also identified by synthesis of comments received from groups of managers, experts, farmers and from secondary data sources, etc. Conducting structured conversations with these groups helps to identify the important attributes (37). The attributes are required to record main aspects of each alternative farming activity promoting or restricting output production. As a sequence, study's attributes encompass not only economic valuations (costs and returns) but also non-economic valuations (risk and restriction).

In the experimental design step, CE aims to weigh advantages–disadvantages balance of possible agricultural projects response to every salinity level in rice soil based on attributes and levels identification. The viable projects are selected and afterward presented to rice farmers in phase 3. In this phase, the main data of CE was collected by interviewing households' directly. The theory of experimental design application helped to reduce implementation costs and improved the statistical efficiency of estimated parameters so that smaller samples may be used (37).

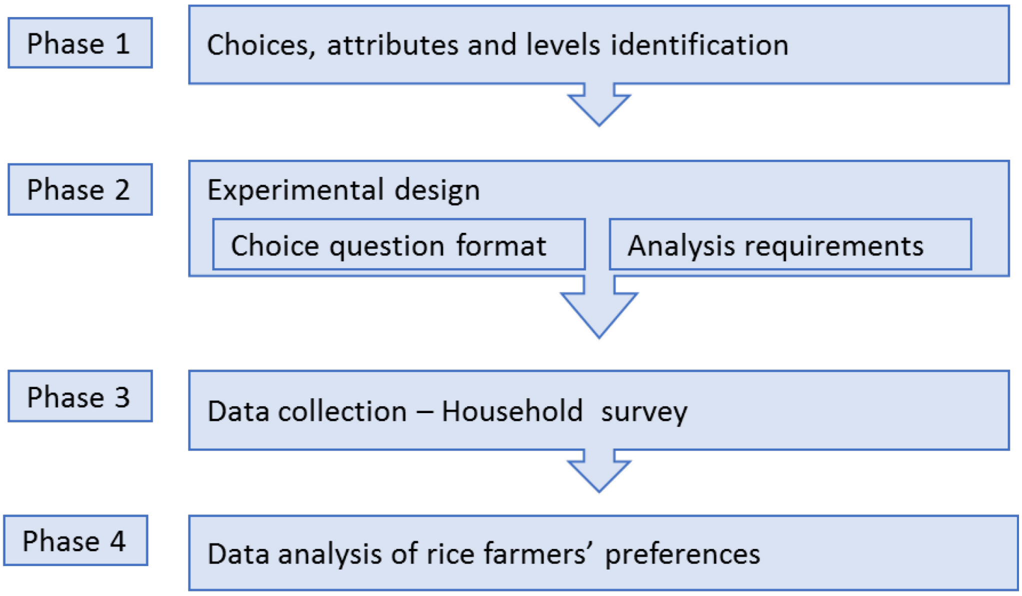

Figure 3.3: Choice experiments phases

In the final phase, I analyzed farmers' preferences with respect to feasible adaptation measures to the increasing salinity. High proportions of farmers prefer certain alternative measures that demonstrate their willingness to invest in productive transformation as well as acceptance of more risk. The suggested measures in CE study are therefore not only conforming to local production conditions but also motivating rice farmers proactively to cope with increasing salinization. More specific details about the design of the choice experiment including attributes and levels specification, choice question format, econometric analysis, predicting adoption outcomes are presented in the third article.

4 Research results

4.1 Article 1- The impact of salinity on paddy production and possible varietal portfolio transition: a Vietnamese case study

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Abstract: Increasing soil salinisation is an environmental stressor that causes significant reduction in crop productivity, and increases the risk of farming and hence reduces the cultivated land area. For these reasons, soil salinisation is considered to be one of the most serious problems threatening food security. In the north central coastal region of Vietnam, saltwater intrusion in the dry season is a major concern for rice farming. To better understand the adverse impacts of soil salinisation in crops, this study investigates impacts of salinity on mean and variability of rice yields in four communes of Thua Thien-Hue Province. In addition, the study looks at possible changes in the portfolio of rice cultivars, which would offer farmers the potential to increase yields and decrease yield variability simultaneously. Results clearly showed that salinity had an impact on yield levels, resulting in an average yield loss of 0.164 tonnes/ha from mean yield levels per unit increase of electrical conductivity (EC). The results did not show that increasing salinity contributes to an increase in variability of yields, but points to the fact that saline water intrusion may lead to consistently lower yields in the study area. Results also indicate that farmers with smaller, scattered plots could be disproportionately affected by salinity and be less capable of managing the saline soils. In addition, saline conditions may also drive the increased use of environmentally damaging inputs, such as pesticides, to offset the decline in yields, and thereby potentially lead to a vicious circle. Utilisation of an optimised portfolio of rice varieties that combine profit-maximisation and risk reduction reveals that farmers can benefit from revised portfolios of existing varieties at initial salinity levels, but need to include salt-resistant varieties in the portfolio as salinity levels increase.

Key words: Salinity, impact assessment, climate change, rice, South-East Asia

4.1.1 Introduction

Climate change adversely affects agricultural production (Patz et al., 2005) because it alters environmental parameters that influence crop growth (precipitation, temperature, soil salinity etc.). The impact of sea water intrusion on agricultural production due to changes in sea levels is gaining increasing attention due to possible impacts on the food security of many countries (Werner et al., 2013; Khong et al., 2018). Saltwater intrusion into freshwater coastal rivers and aquifers has been one of the most significant challenges for coastal water resource managers, agriculture and industry all over the world, and it is exacerbated by changing climate conditions (Ferguson and Gleeson 2012; Niemi et al., 2004). Vietnam is highly vulnerable to rising sea levels, which could significantly impact agriculture, especially paddy farming (Yu et al., 2010; GFDRR, 2011; MONRE, 2012). Currently, the country is the second largest exporter of rice in the world, and changes in production levels could have major economic consequences (Wassmann et al., 2004; Seal and Baten, 2012) on regional and global food security. The impact of saline water intrusion combined with drought events is expected to cause substantial disruption to a livelihood based on rice farming, especially in the Mekong Delta, the coastal north, the south-central area, and some northern delta provinces, triggering large-scale migration from these vulnerable regions (UNDP Vietnam, 2014). Rice cultivation is at least one source of income (in many cases, the primary or sole source) for more than three-quarters of poor households as well as for about 48% of non-poor households (Bingxin et al., 2010) in rural Vietnam.

The increasing number and severity of droughts can be attributed to global climate change (Meisler et al., 1984; Ranjan et al., 2006; CISA, 2012), which has accelerated saltwater intrusion induced by sea level rise. Drought conditions reduce freshwater flows into estuaries, allowing the saltwater wedge to move further and further upstream (Khong et al., 2018). Rises in sea level are projected to occur at an alarming rate over the next 100 years. The Intergovernmental Panel on Climate Change (IPCC) has predicted that by 2100, the sea level will rise between 18 cm and 59 cm (IPCC 2007), while 30 cm is highly likely by the 2050s (Rahmstorf, 2010, Smajgl et al., 2015). Sea level rises will have serious implications for Vietnam, with its extensive coastline; this will lead to salinity intrusion and the loss of productive land (Smajgl et al., 2015). The potential damage to rice production due to changes in soil conditions could be very serious (VAAS, 2014), since rice farming is the largest contributor to agricultural production and food security, and a major contributor to the livelihoods of millions of men and women in rural areas (Vu and Glewwe, 2011). Significant impacts to this rice cropping system from saltwater intrusion would therefore disrupt an important part of the Vietnamese economy (Smajgl et al., 2015).

Rice (*Oryza sativa L.*) is considered to be moderately sensitive to salinity (IRRI, 1997). The symptoms of salt injury in rice include poor tilling, stunted growth, rolled leaves, white tips, drying of older leaves, grain sterility and reduction in the volume of grain (FAO, 2012). The sensitivity of rice to salinity stress varies with the growth stage. Young seedlings are most affected by salinity, but all stages of the growth and development of the rice plant are vulnerable (Shereen et al., 2005; Deepa Sankar et al., 2011). Though rice is vulnerable to salinity in general, different varieties exhibit varying degrees of productive ability and salt tolerance. In recent years, the development of salt-resistant varieties has been proposed as a means of stabilising rice farming in regions affected by salinity (Epstein, 1980). Breeding rice varieties with salt-tolerance traits have been identified as the most promising, least resource-consuming, and economically viable alternative. However, acceptance of new varieties by farmers is often limited (Deepa Sankar et al., 2011).

Rice is the staple food crop of Vietnam. From 2000 to 2012, the population of the country increased from 77.0 to 88.8 million, while the total area of rice cultivation increased just slightly, from 7.7 to 7.8 million ha (General Statistics Office of Vietnam, 2014b). The rapid increase in population has created a growing demand for food production, especially rice. The current scenario demands increased production, despite worsening soil and environmental conditions. It is to be noted that salinity affected agricultural land in Mekong delta could almost triple (16% to 45%) by middle of the century, given the current rate of seal level rise (Khong et al., 2018). Among the provinces in the north-central coastal region of Vietnam, agricultural land in the province of Thua Thien-Hue is particularly affected by soil salinisation. In this region, about 2,500 ha of agricultural soil adjacent to the Tam Giang Lagoon (the biggest lagoon in Southeast Asia with an area of approx. 22,000 ha) are saline (Dan et al., 2006). As such, we consider this area to be an ideal case study region. Greater understanding of the adverse effects of salinisation on rice production in Thua Thien-Hue and the development of possible solutions may enable lessons to be learned, reducing the impacts in other regions of the country and beyond. The purpose of this article is to 1) analyse the impacts of increasing salinity in paddy production, 2) examine whether the responses (mean production and variability) differ with respect to paddy varieties and 3) explore how changes in the portfolio of rice cultivars within the study area (i.e. Thua Thien-Hue Province) can help reduce these impacts. To do this, a comprehensive dataset was collected from a representative set of farmers; we analysed this data using a methodological framework described in the following sections.

4.1.2 Study area

Thua Thien-Hue is the central coastal province of Vietnam, characterised by a long coastline, a lagoon system and a narrow delta. In this province, salt water intrusion has caused negative consequences to agriculture production and the ecology of the lowlands along the Huong and Bo rivers, and around Tam Giang Lagoon (the largest lagoon in Southeast Asia with an area of approx. 22,000 ha) (Dan et al., 2006). Saline water intrusion occurs every year in the dry period from May to August, impacting the rice farming that supports the population’s livelihood. The greatest distance that salinity intrudes up the Huong River is about 30 km from the coastline. The rice-growing area of the province is largely concentrated in low-lying plains of the districts of Phong Dien, Quang Dien, Huong Tra, Phu Vang and Huong Thuy, where 40,000 hectares are used to grow rice and annual crops. This region is located at elevations from -0.5 m to +3.0 m above sea level. A dyke system (with a recommended height of approx. +0.5 m) has been constructed adjacent to the Thuan An and Tu Hien estuaries of Tam Giang-Cau Hai, where the delta has been heavily affected by the rise in sea levels and saltwater intrusion. Any further rise in sea levels could significantly increase salt water intrusion into agricultural lands, posing a significant threat to rice production and to food security.

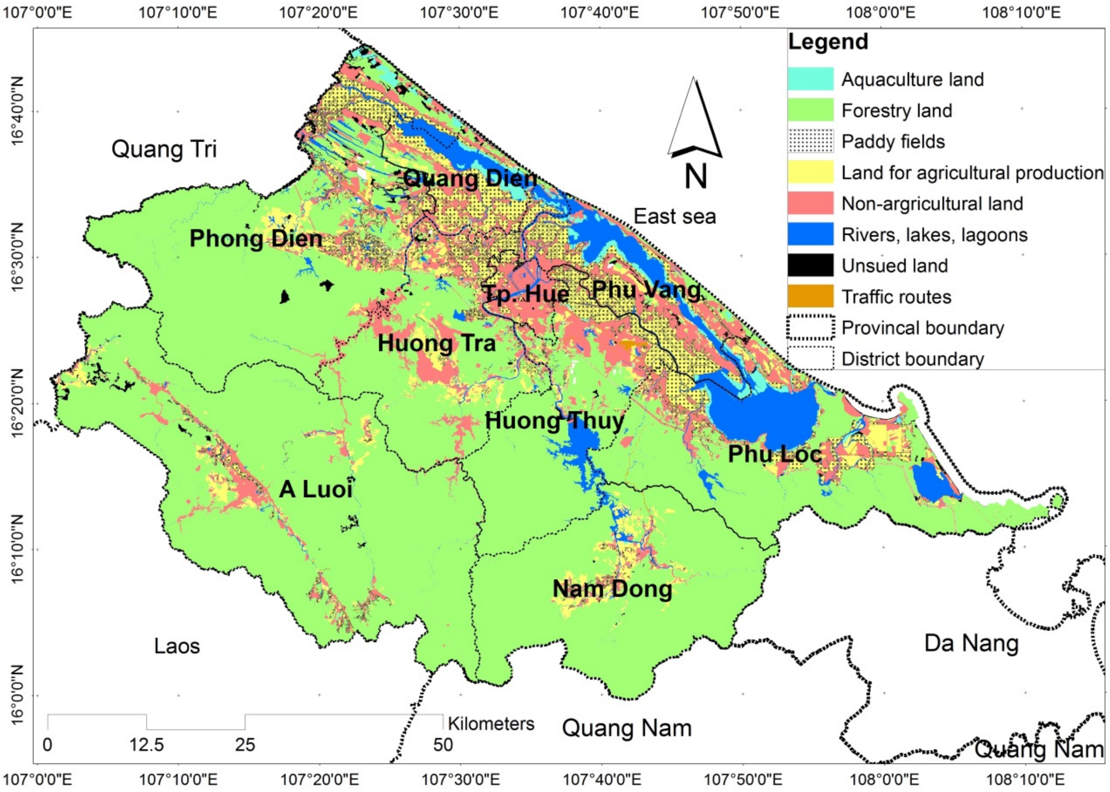

Figure 4.1.1: Land use map of Thua Thien Hue province, 2015

(The source is processed and translated from the land use map of Thua Thien-Hue province provided by the Department of Natural Resources and Environment, 2015)

For our survey, two coastal districts of Thua Thien-Hue Province – Quang Dien and Phu Vang – located adjacent to the Tam Giang Lagoon were chosen (Figure 4.1.1). Rice farming plays an essential role in agricultural production in this region, and pervades the local people's cultural life. The topography of the Quang Dien District is divided into three regions: the rice belt in the Bo River Basin, the inner sandy soil region and the coastal lagoon. The total length of the coast is 12 km and the lagoon area is 4,414 ha. Agricultural land is 5,996.6 ha while 2,368 ha is forest. Phu Vang is a coastal plain district of Thua Thien-Hue province. To the north, it is bordered by the East Sea; to the west, by Huong Tra and Hue City; to the south, by Huong Thuy Town, and to the east, by Phu Loc District. The land area is 280.83 km^2, of which 10,829.44 ha is agricultural land and 13,932.94 ha non-agricultural land; the remaining land is unused. The district has 20 administrative divisions, including 18 communes and two towns. Paddy rice is the dominant land use in the coastal plains, including Quang Dien and Phu Vang.

4.1.3 Method

This study has three major components: (1) data collection, which was divided into (i) a household survey, including rice management and yields and (ii) the measurement of salinity in affected fields; (2) the statistical analysis of salinity impacts on rice productivity and variability and (3) portfolio optimisation of rice varieties under different salinity levels. Each component is explained in the following section.

4.1.3.1 Household and rice production survey

Primary data was collected from four different coastal communes in two districts (Quang Dien and Phu Vang) by using pre-tested questionnaires to personally interview 268 farms/households. Data on rice crop cultivation (winter-spring crop and summer-autumn crop of 2016) related to inputs, rice varieties, yield, soil salinity level, etc. were collected at individual plot level (see Table 4.1.1 for details). The selection of households surveyed was based on a pre-classification of households according to whether or not their fields had been affected by soil salinity. Half of the surveyed rice-producing households were chosen randomly from the area affected by salinity, while the other half was randomly selected from non-affected households from a list provided by rice farming cooperatives. Details of the inputs used by farmers are given in Table 2.

Table 4.1.1: Commune-specific details of the sampled farms and area under rice cultivation

Districts	Communes	Number of rice farms	Total area of rice cultivation (ha)	Total number of plots	Average plot size (ha)
Phu Vang	Vinh Thai	67	27.60	211	0.13
	Vinh Ha	67	28.12	212	0.13
Quang Dien	Sia	67	30.81	226	0.14
	Quang Thai	67	29.63	224	0.13
Total		268	116.16	873	

Farmers in Vietnam are generally organised in cooperatives that take care of input purchases and product sales. They often also provide for machinery for ploughing, puddling, etc. that farmers on a rental basis. Income and expenses are then calculated once per season by the cooperative. This arrangement not only reduces the manual labour of farmers, but also leads to more uniform management of their farms. Therefore, the term “costs of machinery” in Table 4.1.2 includes costs for all mechanical equipment, including tractors, harvesting machines – fees farmers have to pay to rent machinery. Overall fertiliser application seems to be on average reasonable and close to recommended levels.

4.1.3.2 Salt level and electrical conductivity measurements

In order to measure the level of salinity at the surveyed farms, core samples of the soil were taken from composite topsoil, with sample layers of 5 cm and a subsurface layer at the depth of 20 cm. Electrical conductivity (EC) values of the soil samples were measured by the soil testing laboratory using the “EC 1:5 w/v” method. EC 1:5 is a laboratory analysis of the electrical conductivity of a solution consisting of one part air-dried soil as measured by weight (g) to five parts distilled water as measured by volume (mL), which is agitated and then allowed to settle. After sedimentation, the EC of the solution is tested (USSLS, 1969). The EC of a soil or water sample is influenced by the concentration and composition of dissolved salts, and therefore serves as a good measure of salinity. The values of EC can range from 0 to more than 16, and is classified into five salinity levels: 0-2 is considered “non-saline”, while a value of 16 or more is extremely saline (see Table 4.1.3). Salts increase the ability of a solution to conduct an electrical current, so a high EC value indicates a high salinity level. The EC measurements of the analysed samples showed that in the dry season, there were 56 plots with an EC of 2-4 dS/m (slightly saline), 45 plots had an EC range of 4-8 dS/m (moderately saline), and 53 plots had an EC of 8 dS/m to over 16 dS/m (strongly to very strongly saline). Rice plants are sensitive to EC from 4-8 dS/m, and they are highly sensitive at an EC range of 8-16 dS/m, except for some very high saline-tolerant rice varieties.

Table 4.1.2: Descriptive statistics for the factors used in the production functions

Variables		**Mean**	**Min**	**Max**	**STD.ER**
Area	Dry season	0.13	0.05	0.26	0.04
	Wet season	0.13	0.05	0.26	0.04
Yield (tonne/ha)	Dry season	5.2	3.4	6.4	0.6
	Wet season	5.5	4.0	6.6	0.5
N (kg/ha)	Dry season	164.3	100	300	34.0
	Wet season	170.6	60	270	31.5
P (kg/ha)	Dry season	354.1	150	526	72.1
	Wet season	354.1	150	518	70.8
K (kg/ha)	Dry season	116.9	60	190	21.9
	Wet season	102.8	60	160	17.5
Pesticides (number of applications)	Dry season	3.2	2	5	0.8
	Wet season	2.5	1	4	0.6
Cost of machinery (1,000 VND/ha)**	Dry season	4,845	4,600	5,200	212
	Wet season	4,652	4,400	4,800	165
Irrigation (1=applied; 0=not applied)	Dry season	0.6	0	1	0.5
	Wet season	1	1	1	0
Hired labour (1,000 VND/ha)	Dry season	2,154	0	8,100	2,445
	Wet season	2,033	0	7,800	2,327

**VND: Vietnam currency unit (1 USD = 22.740 VND)*

*** Cost of machinery includes all mechanical equipment, including tractors and harvesting machines – fees farmers have to pay to rent machinery.*

The hypothesis tested here is that salinisation induced by sea water intrusion negatively impacts the yield, and significantly increases the variability of rice production, especially in the dry season. Variability represents a production risk, which plays a vital role in farmers' decisions on input allocations and, therefore, output supply. Nevertheless, the responses are assumed to vary with respect to rice varieties. Modern rice varieties such as Xi23, X21 and a number of traditional cultivars, such as HT1, TH5 and KD18, are popular cultivars in Thua Thien-Hue. Currently, saline-tolerant rice varieties such as RVT and ML48 are being tested in some areas, yielding satisfactory results. In the study region, rice plots are small and scattered, with an average area of 0.13 ha. We also hypothesise that the small scale of production of rice farms leads to lower productivity, hindering the management capacity of farmers, resulting in farmers with scattered, smaller plots being disproportionately affected by seawater inundation. An approach based on varietal-specific production function is used in the article to validate the hypotheses. This approach is described in the data analysis section. We also calculate the gross margin for each cultivar at different salinity levels for each season to understand how salinity levels impact the economic viability of rice farming. Our third hypothesis is that the impact of salinity varies for different rice varieties and alternative varietal compositions may exist that may reduce the overall variability of production and increase yields in different salinity classes. For this reason, an attempt is made to optimise the varietal portfolio to understand its potential for reducing the impacts of salinity on rice production and its variability.

Table 4.1.3: Soil salinity classes according to the crop response to salinity

Soil salinity class	Soil salinity	Conductivity of the saturation extract (dS/m)	Effect on crop plants
1	Non-saline	0-2	Salinity effects negligible
2	Slightly saline	2-4	Yields of sensitive crops may be restricted
3	Moderately saline	4-8	Yields of many crops are restricted
4	Strongly saline	8-16	Sensitive crops yield decline drastically
5	Very strongly saline	>16	Only a few very tolerant crops yield satisfactorily

(Source: Abrol et al., 1998; FAO, 1988)

4.1.3.3 Statistical analysis

Existing studies such as those by Chen et al. (2004), Chen and Chang (2005) and Isik and Devadoss (2006), have assessed the impacts of climate factors on yield and yield variability; however, climate factors included in these studies were limited to temperature or rainfall changes. There is a dearth of studies on the assessment of the impact of salinisation on mean yields and the yield variability of field crops. Given this research gap, the first part of our analysis focuses on quantification of the impact of salinity intrusion on rice yield and variability. A stochastic production function approach (Just and Pope Function) is used here to understand how input variables, especially EC as a proxy for salinity level, have influenced rice yield and variability. As a complimentary analysis, an attempt is made to optimise the varietal portfolio to understand whether optimisation of the rice varietal mix can offset these impacts under different levels of salinisation. A portfolio of rice varieties that maximises gross margin, given a target yield variance under each salinity class, is analysed separately to achieve this goal.

Regression analysis

Just and Pope (J-P) stochastic production function specification (Just and Pope, 1978, 1979) allows for analysis of the marginal effects of the independent variables on both mean yield and variance. First, the level of yield variance is tested using a Breusch-Pagan (1980) test with a null hypothesis of homoscedasticity. This tests whether the variance of errors from a regression is dependent on the values of the independent variables. The J-P production function is intended to estimate how salinity influences the probability distribution of rice yields, and therefore yield risk. One good feature of the J-P function is that the mean is separated from variance effects of changes in the input levels. This specification enables a differentiation to be made between the impact of inputs on output and risk. It also offers sufficient flexibility to accommodate both positive and negative marginal risks with respect to inputs (Arshad et al., 2017).

The Just and Pope production function was estimated as given below.

$$\mathrm{Y_i} = \mathrm{f}\,(\mathrm{Z_i};\ \alpha) + \varepsilon_\mathrm{i} \qquad (1)$$

$$\varepsilon_\mathrm{i} = \mathrm{h}\,(\mathrm{X_i};\ \gamma) + \mathrm{E_i} \qquad (2)$$

With $\mathrm{E_i}$ expressed as $\mathrm{E_i} \sim \mathrm{N}\ (0, \sigma_v^2)$

where $\mathrm{Y_i}$ is the yield; $\mathrm{Z_i}$ and $\mathrm{X_i}$ are vectors of explanatory variables, including set of the inputs of fertilisers, pesticides, machinery, and EC levels; $\mathrm{i} = 1, 2, \ldots\ \mathrm{n}$; α and γ are the corresponding parameters of the functions.

The equation set allows agronomic inputs and the salinity variable to be related to yield level and its variance. Equation 1 is the mean yield function, ε_i is an error term and is explicit for heteroskedastic errors, allowing an estimation of variance effects. The parameter estimation of Equation (1) provides the average impact of the explanatory variables on rice yield. In Equation 2, the function explains the impact of explanatory variables, including salinity, on the variability of yields, while $\mathrm{E_i}$ is a random error term. The interpretations of the signs on the parameters of $\mathrm{h}\ (\mathrm{X_i};\ \gamma)$ are straightforward. Next, mean and variance functions were estimated (using Maximum Likelihood Estimation (MLE)) using the dataset collected for each rice variety separately in addition to the regression of the full dataset. This was done to understand the variety-wise differences in salinity impacts in terms of yield and variability. All analyses of the specified J-P function were conducted using STATA V.13.0 (Stata Corporation, College Station, Texas).

Gross margin analysis

$(P_iY_i - C_i)$ is the gross margin of farm activity, which is the difference between the gross revenue earned $(P_iY_i)$and the variable costs (C_i) incurred. Total revenue represents the volume of rice yield from the farm (e.g. physical quantity of the crop multiplied by the unit price), while the total cost is the total value of all farm inputs during a certain period of production. The gross margin for each variety at different salinity levels for each season is also calculated in an effort to broaden the understanding of the impact of salinity on the viability of rice farm enterprises in Vietnam.

Rice varietal portfolio analysis

To examine the existence of alternative rice varietal portfolios that may increase production under different salinity classes (see Table 4.1.3), an optimisation-based analysis was performed as specified below following Nalley et al. (2009). The optimisation of portfolios of cultivars under non-saline conditions was not attempted, as it falls outside of the focus of the current study.

$$Max\ \pi = \textstyle\sum_i^n x_i(P_i\, Y_i - C_i) \qquad (3)$$

Subject to

$$\textstyle\sum_i^n x_i\sigma_i^2 \leq \emptyset \qquad (4)$$

$$\textstyle\sum_i^n x_i = 1 \qquad (5)$$

$$x_i \geq 0 \qquad (6)$$

where, x_i is the area share of each rice cultivar; P_i is the price per tonne and Y_i stands for yield per hectare in tonnes; C_i represents cost of production per ha. $\emptyset$ is the observed aggregate yield variability.

This analysis was carried out for 1) Salinity Class 1; 2) Salinity Class 2; and 3) Classes 3 and 4 together. The procedure allows capturing the cultivar specific response to different salinity levels. This analytical procedure was operationalized using Excel Solver.

4.1.4 Results and discussion

Farmers in Thua Thien-Hue Province grow a number of different cultivars, with different salt tolerances and yield potentials (Table 4.1.4). The farmers prefer to cultivate traditional rice cultivars due to the favoured taste of such cultivars and their management experience. Examples include KD18, HT1 and TH5, which represent the largest share of cultivars in the study area. The cultivars X21 and Xi23 may realise high productivity in the rainy season, but they exhibit high yield declines during the dry season as a response to higher salinity conditions during that season. The shift to cultivating salt-tolerant rice cultivars, however, requires changes in crop management, such as changes in the timing of activities, and the amount and type of fertilisers. This is a major constraint to the application and propagation of salt-tolerant rice cultivars such as RVT and ML48 on salt-intruded areas.

Table 4.1.4: Characteristics of the rice cultivars found in the study region

Cultivars	Characteristics	Salt tolerance
KD 18, HT1, TH5	Traditional cultivars; short growing time; high yield	Low salt tolerance
X21, Xi23	Longer growing time; high yield	Low salt tolerance
RVT, ML48	Short growing time; high yield	High salt tolerance

4.1.4.1 Results of the Just and Pope model regression (mean yield regression)

The results (presented in Table 4.1.5) indicate that increasing salinity is a significant threat to rice farming in the study area, as one unit increase in the EC level reduces 0.23 tonnes (ranging from 0.17 tonnes in Xi23 to 0.25 tonnes in TH5) from the average rice yield. In addition, mean yield is reduced by 0.39 tonnes during the dry season compared to the wet season. These figures clearly demonstrate that seawater intrusion in coastal rice farms as a result of escalating sea levels threatens the sustainability of rice farming in the region. The sign and statistical significance of the estimated coefficients for the regressors in the mean yield function showed that the inputs of potash, pesticides, technology and irrigation variables have a significant positive effect on mean yield and thus have the potential to offset the yield impacts of salinity. The higher mean use of potash (116.9 kg/ha in the dry season versus 106.8 kg/ha in the wet season) and pesticides (3.2 applications in the dry season versus 2.5 in the wet season) despite lower yields in the dry season is indicative of such a strategy pursued by farmers.

Table 4.1.5: Cultivar-specific rice mean yield regression

Cultivar	KD		HT1		TH5		X21		Xi23		All cultivars	
Variables	**Coeff.**	**t**	**Coeff.**	**t**	**Coeff.**	**t**	**Coeff.**	**t**	**Coeff.**	**t**	**Coeff.**	**t**
Area	2.9815	8.95	2.1220	4.34	3.0526	4.91	2.3058	1.58	1.8435	0.76	3.0230	11.72
Season	-0.3700	-10.53	-0.2599	-4.79	-0.4062	-4.96	-0.5088	-3.41	-0.2667	-1.43	-0.3899	-15.06
N	0.0010	1.84	0.0021	2.22	0.0025	1.99	0.0023	0.67	0.0000		0.0007	2.01
P	0.0016	3.22	0.0011	2.92	0.0029	2.26	0.0003	0.16	0.0051	1.56	0.0002	1.22
K	0.0034	3.68	0.0032	2.71	0.0031	1.16	0.0053	0.93	-0.0034	-0.35	0.0042	7.03
Pesticide	0.0674	3.46	0.0464	1.30	0.1128	2.24	-0.1158	-1.21	0.0000		0.1113	7.45
Machinery	0.0000	2.29	0.0000	-0.55	0.0000		0.0000	2.14	0.0000		0.0000	1.24
Irrigation	0.2489	6.95	0.1073	2.10	0.2541	3.18	-0.0208	-0.14	0.0000		0.1922	7.07
Hired labour	0.0000	-2.03	0.0000	-1.18	0.0000	-1.49	0.0000	-0.79	0.0000	0.49	0.0000	-3.12
EC	-0.2464	-25.55	-0.2214	-14.68	-0.2582	-11.83	-0.1953	-6.07	-0.1720	-3.10	-0.2348	-31.29
_cons	3.4209	8.46	4.4387	8.07	2.9147	5.38	-0.4355	-0.16	3.5047	2.64	4.2307	17.91

Potassium plays a crucial role in photosynthesis, protein synthesis, the regulation of plant stomata and water use, the control of ionic balance, the activation of enzymes and many other processes (Marschner, 1995; Reddya et al., 2004; Abbasi et al., 2014). Improving salt tolerance by the addition of K has been reported in rice (Bohra and Doerffing, 1993). Plant growth and salt tolerance sharply declined when exposed to a combination of salt stress and K-deficiency stress (Wang et al., 2013). Given the positive coefficient of pesticide use, many rice farmers in the Thua Thien-Hue Province have tried to offset the yield loss from salinity using an increased number of pesticide sprays. Farmers in the study region often use mixtures of pesticides in the rice fields to both reduce the working time in the field and in an attempt to prevent several crop diseases at the same time. This practice may have more harmful effects on non-target organisms than a single application, even if the total concentration of pesticides used may be the same or even lower. Increasing salinity may prompt farmers to use more pesticide inputs and thus fall into a vicious cycle, causing larger pest-related yield losses over time and increases in pesticide use. Similar strategy of farmers to offset the impacts of salinity is reported from Bangladesh (Khanom, 2016). Further studies are needed to establish the possibility of such undesirable feedback loops. In addition, given the positive coefficient of irrigation (table 5) for KD, HT1 and TH5 varieties, providing additional irrigation during dry season can reduce the salinity levels and yield impacts. Given the size of coefficients of EC -0.2348) and Irrigation (0.1922), it is clear that providing additional irrigation can largely offset yield reduction due to one point increase in EC levels.

4.1.4.2 **Results of the Just and Pope model regression (yield variance regression)**

Table 4.1.6: Yield variance regression of cultivars response to EC

CULTIVAR	KD		HT1		TH5		X21		XI23		ALL CULTIVARS	
VARIABLES	Coeff.	t	Coeff.	t	Coeff.	t	Coeff.	t	Coeff.	t	Coeff.	t
AREA	-3.6411	-1.71	-1.2189	-0.35	-10.4537	-2.42	-8.1038	-1.06	-24.9171	-1.72	-3.4613	-2.28
SEASON	0.0927	0.41	0.3609	0.94	0.2379	0.48	1.7841	2.27	-0.8853	-0.8	0.1513	0.99
N	0.0105	3.12	0.0102	1.48	0.0007	0.1	-0.007	-0.38	0		0.003	1.4
P	0.0027	0.84	0.0061	2.21	-0.0045	-0.58	-0.0001	-0.01	-0.0431	-2.23	-0.0023	-2.25
K	-0.0026	-0.44	0.0033	0.39	0.023	1.44	-0.02	-0.68	0.0111	0.19	0.0088	2.53
PESTICIDE	0.0668	0.54	0.0109	0.04	-0.0951	-0.31	0.7851	1.56	0		0.0453	0.52
TECH	0	0.04	0	-0.42				-2.55	0		0	-2.51
IRRIGATION	-0.5131	-2.24	0.4605	1.27	-0.5506	-1.14	1.1818	1.47	0		-0.1639	-1.02
HIRED LABOUR	0	1.1	0	0.14	0	0.29	0	1.7	0	0.13	0	1.4
EC	-0.0958	-1.56	-0.0657	-0.61	0.0573	0.43	-0.2107	-1.24	-0.3945	-1.2	-0.1146	-2.59
_CONS	-5.6321	-2.18	-7.3163	-1.87	-2.6362	-0.8	29.8071	2.04	16.6341	2.11	-0.4111	-0.3

Though it was expected that increasing saltwater intrusion would intensify variability in rice cultivation, the results show that its impact is generally insignificant (see Table 4.1.6). These results point to the possibility of consistently lower rice yield levels with increase in EC levels. The significantly negative "area" variable shows that smaller scattered farms could exhibit higher yield variability levels. Higher yield variability of smaller plots can cause higher risks in production, especially if affected by salinity, which can significantly lower mean yields.

4.1.4.3 The impact of salinity on economic viability

Previous analyses confirm that productivity will decline, given increasing salinity, despite the differences in crop responses according to varietal characteristics. To understand how the impacts on production turn into economic setbacks, the results of gross margin analysis broken down by salinity classes are presented below.

Gross margin analysis

Table 4.1.7: Gross margins (GM) of cultivars in seasons 1 and 2

Season 1

Salt level	0		1		2		3		Total	
Cultivars	No of plots	Mean GM (1000 VND/ha)	No of plots	Mean GM (1000 VND/ha)	No of plots	Mean GM (1000 VND/ha)	No of plots	Mean GM (1000 VND/ha)	No of plots	Mean GM (1000 VND/ha)
HT1	161	19.827	19	18.894	15	14.644			195	19.338
KD	412	18.497	27	16.359	43	13.699	9	11.290	491	17.827
ML48		0		0	1	20.659		0	1	20.659
RVT		0		0	3	19.807		0	3	19.807
TH5	100	21.473	13	17.948	5	14.894		0	118	20.806
X21	44	19.911	5	19.487	7	16.527		0	56	19.450
Xi23	9	18.161	1	18.507		0		0	10	18.196
Total	726	19.283	65	17.691	74	14.581	9	11.290	874	18.684

Season 2

Salt level	0		2		3		4		Total	
Cultivars	No of plots	Mean GM (1000 VND/ha)	No of plots	Mean GM (1000 VND/ha)	No of plots	Mean GM (1000 VND/ha)	No of plots	Mean GM (1000 VND/ha)	No of plots	Mean GM (1000 VND/ha)
HT1	161	13.523	13	9.155	7	5.885		0	181	12.914
KD	406	11.725	29	6.652	22	4.724		0	457	11.066
ML48		0		0	4	16.476	2	15.135	6	16.029
RVT		0		0	5	16.138		0	5	16.138
TH5	100	13.366	10	7.215	3	3.033		0	113	12.547
X21	44	14.978	4	10.947	3	7.983		0	51	14.250
Xi23	9	11.994		0	1	4.762		0	10	11.271
Total	720	12.557	56	7.641	45	7.323	2	15.135	824	14.928

Table 4.1.7 presents the differences in gross margins among cultivars according to different salinity levels. The results indicate that the gross margin of all cultivars falls significantly in Season 2.

Despite the fact that KD is the most popular variety, with a majority of rice plots, this variety performed the worst in terms of gross margin in the dry season. This drop might be due to KD being the rice variety with the lowest salt tolerance. The smallest declines are observed in salt-tolerant cultivars, including RVT and Ma Lam 48 (ML48), with gross margins of approximately 16 million VND/ha, while cultivars with lower tolerance for salt ranged from about 11,000 to 14 million VND/ha (I USD = 22500 VND in 2016). Cultivars exhibited a range of changes in gross margins in response to different EC levels. Cultivars that were less salt-tolerant, including HT1, KD, TH5, X21 and Xi23, offer higher gross margins in non-saline conditions. At higher EC levels, however, the productivity of these cultivars declines sharply, leading to substantial decreases in profitability. In contrast, salt-tolerant cultivars exhibited higher gross margins under saline conditions. This implies that the improved (salt-tolerant) rice cultivars in saline conditions are more economically viable and therefore have a larger positive return on capital than the unimproved rice variety. According to Zandstra et al., (1981), new technologies that have at least 30% higher return than that of traditional technology, are more likely to be adopted by farmers. As evident from this study, in EC level 3 (4-8 dS/m) in dry crop conditions, the gross margin of the unimproved rice variety is reduced to one-third of the improved cultivars, suggesting a greater potential for adoption. Nevertheless, only a few farmers have adopted salt-tolerant cultivars, which could be due to their strong preference for traditional cultivars, or their lack of awareness of the improved salt-tolerant cultivars. More research is required in this direction, as the advantages of using salt-tolerant cultivars – especially during the dry season – are evident. If traditional cultivars with salt tolerance traits can be developed through breeding efforts, it may increase their chances of adoption among farmers.

Varietal portfolio analysis

The optimised portfolio of rice cultivars was examined using the methodology specified in section 3.3.3. In Salinity Class 1, the optimised portfolio shows an increase in gross margins of up to 20%, without any change in variability. This would require a complete shift to the X21 variety. It would also be possible to minimise variability by up to 72% using a mix of the X21 and KD cultivars. This analysis shows that it is possible that farmers may shift to these cultivars, which would offer a higher gross margin, but therefore may also undermine varietal diversity, especially under lower salinity conditions. The trade-off between variance and mean gross margin is demonstrated in Figure 4.1.2a.

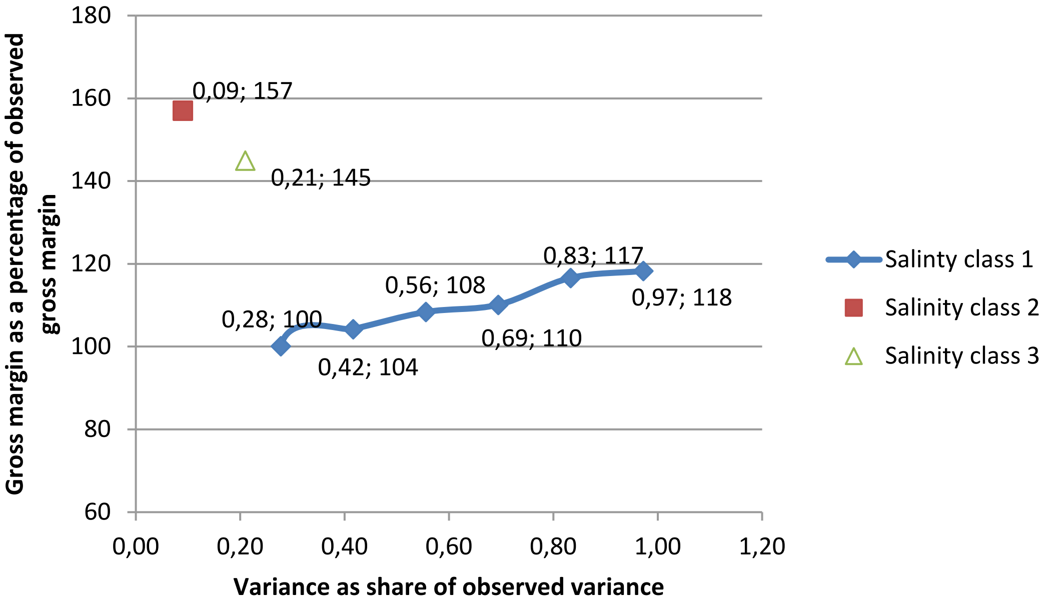

Figure 4.1.2a: Salinity Class 1: Portfolio options and trade-offs between variance and yield – all options of varietal choices show same or higher profit and always lower variance

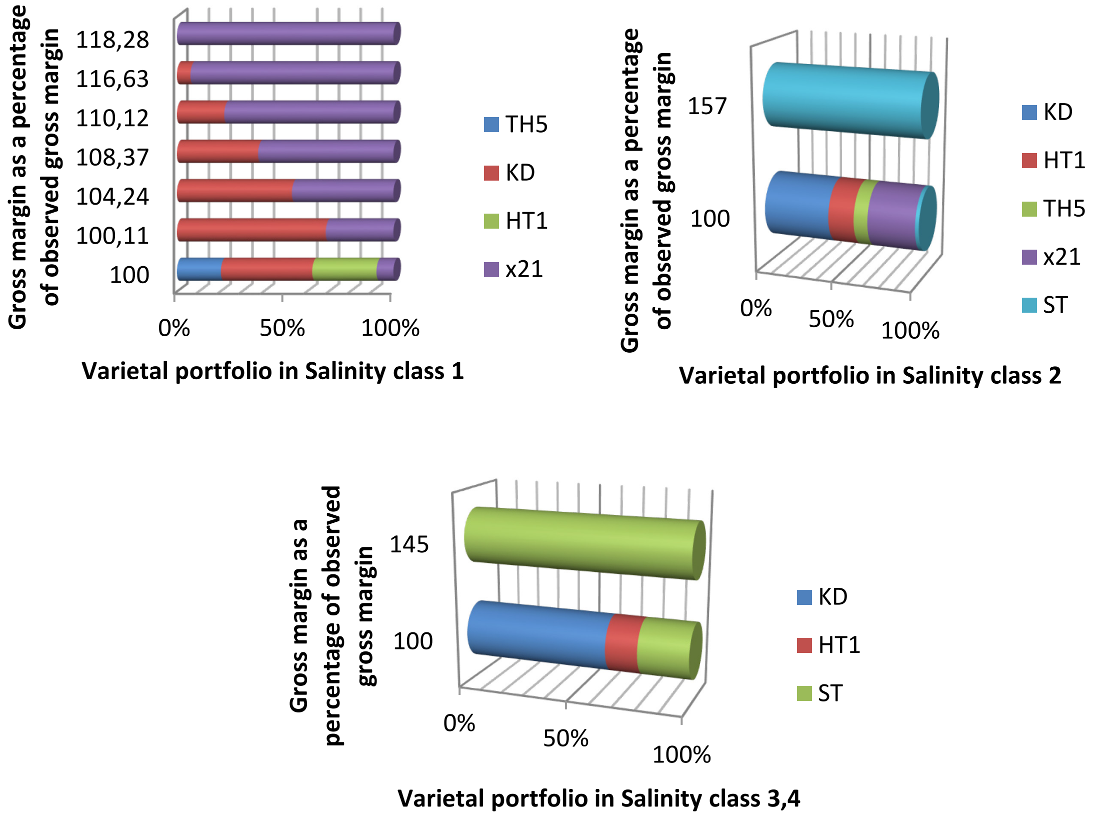

Figure 4.1.2b: Varietal portfolios and profit levels indicated in Figure 2a

In the case of Salinity Class 2, the optimised outcome shows that the varietal mix needs to consist solely of ML48 and RVT, which are salt-tolerant cultivars. Since the salt-tolerant cultivars offer lowest variability in yields, a shift to these cultivars facilitates a reduction in variability. The gross margin increases up to 50% under this changed portfolio. Salinity Classes 3 and 4 were analysed together. Here also, the portfolio would need to be ML48 and RVT, which are salt-tolerant cultivars, to maximise yields. This changed portfolio shows an improvement of gross margins by 45%, while offering a marked reduction in variability.

4.1.5 Conclusions

The results of this study offer quantitative evidence of the agricultural impacts of saline water intrusion in Vietnam in terms of productivity impacts, variance changes and gross margin shifts. In the study area, salinity (indicated by EC values) was shown to significantly impact average yields, while variability was generally unaffected; this ultimately means that yields will be consistently low under saline conditions. The results also reveal that farmers with smaller, scattered plots (which exhibit higher yield variability) are affected disproportionately, as these yields are particularly impacted by salinity intrusion. In addition, farmers may try to compensate for yield losses in saline plots by increasing the number of pesticide sprays, but this may potentially lead to a vicious cycle of pest infestation. In addition providing irrigation during dry season can partially offset the impact. Methods to consolidate plots to increase scale of production can also partially offset the impact of salinity. The gross-margin analysis shows that production impacts are indeed turning into economic impacts, but also that salt-resistant cultivars can offer significant economic gains, especially during the dry season.

Optimizing varietal portfolios as a response to salinity class shifts indicate that farmers could not only have the potential to make larger profits, but also to increase profitability without changes in production risks. These results of the portfolio analysis show that farmers could reduce yield variability to a minimum, or maximise their profit, by cultivating X21 and KD cultivars in plots with mild salinity (Salinity Class 1). In plots in higher salinity classes, the adoption of new salt-tolerant cultivars would facilitate reduced yield variability and maximise profitability. Therefore, to protect rice diversity and to protect farm livelihoods from salinity impacts, the use of locally more appropriate cultivars and the adoption of salt-tolerant cultivars could both play an important role. There is also a need to invest in research efforts to integrate salt tolerance trait to local varieties.

Due to global changes resulting in rising sea levels, rice production in the Thua Thien-Hue Province and similar coastal regions of Vietnam is threatened unless more salt-tolerant rice cultivars are developed and widely adopted. An alternate future scenario can be envisioned in which dams, salinity barriers and increased investment in irrigation systems would supply better conditions for rice farming in Vietnam. Given the large investment needs to construct and maintain these systems, varietal portfolio optimisation and introduction of salinity tolerant rice varieties are required. In areas where salinity intrusion exceeds tolerance limits of rice crops may require a planned conversion to aquaculture farming or other salt-tolerant crops (e.g. quinoa). Further research is required in this direction. It may also be possible to shift the seeding time of summer-autumn seasons and thereby avoid exposure to drought, which compounds salinity impacts. It is also possible to diversify cropping patterns. Potentially, this would entail the screening of cultivars of fruit trees, industrial trees and other food crops with good drought and salt tolerance. Moreover, there is a need to strengthen the forecasting capacity of warning systems of drought and salinity intrusion, stepping up research to find solutions to the salinisation conundrum.

4.1.6 References

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4.2 Article 2 - Paddies in saline waters: analysing variety-specific effects of saline water intrusion on the technical efficiency of rice production in Vietnam

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Abstract

The purpose of our study is to evaluate the impact of saltwater intrusion on the productivity and technical efficiency (TE) of rice farms in Central Vietnam using the stochastic frontier (SF) production function. In contrast to existing studies, this research quantitatively analyses rice variety and season differentiated impact of soil salinity (as measured by electrical conductivity (EC)) on the technical efficiency of rice production. The empirical results indicate that salinity has significantly varying negative impacts on rice yield and technical inefficiency of rice farms depending on the salinity class, variety planted and the season. Technical efficiency begins to sharply decline after reaching salinity class 3 (EC=4-8dS/m) and drops to zero under salinity class 4 (EC=8-16dS/m) unless salt-tolerant (ST) varieties are planted. A one per cent increase in the EC level decreases rice yields by 0.24% in various SF models, while TE shows a cubic relationship with EC, with negative coefficients for linear and quadratic terms. A combination of farm plots consolidation, irrigation, input use and shifts in varietal selection can potentially offset the yield decline caused by saline intrusion for Salinity Classes 1 to 4, while adoption of salt-tolerant varieties seems to be the best option for higher salinity classes over 4. Such adaptation measures could also help farmers to avoid maladaptive options such as increased use of pesticide sprays to offset the yield losses due to soil salinity resulting from saline water intrusion. The insights offered by the study can be applicable to coastal delta regions cultivating rice in whole of Asia and in other continents.

4.2.1 Introduction

Saline water intrusion (Pedroso et al., 2018), which is a significant threat to rice production in Asian deltas (Pedroso et al., 2017), has major regional and global food security implications (Khong et al., 2018). The increasing salinity of coastal deltas can be attributed in part to the rising of sea levels and the increasing frequency of drought events as a result of global climate change (Wassmann et al., 2004; Seal and Baten, 2012). Salinisation in delta regions of Vietnam, a key rice-exporting nation (Vietnam's exports represented 9.5% of the entire world’s rice exports in 2017 (ITC, 2018)), is a prominent example. At least 75% of poor households and 48% of non-poor households (Bingxin et al., 2010) in rural Vietnam depend on rice farming as their primary source of income, and therefore an increase in soil salinity which would impede rice production could have broader economic and social implications. In the 2015-2016 cropping year, a year of strong El Niño phenomena, the dryland rice crop in the Mekong Delta of Vietnam suffered extensive damage due to salinity intrusion (resulting in a significant loss of production in 11 out of 13 provinces in the Mekong Region), causing hardship for two million people (Khong et al., 2018). It is important to note that salinity intrusion significantly affected rice production in other coastal areas as well, including the Red River Delta (1.5 to 11.2% of the area) and areas of Central Vietnam (Tam Giang Lagoon) (Linh et al., 2012; Tran and Shaw, 2007), though these received less attention in the literature. If the projections regarding possible sea-level rises materialise by the 2050s, the resulting salinisation could trigger large-scale migration out of the delta regions of the country (Kim and Le Minh, 2016), especially if the condition combines with more frequent drought events.

Given the strong relationship between rice production and food security in the region, any major threat to the efficiency of rice production is of interest to economists and policymakers in Asia (Richard et al., 2007). Academics and policymakers have increasingly recognised that preserving or enhancing the efficiency of agricultural production may contribute to regional political stability and could prevent large-scale migration (Warner and Afifi, 2013). Although the spread of salinity-affected areas is a major threat to rice (Oryza sativa L.) production, only a handful of studies have attempted to quantify its effect on the efficiency of production in Vietnam (Tran, 2002; Hien, 2003; Linh, 2007 and Khong et al., 2018). In addition, no studies have attempted to differentiate the impacts according to the variety of rice; this article attempts to address this research void.

Technical efficiency – the ability of a farm unit to produce a unit of output from a bundle of inputs relative to other farm units in the group – is one component of economic efficiency (Lau and Yotopoulus, 1971; Watkins et al., 2013). A farmer is technically efficient if the farm unit uses the least amount of input (input minimisation) to produce a unit of output or produces the maximum amount of output from a given amount of inputs (output maximisation). The two competing models for determining efficiency at the farm household level are 1) the Stochastic Production Frontier Model (SPF) (Tzouvelekas et al., 2001; Wadud and White, 2000; Sharma et al., 1999; Battesse and Coelli, 1995; Pedroso et al., 2018) and 2) Data Envelopment analysis (DEA) (Coelli et al., 2002; Rios and Shively, 2005; Bravo-Ureta et al., 2007). This study uses the Stochastic Production Frontier Model to discover the impact of salinity on rice production, using a case study in Central Vietnam. An existing study (Pedroso et al., 2018) that took an SFA (Stochastic Frontier Analysis) approach to estimate technical efficiency (of rice production) in Central Vietnam used a proxy-variable approach, i.e. the operation time of irrigation pumps to represent the amount of salinity. Our study utilises laboratory-measured values of the electrical conductivity (EC) of soil samples to represent the salt content and are therefore scientifically more robust than the previous approach. With the exception of the study by Pedroso et al., (2018), most previous studies (Kompas et al., 2012; Khai and Yabe, 2011) that attempted to estimate the technical efficiency of rice farming in the delta regions of Vietnam omitted the crucial variable of soil salinity (Pedroso et al., 2018) altogether.

The objective of this study is to estimate the effect of salinisation on variety-specific rice production and subsequently determine its technical efficiency, using Central Vietnam, specifically Thua Thien-Hue Province, as a case study region.

4.2.2 Materials and methods

4.2.2.1 The study area

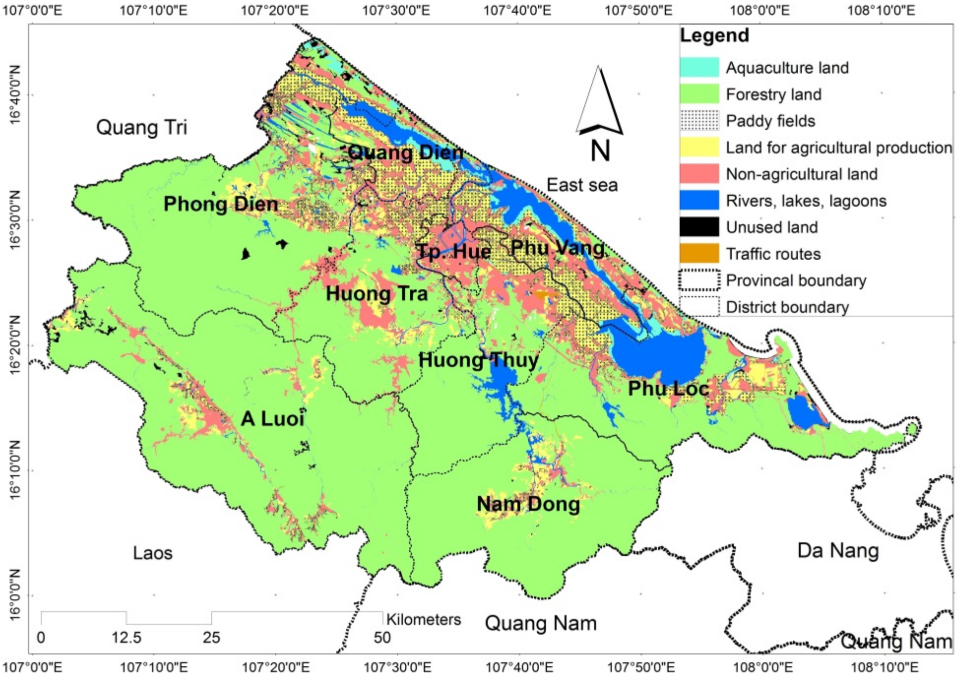

Figure 4.2.1: Land use map of Thua Thien-Hue Province, 2015

(This map has been processed and translated from an original land use map of Thua Thien-Hue Province created by the Department of Natural Resources and Environment, Vietnam, 2015)

Thua Thien-Hue is a coastal province in the central region of Vietnam, situated around Tam Giang Lagoon (the largest lagoon in Southeast Asia, with an area of approx. 22,000 ha); it is characterised by a long coastline and a narrow delta (Dan et al., 2006). The rice-growing area of the province is largely concentrated in low-lying plains (the districts of Phong Dien, Quang Dien, Huong Tra, Phu Vang and Huong Thuy). In the dry period from May to August, saltwater intrusion affects lowland rice farming along the Huong and Bo rivers, and has negatively affected rural livelihoods. Saltwater has intruded up the Huong River to 30 km from the coastline. This region is located at an elevation from between -0.5 m and +3.0 m above sea level. Due to the rise in sea levels and increased saltwater intrusion, a dyke system (approx. +0.5 m high) has been constructed adjacent to the Thuan An and Tu Hien estuaries of the Tam Giang-Cau Hai Lagoon. The projected rise in sea levels could exacerbate saltwater intrusion into paddy lands, posing a significant threat to rice production and to food security. Raising the dykes is necessary to reduce the damage, but a lack of public funds could prevent such construction (Khong et al., 2018).

4.2.2.2 The data

We collected primary data from farmers in two coastal districts of Thua Thien-Hue – Quang Dien and Phu Vang – located adjacent to the Tam Giang Lagoon (Figure 1). The Quang Dien District is divided into four regions: 5,996.6 ha of rice farming area in the Bo River Basin, a 12 km long region of sandy soil, a 4,414 ha coastal lagoon and 2,368 ha of forest. Phu Vang is a coastal plain district of Thua Thien-Hue Province located near Hue City with 10,829.44 ha of agricultural land and 13,932.94 ha of non-agricultural land. Paddy rice (denoted as "agriculture" in the land use map shown in Figure 4.2.1) is the dominant land use in the coastal plains, including in Quang Dien and Phu Vang. Rice farming plays an essential role in agricultural production in this region, and is the core of the local people's cultural life. The Vinh Thai and Vinh Ha communes of Phu Vang, and the Sia and Quang Thai communes of Quang Dien were selected as areas characterised by their amount of saltwater intrusion.

The data related to rice varieties, input, yield, soil salinity class, etc. (see Table 4.2.1 for details) was collected from 268 rice-farming households (winter-spring and summer-autumn crops of 2016). Each farmer cultivated multiple land parcels, and therefore data on 873 rice plots was used in the study. Half of the rice-producing households surveyed were chosen randomly from the salinity-affected area, while the other half of was randomly selected from non-affected households, from a list of farmers provided by cooperatives.

Table 4.2.1: The sampling frame

Districts	Communes	Number of rice farms	Total area of rice cultivation (ha)	Total number of plots	Average plot size (ha)
Phu Vang	Vinh Thai	67	27.60	211	0.13
	Vinh Ha	67	28.12	212	0.13
Quang Dien	Sia	67	30.81	226	0.14
	Quang Thai	67	29.63	224	0.13
Total		268	116.16	873	

4.2.2.3 Salt levels and electrical conductivity measurements

The presence of salts enhances the ability of a solution to conduct an electrical current, and therefore high electrical conductivity (EC) values indicate high salinity levels. The values of EC can range from 0 to more than 16, and are classified into five Salinity Classes: 0-2 is considered "non-saline", while a value of 16 or more is extremely saline (see Table 4.2.2). In order to measure the amount of salinity at the farms under study, core samples of the soil were taken from composite topsoil, with sample layers of 5 cm and a subsurface layer at a depth of 20 cm. EC values of the soil samples were measured at a soil testing laboratory using the "EC 1:5 w/v" method. This method measures the EC of a solution consisting of one part air-dried soil as measured by weight (g) to five parts distilled water as measured by volume (mL), which is agitated and then allowed to settle. The EC measurements of the samples analysed showed that in the dry season, there were 56 plots with an EC of 2-4 dS/m (slightly saline), 45 plots had an EC range of 4-8 dS/m (moderately saline), and 53 plots had an EC of 8 dS/m to more than 16 dS/m (strongly to very strongly saline). Rice plants are sensitive to soil with an EC from 4-8 dS/m, and are highly sensitive in the EC range of 8-16 dS/m, except for some extremely salt-tolerant rice varieties.

Table 4.2.2: Soil salinity classes according to the crop response to salinity, measured as conductivity of the saturation extract

Salinity class	Soil salinity	Conductivity (dS/m)	Effect on crop plants
1	Non-saline	0-2	Salinity effects negligible
2	Slightly saline	2-4	Yields of sensitive crops may be restricted
3	Moderately saline	4-8	Yields of many crops are restricted
4	Strongly saline	8-16	Only tolerant crops produce satisfactory yields
5	Very strongly saline	>16	Only a few very tolerant crops produce satisfactory yields

(Source: Abrol et al., 1998; FAO, 1988)

Our hypothesis is that soil salinisation induced by seawater intrusion reduces the technical efficiency (TE) of rice farming, especially in the dry season. Given the results of previous studies, we also hypothesis that the small scale of production of rice farms affects TE as well, as it hinders farmers' management capacity. This could mean that farmers with fragmented smaller plots are disproportionately affected by seawater intrusion. Since our focus is on salinity intrusion, we did not conduct a second-stage regression analysis of the factors affecting the efficiency of rice farms. Instead, we focused on further understanding the general pattern of the salinity-efficiency relationship and how different classes of salinity affect the technical efficiency of paddy production. We expect this to shed further light on possibilities of adaptation, especially by changing current rice varieties to salt-tolerant ones.

4.2.2.4 The analytical framework

Technical efficiency is concerned with the relative performance of the process used in transforming input(s) into output(s) (Kea et al., 2016). By defining TE this way, the efficiency of any given farm plot is a relative measure to the other farm plots in the sample set. The stochastic frontier model, which considers random variability, is an extension of original deterministic versions that considered any deviation from the frontier as inefficiency. In case of SFA, the error term consists of random and efficiency components (Mango et al., 2015). The SF model (SPF) to estimate TE presented below uses the Cobb-Douglas production function to model rice farming,

$$\mathrm{Ln}\ (\mathrm{Z_i}) = \theta_0 + \textstyle\sum_{\mathrm{i}}^{\mathrm{n}} \theta_{\mathrm{i}} \mathrm{Ln}\ \mathrm{X_i} + \mathrm{d_i D_{ij}} + \varepsilon_{\mathrm{i}}\ , \qquad (1)$$

$\theta_0 + \sum_{\mathrm{i}}^{\mathrm{n}} \theta_{\mathrm{i}} \mathrm{Ln}\ \mathrm{X_i} + \mathrm{d_i D_{ij}}$ forms the deterministic part of the function

Where:

$\mathrm{Z_i}$ is the rice productivity of the $\mathrm{i^{th}}$ household $\mathrm{X_i}$: input factors include land area of rice plot (hectares); N, P and K fertilisers; pesticides; machinery; irrigation; hired labour; seasonal changes; EC (as a proxy for salinity effect); Ln stands for natural logarithmic transformation.

$\theta_\mathrm{i}, \mathrm{d_i}$: vectors of unknown parameters to be estimated

$\mathrm{D_{ij}}$: dummy variables where i represents different rice varieties, j has the value "1" or "0".

If coefficients $\theta_i$and $\mathrm{d_i}$> 0, this means that an increase in inputs is expected to increase rice production.

ε_i is the error term, which is assumed to consist of statistical noise $(\mathrm{v_i})$ and inefficiency $(\mathrm{u_i})$

$$\varepsilon_\mathrm{i} = \mathrm{v_i} - \mathrm{u_i} \qquad (2)$$

(u_i) technical inefficiency effects in the model where $\mathrm{u_i} \geq 0$ and $\mathrm{i} = 1, 2, \dots, \mathrm{n}$.

In other words, a zero value of $\mathrm{u_i}$ implies that the farm is completely efficient, while a high value of $\mathrm{u_i}$ implies a high degree of technical inefficiency. For v_i, a normal distribution with zero mean (N $(0, \sigma_\mathrm{v}^2)$;) is assumed. The error term $\mathrm{u_i}$ captures inefficiency; it is distributed independently of $\mathrm{v_i}$ (exponential and half-normal distributions are tested), and satisfies the condition of $\mathrm{u_i} \geq 0$.

The TE of the $\mathrm{i^{th}}$ household $(\mathrm{TE_i})$ is

$$TE_i = \exp(-\mathrm{u_i}) \qquad (3)$$

The TE scores are scaled between 0 and 100 in this study, where scores below 100 show inefficient production. The $\theta_\mathrm{i}, \mathrm{d_i}$ parameters and the efficiency scores ($\mathrm{TE_i}$) were calculated using the Frontier Package of Stata 13.0. Subsequently, efficiency score of the rice farmers is modelled as a function of EC and cultivars in addition to farm inputs.

4.2.3 Results

4.2.3.1 Descriptive statistics

a. Characteristics of different rice cultivars

The general characteristics of different rice cultivars used by farmers in the study area are given in Table 4.2.3. Farmers grow traditional varieties with short growing seasons, such as KD18, HT1 and TH5; other varieties such as X21, Xi23 with a longer growing season; and salt-tolerant varieties, such as RVT and ML48.

Table 4.2.3: Characteristics of different kinds of rice cultivars used by farmers in study area

Rice cultivars	Characteristics	Salt tolerance
KD18, HT1, TH5	Traditional cultivars; short growing time; high yield	Low salt tolerance
X21, Xi23	Longer growing time; high yield	Low salt tolerance
RVT, ML48	Short growing time; high yield	High salt tolerance

b. Descriptive statistics of the inputs

Table 4.2.4: Descriptive statistics for the inputs used among the sampled farmers

Variables		Mean	Min	Max	STD.ER
Area (plot)	Dry season	0.13	0.05	0.26	0.04
	Wet season	0.13	0.05	0.26	0.04
Yield (tonne/ha)	Dry season	5.2	3.4	6.4	0.6
	Wet season	5.5	4.0	6.6	0.5
N (kg/ha)	Dry season	164.3	100	300	34.0
	Wet season	170.6	60	270	31.5
P (kg/ha)	Dry season	354.1	150	526	72.1
	Wet season	354.1	150	518	70.8
K (kg/ha)	Dry season	116.9	60	190	21.9
	Wet season	102.8	60	160	17.5
Pesticides (number of applications)	Dry season	3.2	2	5	0.8
	Wet season	2.5	1	4	0.6
Costs of machine use **(1,000 VND/ha)	Dry season	4,845	4,600	5,200	212
	Wet season	4,652	4,400	4,800	165
Irrigation (1=applied; 0=not applied)	Dry season	0.6	0	1	0.5
	Wet season	1	1	1	0
Hired labour *(1,000 VND/ha)	Dry season	2,154	0	8,100	2,445
	Wet season	2,033	0	7,800	2,327

** VND: Vietnamese Dong (1 USD = 23.240 VND)*

*** Costs of machine use include all mechanical equipment, including tractors and harvesting machines – fees farmers have to pay to rent machinery.*

The details of the inputs used by rice farmers are given in Table 4.2.4. Farmers in Vietnam generally organise into cooperatives for input purchases and product sales. Cooperatives provide machinery for ploughing, puddling, etc. on a rental basis to farmers. Income and expenses are then calculated once per season by the cooperative. This arrangement leads to more uniform management of the farms and reduces the farmers' manual labour. Therefore, the term "costs of machine use" in Table 4 includes rental costs for all mechanical equipment, including tractors and harvesting machines. Fertiliser application is found to be close to recommended levels for the region.

4.2.3.2 Stochastic frontier regression results

Two SFA model variants were calculated here: Model 1 with half-normal distribution assumptions and Model 2 with exponential error distributional assumptions, as described in the methodology above. The results are shown in Table 4.2.5.

Table 4.2.5: Stochastic frontier regression results

Yield	Model 1: Half-normal		Model 2: Exponential	
	Coef.	**t-value**	**Coef.**	**t-value**
Area	2.3740	11.20	2.1757	11.26
N	0.0018	4.76	0.0018	5.21
P	0.0018	7.37	0.0019	8.63
K	0.0032	5.65	0.0032	6.34
Pesticide	0.0830	6.10	0.0768	6.14
EC	-0.2391	-38.20	-0.2465	-43.20
Machinery	9.23 e-08	2.02	7.03 e-08	1.68
Irrigation	0.1669	7.35	0.1705	8.07
Hired labour	-9.63 e-	-2.99	-7.67 e-09	-2.58
Season	09	-14.87	-0.3166	-15.57
HT1	-0.3296	-7.00	-0.1464	-8.18
TH5	-0.1388	-6.70	-0.3207	-7.45
Xi23	-0.3127	-6.95	-0.5267	-7.72
X21	-0.5200	6.04	0.2908	7.09
Salt-tolerant	0.2682	10.56	1.0133	11.53
variety	0.9434	16.18	3.9948	17.55
_cons	4.0104			
Sigma_u	0.5217	37.36	0.3037	26.75
Sigma_v	0.1676	21.22	0.1870	28.25
Lambda	3.1127	164.34	1.6244	106.54

If λ (lambda) = 0 (see Table 5), this implies that there is no significant technical inefficiency, and all deviations from the frontier are due to random variation or noise (Aigner et al. 1977). Table 4.2.5 shows that estimated values of λ of both models are significantly different from zero, suggesting the existence of inefficiency among rice farmers. Figure 2 shows the distribution (kernel density plot) of efficiency scores; most farmers fall in the range of 70% to 90% efficiency levels, with an average TE of 87%.

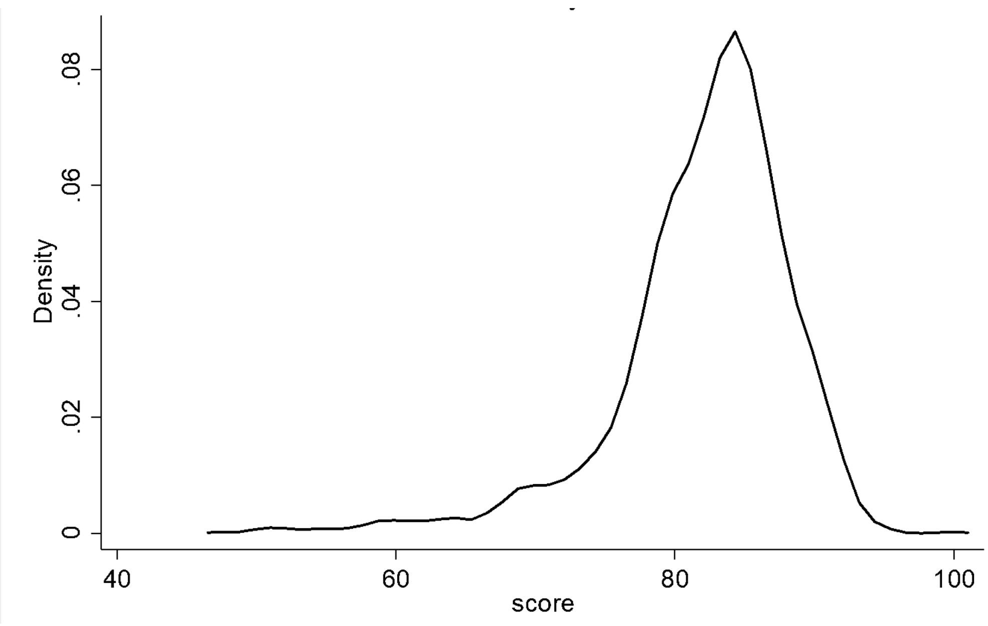

Figure 4.2.2: Distribution of technical efficiency scores

(Source: Authors' calculations)

To examine the impact of salinity on the technical efficiency of farmers, we calculated TE scores based on salinity classes. These results are presented in Table 4.2.6.

Table 4.2.6: Efficiency score response to salinity amounts in both seasons

EC (dS/m)	No. of plots	Status	Type of varieties farmers use	Average yield (tonne/ha)	Max TE	Min TE	Average TE (%)
0-2 (Class 1)	65	Rice cultivation	Traditional varieties	5.3	92.1	75.9	84.9
2-4 (Class 2)	130	Rice cultivation	Traditional varieties	4.6	90.0	68.5	78.7
4-8 (Class 3)	54	Rice cultivation	42 plots using traditional varieties, 8 plots using salt-tolerant varieties	4.1	80.9	58.6	68.3
8-16 (Class 4)	28	Rice cultivation (3 plots); abandoned (25 plots)	Salt-tolerant varieties	4.3	65.2	60.4	63.0*
>16 (Class 5)	25	Abandoned	-				-

** This TE result was only derived from the three rice plots that were cultivated*

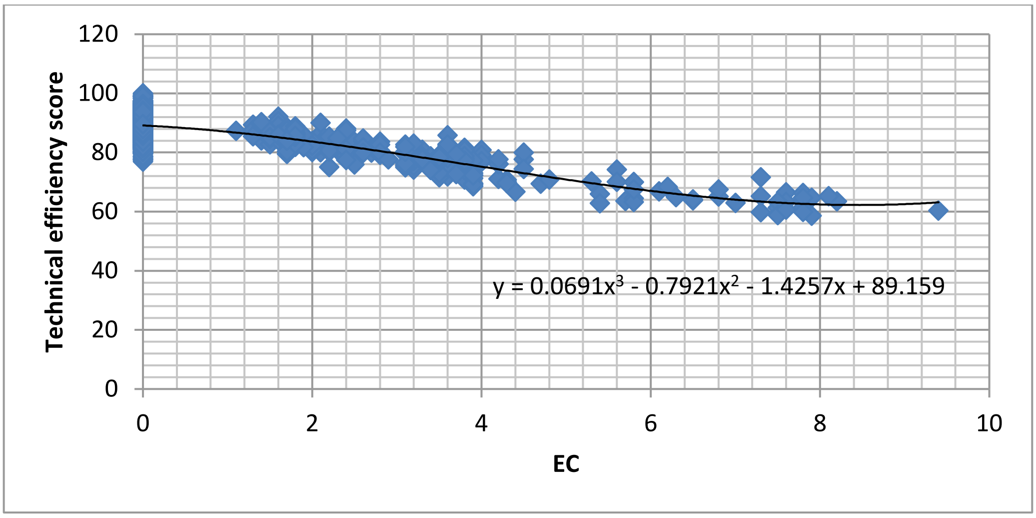

Figure 4.2.3: Relationship between TE and EC

To further understand the negative relationship between EC and TE, the variables were plotted graphically, and a best-fit equation ($y = 0.0691x^3 - 0.7921x^2 - 1.4257x + 89.159$) was derived (Figure 4.2.3). Here, x represents the EC value. The trend lines of the technical efficiency score show a significant decline of TE between EC values of 0 and 8, with a levelling off after 8. The apparent subsiding of the TE decline in Figure 4.2.3 is due to the use of ST varieties in soil with Salinity Class 4 (EC from 8-10 dS/m); otherwise, TE would have dropped to zero.

Table 4.2.7: Efficiency score response according to different varieties

TE rating (%)		**<70**	**70-80**	**80-90**	**90-100**	**Total**
KD	No. of plots	18	59	532	340	949
	Average yield	3.9	4.5	5.3	5.8	5.4
HT1	No. of plots	6	30	208	132	376
	Average yield	3.9	4.5	5.2	5.6	5.3
TH5	No. of plots	2	12	77	140	231
	Average yield	3.5	4.2	5.1	5.8	5.5
X21	No. of plots	4	16	80	7	107
	Average yield	3.9	4.8	5.2	5.6	5.1
Xi23	No. of plots	1	-	10	9	20
	Average yield	3.6	-	4.9	5.2	5.0
ST varieties	No. of plots	7	-	3	1	11
	Average yield	4.8	-	5.1	5.4	4.9
Total	No. of plots	42	117	910	629	1698
	Average yield	3.9	4.5	5.1	5.4	5.1

**Unit of average yield: tonne/ha*

In the next stage, we divided the TE scores into four classes: <70%, 70-80%, 80-90% and 90-100%, and checked how yield levels of each variety corroborate with TE levels. Table 4.2.7 shows that yield levels predominantly determined efficiency levels, and the varieties performed differently within each TE class.

4.2.4 Discussion

4.2.4.1 Discussion

a. The role of inputs and different varieties in regression models

The interaction of salinity, season and input use in rice production were clearly revealed in the stochastic frontier regression results. Under both the half-normal and the exponential model variants, the coefficient of EC value representing salinity is negative and significant. A one per cent increase in the EC level (soil salinity) decreases rice yield by 0.24% in both models. The area of rice plots is a positive and significant factor, showing the potential for increasing production by consolidating farm plots and therefore tapping into the advantage of scale. In the case of fertilisers, the positive coefficient indicates that their increased use could enhance output levels. The yield losses due to increasing salinity has forced many farmers in the region to compensate by reducing the losses inflicted by pests and disease, and the coefficients of potash fertilisers and pesticides show that such a strategy may work, at least for the short term. The larger coefficient for K fertiliser represents the fact that there has been a need to increase its application to balance N and P fertiliser use. Machinery use shows a positive impact, while manual labour shows a negative relationship; this finding can be interpreted as indicating that more mechanisation and a reduction in manual labour can positively impact the technical efficiency of rice farming. It is also clear that the season affects production, irrespective of input levels, with a 0.3% reduction in the dry season compared to the wet season, even after accounting for salinity and irrigation differences. Irrigation may offset the salinity impacts, and it ensures an adequate water supply for transporting nutrients to different parts of the rice plant. The results show that increasing irrigation can partly offset the impact of salinity, and thus increase yield levels. In summary, a combination of plot consolidation, irrigation and the use of other inputs can potentially offset the yield decline caused by saline intrusion for at least Salinity Classes 1 to 4.

The results of the varietal variables are also interesting. It is important to note that the coefficients should be interpreted in relation to the KD18 variety, the effect of which is captured in the intercept. The coefficients of HT1, TH5 and Xi23 were negative, showing their lower performance compared to the KD18 variety under various salinity levels. However, X21 and the salt-tolerant varieties showed a positive coefficient, indicating superior performance compared to KD18. The use of X21 would produce 0.27% higher rice yield compared to KD18. The significant and positive coefficient (0.9434) affirms the ability of salt-tolerant varieties to enhance rice yield, especially in saline conditions, compared to other varieties. The ST varieties are useful in offsetting the impacts of EC.

b. The impacts of EC on technical efficiency

As Table 4.2.6 shows, average TE decreased from 84.9% to 68.3% between Salinity Class 1 and Salinity Class 3. In Class 4, only salt-tolerant varieties were cultivated, with a 63% TE. The results prove our hypothesis on the negative and significant effect of salinity on the TE of rice farming. Out of the 28 plots reporting Class 4 salinity, traditional rice varieties did not germinate at all in 25 plots, and farmers replanted these plots up to three times with unsuitable traditional rice varieties before abandoning cultivation altogether. In contrast, the ST varieties managed an average TE of 63% in plots with a similar salinity class, unlike traditional varieties. This shows the potential for ST varieties in enhancing rice output in salinity-affected areas of Thua Thien-Hue Province specifically, and in Vietnam in general. Even in the case of Salinity Classes 1, 2 and 3, the wide gap between the maximum TE of 92.1, 90.0 and 80.9 and the average TE of 84.9, 78.7 and 68.3, respectively, indicate that there is significant potential to increase TE by changing varieties and changing the use of inputs, including irrigation practices. Major hurdles to attain the efficiency gains include the strong preference and familiarity of local rice varieties; inadequate awareness of salt-tolerant varieties that have good yield performance as well as higher grain quality; and low awareness among farmers of the level of salinity at their different plots. In addition, the fragmented nature of rice plots with salinity issues also affects the wider adoption of ST varieties.

c. Variety-specific technical efficiency

Among varieties represented in Table 4.2.7, KD was clearly the dominant variety with respect to the number of plots, as well as higher yields and higher efficiency scores. In reality, the majority of farmers planted KD on plots that had a better soil quality, with lower levels of salinisation. This shows that Vietnam farmers prefer higher yields of KD, even though the quality is not on a par with other varieties. Out of a total of 949 KD plots, 872 KD plots had an efficiency score of more than 80%, with the mean yield ranging from 5.3 to 5.8 tonnes/ha. HT1 showed the same tendency as KD with fewer plots in each TE level group. There were 140 TH5 plots out of a total of 231 that were classified as TE >90%, while X21 only had 7 plots out of a total of 107. 19 plots out of a total of 20 where Xi23 was planted had a TE of over 80%, though the cultivation of this variety might not be popular because it produces lower yields than other traditional varieties. These traditional varieties, however, had lower yields and lower TE in rice plots with medium levels of salinity. In lower efficiency classes, especially due to higher salinity, salt-tolerant varieties showed significant yield gains. The gains in TE may, however, not indicate economic gains, as we did not include input costs in this analysis.

The results also indicate the positive performance of ST varieties; four plots out of a total of 11 presented have a TE >80% with an average yield of between 5.1 and 5.4 tonnes/ha. The remaining seven saline plots have a TE <70% with an average yield of 4.8 tonnes/ha, which was nevertheless significantly higher than yields of other varieties. Note again that the 11 rice plots that used ST varieties were cultivated in plots with Salinity Classes of 3 and 4 (>4 dS/m), where traditional varieties failed to grow. Therefore, ST cultivars improved TE in plots of medium Salinity Classes, and created higher TE in highly saline plots. This also indicates the existence of potential increases in the rice production efficiency of Thua Thien-Hue farmers by adopting ST varieties in rice production, especially under conditions of higher levels of salinity expected in the future.

4.2.4.2 Advanced knowledge compare to other studies

Our results estimates an average TE of 87%, which is higher than the national average of 81.6% presented by Khai and Yabe (2011) and the national averages of 77.5% and 63.4% presented by Kompas et al. (2012) and Linh (2012). Our TE is also higher than Pedroso et al. (2018) (TE 81%) which presents TE estimates for the rice farming in Central Vietnam. Nationally, Kompas et al. (2012) found that farm size and average plot size had a positive effect on TE and Linh (2012) found that large farms were more efficient than others smaller, and also the land/labor ratio impact on TE positively affirming the findings of the current study. In case of central Vietnam, TE in Pedroso et al. (2018) is found to be predominantly impacted by the scale of production, fragmentation and salinity factors. Further evidence of salinity to TE is presented in Dhehibi et al. (2015). Nevertheless there is only limited research works that considered environmental factors in rice production efficiency estimation viz. Sarker et al. (2012a), Basak et al. (2010), Hossain et al. (2013), Mishra et al. (2018). Our results support the fact that the non-consideration of environmental heterogeneous production conditions leads not only to omitted variables bias, but also to downward biased estimates of TE (Rahman and Hasan, 2008, Sherlund et al., 2002). It is worth to note that, technical efficiency is assumed as the ability of a farm to achieve the highest possible production given the level of inputs, environmental conditions (EC) and cultivars performance in the current study. While recent studies such as Mishra et al. (2005), Dhehibi et al. (2015), Mishra et al. (2018), Pedroso et al. (2018) have not considered the differential effect of salinity impacts according to the varieties on rice planted by the farmers.

To enhance productivity and technical efficiency of rice production in major rice producing countries of Asia influenced by abiotic stress factors, breeding rice varieties have been identified as the most promising, less resource-consuming, and economically viable strategy. Our study shows the benefits of breeding locally acceptable rice varieties with specific trait of salinity tolerance (Thomson et al., 2010). Mishra et al. (2015) recommends a greater investment in developing and disseminating rice varieties tolerant to abiotic stresses including salinity problems that significantly reduce rice productivity and thus technical efficiency of poor rice farmers in Bangladesh. Naklang et al. (2006) showed that some rice varieties in Thailand have higher potential yield when optimal water and nutrient management are practiced. Our study suggests possible productivity and TE enhancement by changing rice varieties and adopting salt-tolerant cultivar depending on salinity class. In other words, our analysis shows the need of further research and development of rice cultivars with soil salinity trait that are acceptable to local palates, given the future threat of increased salinity.

A very few studies concerning the technical efficiency of rice production in Central Vietnam are found that excludes the possibility of comparing our results and gaining further insights. Most of the TE studies in rice production undertaken so far for Vietnam concentrate predominantly on the Red River Delta (RRD) and the Vietnamese Mekong River Delta (MRD) or the whole country and using Stochastic Frontier Analysis (SFA) or Data Envelopment

Analysis (DEA) (Pedroso et al., 2018). Our study has taken a step forward in advanced efficiency studies in coastal central Vietnam, by presenting explicit TE results as the model considering actual salinity levels (measured using laboratory based analysis) and the rice varietal performance. It also shows that consolidation of farm plots, additional irrigation and increased pest management can partly offset the soil salinity impacts though increased spraying of pesticides can lead to increased pest damages in future. Developing appropriate strategies of farm consolidation, irrigation facilities and pest management can also enhance the efficiency of the farmers.

4.2.5 Summary and conclusions

The application of a stochastic frontier production function to explore the technical efficiency of rice farming under increasing salinity levels in Central Vietnam (Thua Thien-Hue) provides a nuanced estimate of the impact of salinity, as the model considers actual EC values measured using laboratory-based analysis and includes considers the rice variety specific impacts. The study used detailed plot-level data (873 plots) from 268 households for two seasons was collected by personal interviews using structured questionnaires. It should be noted that most of the previous studies focused or Red or Mekong river deltas and not central Vietnam. The study tested various hypotheses on the yield and efficiency impact of different levels of salinity and rice varieties on TE, in addition to the role of input use, land fragmentation and seasons.

Given climatic predictions on the increased frequency of droughts and rising salinity levels, the findings of the study are highly relevant. Salinity is a single variable that can reduce yields to very low levels, unless salt-tolerant (ST) rice varieties are widely adopted. Even in lower salinity classes, reductions in technical efficiency indicate a reduction of economic gains from rice farming, which could have serious implications on rural livelihoods. In the analysis, the positive (with smaller coefficients) association between productivity and fertiliser use indicates positive but limited potential to offset the yield declines by adjusting fertiliser inputs. However, irrigation is a crucial variable that could also offset salinity impacts. In the short term, rice production in Thua Thien-Hue can be increased by improving groundwater irrigation. It is important to note that the imbalance of water levels caused by water diversions for canal irrigation in the dry season is itself a major cause of the increased salinity intrusion in the region. One undesirable change could be the increased application of pesticides to offset the losses caused by increased salinity.

The results also show that rice varieties have an important role in determining the scale of losses due to increasing salinity. For lower salinity classes, using alternative traditional or improved varieties could increase production and technical efficiency. However, to mitigate the salinity impact in higher salinity classes, the adoption of new rice salt-tolerant cultivars is absolutely necessary. In rice plots that have been abandoned due to extremely high salinity levels that may preclude rice cultivation, it is necessary to plan a conversion to aquaculture farming or other salt-tolerant crops (e.g. quinoa). Strategies such as rearranging the structure of crops, diversifying cropping patterns and introducing new crops that are adaptable to salinity intrusion are also possible, which is out of the scope of this current study. To foster such strategies farmers need to be encouraged to test the soil from different plots for salinity levels and awareness about the existence of salt tolerant varieties needs to be enhanced. In the longer term, it is possible to envision warning systems for drought and salinity intrusion, increased abilities to provide irrigation water in the dry season and the construction of infrastructure such as salinity barriers. Further research is needed to breed locally preferred varieties with salt-tolerance traits that can be remunerative for farmers facing the increasing threat of salinisation and seawater intrusion. The insights from the study are in general applicable for coastal areas cultivating rice globally that face the threat of saline water intrusion due to climatic change and sea level rise.

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4.3 Article - Incremental and transformative adaptation preferences of rice farmers against increasing soil salinity - Evidence from choice experiments in North Central Vietnam

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Abstract

Increasing salinity levels demand adaptive and transformative changes in farming systems in regions affected by saltwater intrusion intensified by global climate change. The current study reports a novel choice experiment (CE) approach to understand the adaptive (incremental changes such as a shift to salt tolerant (ST) rice varieties) and transformative (Conversion to fish and shrimp aquaculture) farming system choices of rice farmers facing saline water intrusion due to rising sea levels in a Vietnamese province. The study analysed the role of risk attitude, expected returns, production costs, effort levels and legal restrictions on the preferences for adaptation alternatives and their interactions with salinity levels, using random parameter models. The results reveal the role of perceived risks and labour efforts in adaptive and transformative choices and point towards the need of risk offset mechanisms as well as mechanization and other labour saving interventions. The simulations using the estimated random parameter models predict farmers affected with salinity levels below critical threshold of 4 dS/m of electrical conductivity (EC) will have 34.4% adoption rate for the traditional rice and the 43.6% for salinity tolerant rice varieties, which will drop by 2 to 3 percentage points when current legal restrictions on conversion to aquaculture is waived. In case of farmers facing higher salinity levels, transformation to aquaculture would likely become the dominant option for farmers affected by salinity with 40% of the cohort of farmers adopting it (17.2% adoption of shrimp farming and 22.4% adoption of polyculture fish farming), followed by Saline tolerant rice (36 to 38%), The study reveals the need for increased investment in rice breeding for salinity tolerance, market development for alternative crops, the introduction of risk offset mechanisms and a planned shift to transformative alternatives like aquaculture. The study calls for a balanced effort for adaptive and transformative options for rice farmers, infrastructural options preventing salinity intrusion as well as enhanced global mitigation efforts to reduce possible rise in sea levels and limiting salinity intrusion.

Key words: Choice experiment, saltwater intrusion, rice farmers, farmers' preferences, transformative adaptation.

4.3.1 Introduction

Farmlands in Vietnamese deltas, like many other coastal regions, are highly vulnerable to saltwater intrusion (Yu et al., 2010; Smajgl et al., 2015 Ali and El-Magd, 2016; Wu et al., 2018, Aravindakshan et al., 2020). A number of factors such as rising sea levels, shifting rainfall patterns, rising average temperatures, changing river flow discharges, and increasing groundwater extraction rates (Vu et al., 2018; Renaud et al., 2015) contribute to the expansion of the landmass affected by salinity. This phenomenon is already disrupting agriculture in Vietnamese deltas by reducing the economic viability of key crops, especially rice (Lam et al., 2014; Renaud et al., 2015, Dam et al., 2019). It is expected that rising sea levels due to climate change could allow saltwater to intrude further inland in the country (Wu et al., 2018) and Vietnam's Ministry of Agriculture and Rural Development (2011) estimates that around 100,000 ha of Vietnam's 650,000 ha under rice is at risk of salinity intrusion. The impact of salt intrusion on agricultural production is gaining global attention due to its' ramifications to food security (Werner et al., 2013; Ferguson and Gleeson 2012; Niemi et al., 2004). Since Vietnam is the fifth-largest rice producer and one of the leading global rice exporters, the potential production disruption could impact global food security. In addition, rice farming is a significant source of income for more than 75% of poor households as well as for around half of non-poor households in Vietnam (Yu et al., 2010) and hence an expansion of the area affected by salinity can turn disruptive for the local economy.

From a biophysical perspective, saline intrusion creates a shift from a freshwater environment to a brackish water environment, resulting in various impacts on water-related ecosystems and the services they provide (Renaud et al. 2015). Agricultural systems such as rice paddies are directly affected by soil salinity [especially above an electrical conductivity (EC) of 4 decisiemens/meter (dS/m)] and indirectly by the reduction in freshwater availability for irrigation. This in turn has implications for social systems, as farmers have to adapt to a regime shift to a brackish environment, and communities have to deal with increased shortages of freshwater resources. Farmers need to be considered as crucial decision-makers when it comes to designing and adopting various adaptation measures to manage salinity in agriculture.

However, the existing literature still largely lacks a clear understanding of the farmer's preferred adaptive and transformative responses to the salinity problem under different social, economic and legal conditions (Islam et al., 2020). Except from a handful very recent studies (Tran et al., 2019, and Khong et al ., 2020), the existing studies on salinity responses in Vietnam have focused mainly on the impacts on drinking water scarcity and health issues (Abedin et al., 2014; Habiba et al., 2013; Jabed et al., 2020), or on land degradation (Kington and Pannell, 2003), and vulnerability (Binh, 2011). The current study therefore attempts to provide further insights into farmers' preferences, in response to increasing salinity, for adaptive and transformative choices shaping an agricultural system transition.

Farmers' adaptation choices in the context of increasing salinity intrusion (Käkönen, 2008) may range from growing salinity-tolerant (or resistant) rice varieties, to changes in cropping patterns (Khong et al., 2019) or to even a complete switchover to new enterprises, such as aquaculture (Tran et al., 2019). In addition to the level of salinity, motivation and interests of farmers, risk taking capacity with investment costs, their management skills and the expected returns shape incremental adaptation to transformative change of farming systems. Furthermore, like in many other Asian countries the complete conversion from rice to other land uses often faces legal restrictions in Vietnam. Hence how risk acceptance, investment costs, return expectations and preferences with respect to personal consumption can influence the adaptation strategies of rice farmers in a context of increasing salinity, given the legal restrictions, is indeed intriguing. However, the trade-offs among the various adaptation possibilities are not well understood. Approaches to understand farmers' choices and trade-offs are of increasing relevance but studies on preferences for changes in farming systems, especially in a context of exogenously changing circumstances (like increasing salinity) are not that common in literature (Ortega et al., 2016; Bro et al. 2019). This article intends to address this research void using the method of Choice Experiments (CE), which may prove an innovative way to understand agricultural system level adaptive or transformative preferences of farmers and their tradeoffs in a context of saline intrusion-. An additional advantage of using CE is that it allows to communicate potential investment-risk information as well as expected return of each adaptive farming activity to farmers (Oyinbo et al., 2019).

The research documented here therefore investigates rice farmers' preferences and motivations for choosing adaptation options that ranged from incremental changes in farming practices such as shifting to saline tolerant rice varieties to transformative shifts to aquaculture. This study develops a CE to understand farmer preferences, given a set of attributes characterizing the available alternatives, in comparison to the status quo, i.e. the rice-based farming system. We also attempt to identify the determinants of farmers' adaptation choices in the context of saline intrusion in order to propose appropriate incentives to promote the most preferable alternatives. The main research objectives of this study are thus as follows:

- Understanding farmers' preferences on their adaptation choices to mitigate the impacts of saltwater intrusion, given the risks and opportunities.
- Identify and determine the acceptability of adopting stress tolerant rice varieties, changes in cropping sequences, or a transformative shift to aquaculture, given the degree of saltwater intrusion.
- Gaining insight into required policy changes to facilitate adaptation against saltwater intrusion in rice farming deltas.

4.3.2 Study area and data collection

4.3.2.1 Study area

Thua Thien Hue Province, which lies in the north-central coastal region of Vietnam, was selected for this research. This province includes the largest lagoon system (the Tam Giang lagoon) in Southeast Asia. It is a narrow delta affected by rising sea levels as well as by diminishing rainfall during the dry season. As a result, this region faces significant salt-water intrusion. About 2500 ha of agricultural soil in this region adjacent to the Tam Giang lagoon is saline, especially during the dry season from May to August (Dan et al., 2006). Saltwater intrusion in the agricultural areas of Thua Thien Hue has seriously affected the livelihoods of farmers and the local economy. The land use map (Figure 4.3.1) reveals that the dominant agricultural activity in the coastal plain of this province is rice cultivation. Nevertheless, increasing salt-water intrusion poses high risk of rice crop failure, especially in combination with drought conditions. All these factors make Thua Thien Hue Province an ideal case study region to understand farmers' preferences regarding adaptation possibilities to salinity and the associated trade-offs.

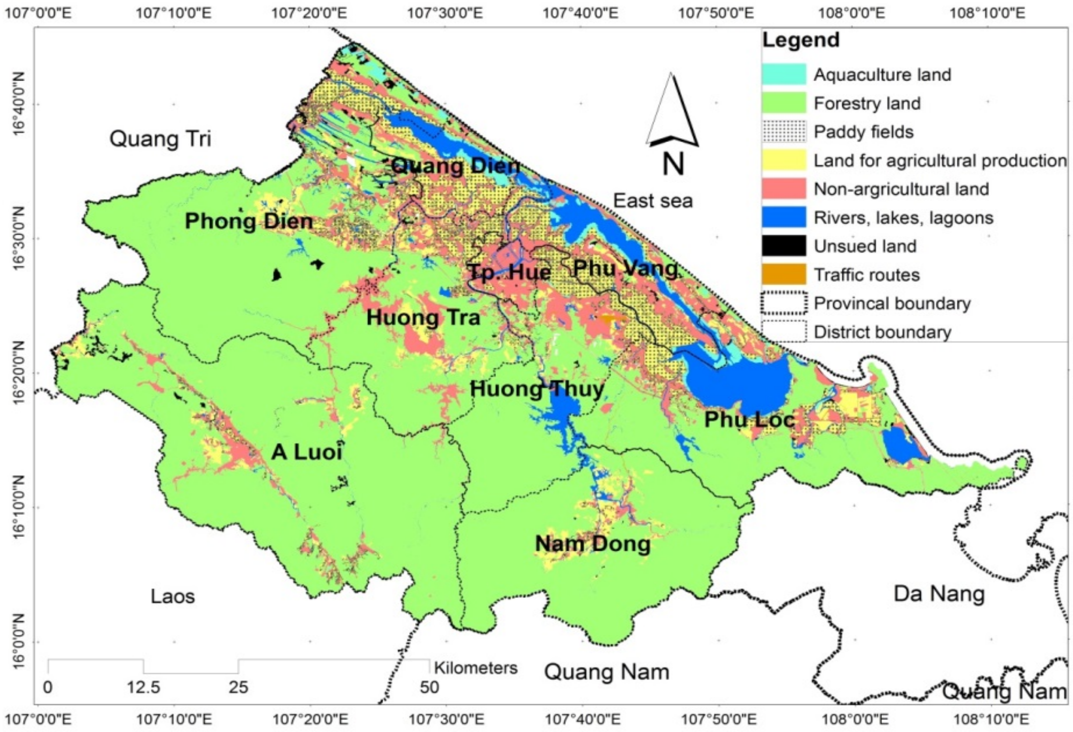


Figure 4.3.1: Land use map of Thua Thien Hue Province, 2015 *(The image has been processed and translated from the land use map of Thua Thien-Hue Province provided by Vietnam's Department of Natural Resources and Environment, 2015)*

Rice is a salt-sensitive crop, and soil salinity is one of the major abiotic stresses that reduces rice production (Jing et al., 2007; Yeo et al., 1990). Given the threat, farmers in the research area have been considering alternative cropping systems that are more suitable for saline conditions. There are two rice cropping seasons in Thua Thien Hue Province: winter–spring cropping from January to May, and summer–autumn cropping from May to September. Cultivating salt-tolerant rice varieties in the dry season could be a good alternative to allow farmers to continue rice cultivation in saline soil. The productivity and profitability of salt-tolerant rice varieties are, however, lower than current varieties grown under non-saline conditions. Moreover, salt-tolerant rice varieties need more irrigation. Other adaptation options include retaining the winter-spring rice crop, but utilising the summer-autumn season to grow other crops such as fruits and vegetables. Another possibility is to opt for a transformative adaptation, i.e. a complete conversion of agricultural land into aquaculture farms. However, a conversion to aquaculture, though more profitable than rice farming, is often constrained by legal restrictions and conflicts with rice production in neighbouring areas (Kiatpathomchai et al., 2008). It also requires significantly higher investment, and an ability to take higher risks (Joffre et al., 2018).

4.3.2.2 **Data collection**

Primary data was gathered through a detailed face to face survey of the rice farmers in the research location. Information about the soil salinity of the affected rice fields was acquired by analysing the soil samples collected from the farmers' rice fields during the survey visits. The proximity to Tam Giang lagoon defines the degree of saline intrusion in the Thua Thien Hue Province and four coastal communities satisfying this criterion were randomly selected from Quang Dien District and Phu Vang District of this province. A total of 268 rice-farming households were surveyed from these four coastal communities during 2017. Households were chosen randomly from a list provided by the rice farmer cooperatives. The survey consisted of questions related to the households' socioeconomic characteristics, rice production information, adaptive behavior and the CE reported in the study. In the choice experiment detailed in the following section; each farmer was asked to choose their preferred alternative from a set of adaptation options with predefined attributes. Six trained enumerators were engaged to collect the data from the selected households.

In order to quantify the degree of soil salinity, the soil samples were collected from surveyed farmers' rice fields and the electrical conductivity (EC) was measured. Salt increases the ability of a solution to conduct an electrical current, so a high EC value indicates a high salinity level. Core samples of the soil were taken from composite topsoil, with sample layers of 5 cm and a subsurface layer at the depth of 20 cm. EC values of the soil samples were measured at the soil testing laboratory using the "EC 1:5 w/v" method (One part air-dried soil as measured by weight (g) to five parts distilled water as measured by volume (mL), which is agitated and then allowed to settle**.)**. The values of EC may range from 0 to more than 16 dS/m; these were classified into five salinity levels. EC values between 0-2 dS/m were considered non-saline, while a value of 16 dS/m or more was extremely saline (see Table 4.3.A1 in the appendix).

4.3.2.3 **Design of choice experiment (CE)**

A CE was used to model rice farmers' decisions to adopt alternative systems when confronted with saltwater intrusion. Simulating a market situation, farmers were asked to choose between hypothetical alternative crop sequences described according to key characteristics. Choice design refers to the process of generating specific combinations of attributes and levels that respondents evaluate in choice questions. The attributes and levels, the choice question format, and the selected model of data analysis together form the basis for the experimental design of the CE (Johnson et al., 2013). Therefore, the following description starts with the first question: what are the possible alternatives (choices) that can be presented to rice farmers?

Attributes and levels

Attributes and levels are the individual features of the choices in the survey, which is designed to elicit the trade-offs (Johnson et al., 2013). Rice farmers were presented with descriptions of alternative crop/enterprise sequences differentiated by these attributes and levels. The crop /enterprise sequences constitute the labels of the alternatives. A detailed description of each attribute and its levels were provided in the local language in order to ensure a good understanding of each attribute by the respondents. Farmers were asked to choose their preferred alternative. We identified the attributes associated with these adaptation alternatives for salinity intrusion which were most credible and relevant i.e. the crucial dimensions shaping farmers' decisions. Based on the practices of farmers dealing with saline intrusion and with help from local experts, five possible adaptation options which include complete conversions and partial conversions of rice farms were identified. The choices provided to the farmers who were engaged in two season rice cultivation sequences were 1) rice – salt tolerant (ST) rice, 2) rice – vegetables, 3) rice – fruit crop, 4) shrimp – shrimp, 5) fish-shrimp polyculture – fish-shrimp polyculture.

Given the fact that respondents are only able to evaluate the trade-offs of a limited number of combinations of alternatives and their attributes within a given time (Hensher et al., 2005; Bunch et al., 1996; Lagarde, 2013; Collins et al., 2013), it is crucial to design the CE in a way that maximises its efficiency. This study employed the fractional factorial design obtained using SAS software as described by Kuhfeld (2010) which ensured a minimum D-error ($\mathrm{D-optimality}$), the most common metric for efficient linear choice designs (Carson et al., 1994; Zwerina et al., 1996; Rose et al., 2008; Louviere et al., 2010). D-efficiency measures efficiency of the design by maximising the determinant of the Fisher information matrix (Johnson et al., 2006)

In light of the purpose of the study, the following five attributes were identified and evaluated for each adaptation option: production risk, production costs, management effort, expected net return and legal restrictions (Table 4.3.1). Quantitative measurements were used for attributes which have commonly recognized units, like cost and returns which are generally expressed in monetary terms (Table 4.3.2). Three quantitative levels of production costs (high, medium, low) were applied for each alternative choice while two possible levels (high and low) of expected returns were presented. Two other attributes namely production risk and management effort, were qualitatively rated (either low or high level) with the current system as a reference point. The management effort or production risk could be expressed in full time equivalent (FTE) labour use or risk ratios, but we presented them qualitatively in relation to the status quo i.e. rice farming (i.e. risk or effort significantly higher or lower than rice enterprise). We believe that such a setting is better for decision making in the rural farm settings than quantitative FTE (labour) values or risk ratios. The last attribute presented legal restrictions regarding a particular adaptation choice. The current legal restriction applies to conversion from rice cultivation to aquaculture. Here, the farmer was also presented with a hypothetical scenario in which current legal restrictions for a transition to aquaculture would be waived.

Table 4.3.1: **Attributes and descriptions**

Attributes	Descriptions
Production risk	Production risks stemming from weather, pests, diseases, genetic vulnerabilities, quality of inputs, etc.
Production cost	Production costs of rice and vegetable cultivation consist of the cost of seed, fertilisers, pesticides, machinery and labour. Aquaculture sequences include costs of pond preparing, fingerlings, feeds, lime, vitamins and fuel (electricity, diesel).
Management effort	Labour effort in organising and operating a presented alternative
Net Return	The potential net profit of each alternative obtained after deducting production costs from revenue
Legal restriction	Legal restriction applicable to adaptation choice. Currently government permission is needed to convert rice land to aquaculture purposes (arbitrary conversion/ not arbitrary).

The final SAS design output for the CE consists of six choice sets with five alternatives; this efficient and balanced design had a high D-efficiency. Accordingly, the choice cards were designed on six cards with five options each. Five of the labeled sequence alternatives presented to farmers included rice – salt-tolerant rice, rice – vegetables (tomato, cucumber or cantaloupe or a mix of them) , rice – fruit crop (watermelon or golden melon), shrimp – shrimp, polyculture – polyculture (mix-cultivation of fish and shrimp). We have added the status quo alternative (rice-rice sequence) as a sixth option in choice cards with the aim of helping farmers to have a direct and clear reference point between their rice – rice sequence over a year and the other available sequences.

Table 4.3.2: Levels of attributes for each alternative presented in CE

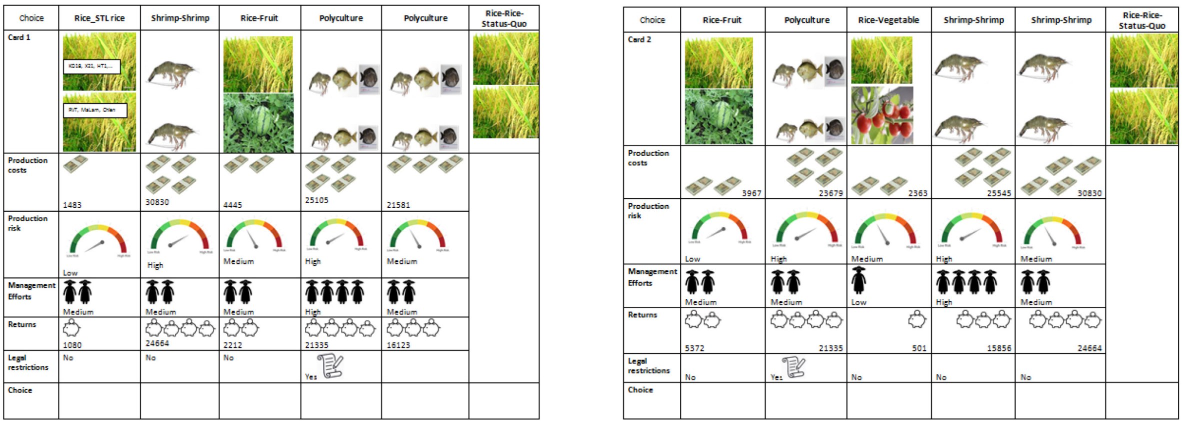
Attributes		**Levels of attributes**				
		Rice–ST rice	Rice–vegetables	Rice–fruit	Shrimp–shrimp	Polyculture–polyculture
Production risk	Low Medium High	Low Medium	Low Medium	Low Medium	Low Medium High	Low Medium High
Production cost (1000 VND*)	Low	1241	1996	3967	25545	21581
	Medium	1483	2363	4445	28188	23679
	High	1888	2736	4929	30830	25105
Management effort	Low Medium High	Low Medium	Low Medium	Low Medium	Low High Medium	Low High Medium
Net return (1000 VND*)	Low	1080	501	2212	15856	16123
	High	2925	1751	5372	24664	21335
Legal restrictions	Yes No	No	No	No	Yes No	Yes No

**VND: Vietnamese dong (1 USD = 22,740 VND)*

Choice question format

The choice question format defines how respondents evaluate a series of alternative sets and attribute-level combinations (Johnson et al., 2013; Gelaw et al., 2016). In the current study, farmers had to evaluate five profiles (choice and attribute) on each choice card. In addition, choice cards contained a status "quo" alternative in each choice set as a baseline condition to estimate utility changes. Given the fact that famers in the research area are familiar with the presented options (e.g. through interactions with farmers in other salinity affected areas and through media), we were not expecting a cognitive overload for farmers in evaluating the options. Examples of two choice cards used in this study are depicted in Figure 4.3.2. The choice cards utilised images which made the alternatives explicit to farmers. This helped farmers to understand the presented options quickly and to make well-informed choices.

CE's might be subject to hypothetical bias since respondents do not have a commitment to adopt the proposed strategies while making their decisions. In order to reduce hypothetical bias, literature suggests making the choice task close to reality by framing the experiments in a way that resembles individual decisions. Before the actual choice experiment, an introductory talk was included to ensure that all the farmers understood the attributes in the same way and to emphasize the importance of making decisions as they would in reality. The design also included an opt-out to avoid forcing the respondents to select one of the described alternative sequences, in this case referred to the maintenance of the status quo which is traditional production of rice. This opt-out was defined during a pre-survey in order to obtain their current production costs and returns. This allowed us to introduce a closer link to the real market decision of each of the respondents. Finally, the different suggested alternatives include adaptive solutions that have been perceived by farmers as highly feasible, defined by values obtained from conducted trials.



Choice	Rice_STL rice	Shrimp-Shrimp	Rice-Fruit	Polyculture	Polyculture	Rice-Rice-Status-Quo
Card 1	KD18, X21, HT1,... RVT, MaLam, Chlen					
Production costs	1483	30830	4445	25105	21581	
Production risk	Low	High	Medium	High	Medium	
Management Efforts	Medium	Medium	Medium	High	Medium	
Returns	1080	24664	2212	21335	16123	
Legal restrictions	No	No	No	Yes		
Choice						

Choice	Rice-Fruit	Polyculture	Rice-Vegetable	Shrimp-Shrimp	Shrimp-Shrimp	Rice-Rice-Status-Quo
Card 2						
Production costs	3967	23679	2363	25545	30830	
Production risk	Low	High	Medium	High	Medium	
Management Efforts	Medium	Medium	Low	High	Medium	
Returns	5372	21335	501	15856	24664	
Legal restrictions	No	Yes	No	No	No	
Choice						

Figure 4.3.2: Examples of choice cards 1 and 2 out of a total of 6 choice cards

Econometric analysis

The analytical strategy considers how the retrieved data can be analysed to predict choices and produce estimated preference weights, or choice-model parameters, that would be consistent with the observed pattern of choices by respondents. The analytical concept of choice modelling is grounded in random utility theory, assuming that the benefit which an individual derives from a good is a function of the frequency they choose it over other similar alternative goods, defined by the combination of key characteristics of these goods. This allows preference estimation of complex multidimensional goods. This study employs a random utility model as a basis for the econometric analysis of farmer choices within a discrete environment. In this study, we examined farmers' choices among a set of crop sequence alternatives by using a Random Parameter Logit Model.

A Random Parameter Model allows deriving the utility from a set of alternatives for each individual, where the explanatory variables are the characteristics of those alternatives (McFadden & Train, 2000; Hauber et al., 2016). Suppose that Y_j represents a discrete choice among j alternatives. Let U_{ij} represent the value or *utility* of the j^{th} choice to the i^{th} individual. We treat U_{ij} as an independent random variable with a systematic component η_{ij} and a random component ϵ_{ij} (McFadden, 1986; Louviere et al., 2000) such that:

$$U_{ij}=\eta_{ji} + \epsilon_{ji}, \qquad (1)$$

Where η is the deterministic component (defined by relevant attributes and any identifiable interaction terms) and ϵ is the non-observable component of individual choice, which allows a probabilistic analysis of farmer behaviour by assuming a specific parametric error distribution.

We assume that individuals act in a rational way, maximising their utility. Thus, subject i will choose alternative j if U_{ij} is the largest in the set of $U_{i1},\ldots,U_{iJ}$. Note that the choice has a random component, since it depends on random utilities. The *probability* that subject i will choose alternative j in choice situation t is:

$$P_{ij} = Prob(\eta_{jit} + \epsilon_{jit} > \eta_{kit} + \epsilon_{kit}) \quad \forall k \neq j$$

$$= Prob(\eta_{jit} - \eta_{kit} + \epsilon_{jit} > \epsilon_{kit}) \ \forall k \neq j \qquad (2)$$

It can be shown that if the error terms ϵ_{ij} have standard Type I extreme value distributions with density

$$f(\epsilon)=\exp\{-\epsilon-\exp\{-\epsilon\}\} \qquad (3)$$

Then, the specification can be generalized to allow for repeated choices by respondents, assuming that the systematic utility component η_{ji} is a linear function of the attributes and follows a generalised regression specification, this leads to:

$$U_{ijt} = \beta_i' X_{ijt} + \epsilon_{ijt} \qquad (4)$$

Where X_{ijt} are observed variables related to the alternative j, and β_i is a vector of individual preference varying over farmers. The preferences for each of the sequences also enters the utility function, including the final specification of alternative specific constants related to each of the described sequences. The characteristics of the individual are constant across the alternatives. Consequently, the only way they can affect choice probabilities is by having a different impact on the various alternatives.

The Random Parameter model assumes heterogeneity in the individual preferences for each attribute but assumes them to be constant over choice situations. The heterogeneity of the individual preferences is accounted by the specification of coefficients as random terms. The distributions of the parameters may vary from one parameter to the other. In this study, a uniform distribution was assigned to the discrete variables, while continuous variables were assigned a normal distribution. We also tested scale heterogeneity assumption using generalized mixed logit Model (GML) which is an extension of the random parameter model by using an individual scaling coefficient. As we did not find significant scale heterogeneity, we report the results in appendix table A1 and the methodology is explained in appendix A.

In this study, the data of the CE were analysed in two steps. In the first step, we used a random parameter logit model analysis to estimate the preferences for attributes and the different sequences, by assuming the traditional rice – rice sequence as reference. As opposed to previous studies of CE, the real values of their current choice were introduced, describing their attributes. Besides calculating preferences for the different attributes, we also calculated preferences for the different sequences. The second step consisted of applying an interaction with the levels of salinity in the model. These variables capture preferences for the proposed sequences when the level of salinity is high. The baseline is the traditional rice sequence as described above. The interpretation of the coefficients should be done as follows: the different attributes for sequences must be interpreted as the willingness to shift from traditional rice cultivation to one of the proposed options. Risk (production risk) in the baseline is considered to be low. Therefore, two separate attributes consider a preference to be a change in risk. *Risk medium* shows respondents' preference for a change from a low-risk to a medium-risk situation. *Risk high* expresses the preference for the shift from a low risk to a high risk. A similar logic is applied for effort (management effort) (Table 1). The baseline stands for low effort, so the two variables have to be interpreted as preferences for going from low effort to medium effort (*Effort medium*) and from low to high effort (*Effort high*). Returns (net returns) and costs (production cost) are treated as continuous variables. Legal restrictions express the preference for licensing (permission for conversion of rice fields to aquaculture ponds), but it does not affect all alternatives (only shrimp and fish polyculture alternatives).

Predicting adoption outcomes

To assess the potential adoption of the different crop sequences by farmers in the region, the next step was to use the model results to simulate the respondents' adoption outcomes at different salinity levels. More specifically, various crops were defined in terms of their attribute values, describing the most likely characteristics under different salinity conditions. Louviere et al. (2000) showed that the probability of Consumer *i* choosing Alternative *j* conditional to the distribution of the β parameters, is given by a random parameter model:

$$P(j \text{ is chosen}) = \frac{\exp\,(\beta_i' X_{ij})}{\sum_{j=1}^{j} exp\,(\beta_i' X_{ijt})}$$

The resulting probability figures depict the adoption rate for each crop under the described characteristics (Appendix Tables A3 and A4). These outcomes were obtained after considering all sequences with their specific average returns and costs of production. The returns and costs of production were assumed to remain constant with the changes of salinity. However, levels of risk and effort change if salinity is present.

4.3.3 Results

The results of this study are presented in three parts: the first part gives descriptive results of EC measurements during fieldwork and the cultivation performance of rice on saline soils (4.3.4.1); the second part presents the results of the random parameter logit (RPL) models based on the choice experiment data (4.3.4.2) while the third part contains the predicted market shares of the adaptive or transformative alternatives with respect to salinity impacts, based on RPL model results (4.3.4.3).

4.3.3.1 Descriptive results

Before presenting the CE data analysis, the descriptive information of salinity levels of the cultivated plots of each household and their rice production levels (Table 4.3.3) are provided to draw the background which can contribute towards understanding the CE results.

Table 4.3.3: Soil salinity levels and cultivation performance of rice in fields affected by salinity

EC levels (dS/m)	Soil salinity level	No. of households affected by salinity	Total of saline area (ha)	No. of plots	No. of cultivated plots	No. of abandoned plots	Average yield (ton/ha)
2-4	Slightly saline	54	6.18	56	56	0	4.5
4-8	Moderately saline	43	4.71	45	45	0	4.1
8-16	Highly saline	27	3.40	28	3	25	4.3
>16	Extremely saline	23	1.88	25	0	25	0
Total		147	16.17	154	104	50	

Except for a few saline-tolerant rice varieties, generally rice plants are moderately sensitive at an EC range of 4-8 dS/m, and are highly sensitive at an EC range of 8-16 dS/m (Rad et al., 2012; Balaji, 2018). Out of 268 respondents from rice-farming households, 147 were impacted by salinity intrusion, totalling an area of 16.17 ha (Table 3). Of these, 54 households had 56 rice plots that were slightly affected by salinity (2-4 dS/m). The average rice yield in slightly saline soil was 4.5 tonnes/ha. 45 moderately saline plots (4-8 dS/m) belonged to 43 rice-farming households; these had an average rice yield of 4.1 tonnes/ha. In highly saline plots (8-16 dS/m), the average rice yield was 4.3 tonnes/ha, but this was due to the use of new salt-tolerant rice varieties. All the 25 plots with extreme saline conditions (>16 dS/m) were abandoned and fallowed. The farm-level salinity measurements indicate that rice farmers in Thua Thien Hue Province are confronted with increasing salinity levels and are in need of various adaptation possibilities.

Table 4.3.4: Proportion of preference provided by rice-farming households for different crop sequences choices

Choice crop sequences	Proportion (%)
Status quo (rice-rice)	29
Rice – salt-tolerant rice	20
Rice – vegetables	18
Polyculture – polyculture	15
Shrimp – shrimp	14
Rice – fruit	4

As a first evaluation of the choice experiment, table 4.3.4 depicts the choice frequency for each adaptation option within the CE. The status quo was selected by 29% of the rice farmers. Among the proposed sequences, the “rice – salt-tolerant rice” sequence (20%) was chosen more often, closely followed by rice – vegetables (18%) and polyculture of fish (15%). The least frequently selected sequence was the rice – fruit sequence (4%). These choices suggest that farmers prefer to follow the traditional rice – rice patterns, rather than shifting to other crops. If changes in cultivation pattern have to be made due to the higher level of salinity, priority seems to be given to saline-tolerant rice varieties. This may change when legal restrictions on rice land conversion are waived, which is investigated in the following sections. Furthermore, the effect of the salinity level on these adaptive and transformative choices is assessed.

4.3.3.2 Results of the random Parameter logit models

Two models were analysed to elicit farmers' preferences for the different farming system possibilities and attributes. In the first model (Model A), rice farmers' general preferences in the region for adaptation possibilities are examined. In the second model (Model B), however, interaction of salinity levels with preferences for crop sequences is the major focus. An interaction term representing rice plots with EC levels higher than 4 ds/m is designed to capture farmers' preferences to switch over to different proposed sequences when salinity is rising. In the model, preferences for the fish-shrimp polyculture sequence and the shrimp sequence were considered together, under the label "aquaculture". The reason for this consideration was to observe together the preference for the agricultural enterprises subject to legal restrictions. The results from the two random parameter logit models are described in Table 4.3.5.

In Model A, the coefficients of the analysis show that farmers had a positive preference for higher returns, while they had negative preference for higher risk, higher costs and higher effort. The revealed significant negative preference for risk and effort are consistent with theoretical expectations. The negative coefficient for the risk variable indicates a dispreference for higher risk levels, revealing the risk-averse nature of farmers in the study area. Similarly, the results show higher negative preference for increasing effort from low to medium and medium to high. Higher effort and risks associated with specific crop sequences would have to be compensated by an increase in returns. When comparing the coefficients of effort and risk, the results suggest that farmers would be ready to make greater efforts if there were less risk in the switch to adaptation options. In other words, the risk level has a higher impact on the choice than the effort level. This suggests that risk offset mechanisms for available adaptive or transformative options, might facilitate the transitions to these options. The results show a significant negative influence of the legal restriction to convert rice land to aquaculture ponds. Even though a positive preference exists for aquaculture, the requirement to obtain a licence for this sequence offsets part of the preference for the aquaculture sequences (shrimp and fish polyculture).

Table 4.3.5: Results of the Random

		Model A		**Model B**	
		RP		**RP with interaction with salinity**	
Variables		*Coefficient*	*P-value*	*Coefficient*	*P-value*
Mean estimates					
Production costs (1000 VND[!])		-0.0009***	0	-0.00083***	0
Risk	**Low**				
	Medium	-1.714***	0.2	-1.866***	0.21
	High	-3.206***	0.35	-3.630***	0.35
Effort	**Low**				
	Medium	-1.936***	0.22	-2.099***	0.24

	High	-2.697***	0.31		-2.975***	0.34
Returns (1000 VND[!])		0.0003***	0		0.00027***	0
Legal restriction		-2.916***	0.51		-3.256***	0.46
Crop	**Rice**					
	Rice – ST rice[#]	1.91***	0.35		2.244***	0.39
	Rice – vegetable	-0.462	1.34		1.407	1.12
	Rice – fruit	-3.044**	1.25		-2.447**	1.05
	Aquaculture	12.422***	1.26		7.439***	1.18
				(Interaction with high salinity, binary variable EC > 4 = 1)[#]		
				Rice – ST rice x EC > 4	-2.843***	0.69
				Rice – vegetable x EC > 4	3.581***	0.87
				Rice – fruit x EC > 4	2.539***	0.98
				Aquaculture x EC > 4	12.568***	2.24
Standard deviation estimates						
Production costs (1000 VND[!])		0.0008***	0		0.00074***	0
Risk	**Low**					
	Medium	0.103	0.33		0.29815	0.32
	High	1.333**	0.67		1.828***	0.49
Effort	**Low**					
	Medium	0.67	0.55		0.377	0.49
	High	0.591	0.77		0.898	0.58
Returns (1000 VND[!])		0.00006***	0		0.00001	0
Legal restriction		1.518	1.2		2.582***	0.85
Crop	**Rice**					
	Rice – ST rice[#]	6.513***	0.64		7.602***	0.75
	Rice – vegetable	12.855***	1.58		13.090***	1.42
	Rice – fruit	10.650***	2.08		8.323***	1.55
	Aquaculture	4.269***	0.77		3.786***	0.94

****, **, * = significance at the 1%, 5%, 10% level.*
[#] Salt-tolerant. [!] VND: Vietnamese dong (1 USD = 22,740 VND) ,
 # EC is measured as dS/m

Regarding the proposed sequences in Model A, positive preferences were found for sequences of salt-tolerant rice (ST) and aquaculture (shrimp sequence or polyculture sequence). There were negative preferences for sequences with rice followed by fruit. No significant preference was found for vegetables. This is due to the low profitability and volatility of prices in vegetable markets, which vegetable farmers in the province have cited as their main concerns. The results of Model B (with interaction terms) are similar to the results of Model A. The farmers indicated a positive preference for higher returns, while they had negative preference about higher risks, higher costs and higher levels of effort. When considering the proposed sequences, the farmers in general revealed a positive preference for the rice-rice sequence including ST rice as well as aquaculture with a negative preference for rice – fruit sequences. However, based on the interaction with salinity, we found that, for farms affected by salinity, preferences shifted towards sequences with vegetables, fruit and aquaculture. This suggests that farmers would consider conversion as one strategy when affected by salinity. Similarly, the preferences for ST rice were found to be negative for farmers confronted with high salinity levels, offsetting the preference for this sequence. In contrast, the preference for vegetables and fruit under saline conditions becomes positive, though the impact for fruit farming remains low. Despite a positive preference for aquaculture in high salinity conditions, the legal framework restricts its implementation by farmers. This situation may lead to abandoning of fields as observed in the study area.

All findings considered, the major take-away from Model B is that the preference for the different adaptation options including a transformative shift to aquaculture is indeed influenced by salinity levels. In case of severe salinity (EC > 4 dS/m), preferences for aquaculture, the rice – fruit sequence and the rice – vegetable sequence increase, and in particular there was a dramatic increase in preferences for aquaculture and vegetable options. The results also suggest that it might be the current legal restrictions for aquaculture options in the areas of severe salinity that prevent farmers from shifting to aquaculture. Results in model A and B also show significant preference variation over farmers for the proposed sequences, the production costs, higher levels of risk and legal restrictions (in model B). However, larger standard deviations from the mean were found related to the proposed sequences, particularly in the case of ST rice, vegetable and fruit sequences. The large variations found indicate that some farmers could have opposite preferences towards the sequences than those found in the mean estimates.

4.3.3.3 **Predicted market shares for the alternatives**

Using the model with the interaction with salinity (Model B), the last step was to simulate adoption outcomes for the different crop alternatives (Table 4.3.6). The different simulated adoption outcomes were obtained in terms of the expected characteristics of the different alternatives. We used Model B to predict how farmers would choose under these characteristics. For that purpose, four different scenarios were defined based on two factors: affected by salinity (yes or no) and legal restrictions (with and without). The results showed differences in the predicted adoption rates under the four scenarios. The expected adoption rates of farmers not affected by salinity (salinity levels below critical threshold of 4 dS/m) are higher for the traditional rice and the ST rice varieties, accounting for 34.4% and 43.6% of the outcomes. The adoption rates for fruit and vegetable sequences were found to be low, with a 2.4% adoption of fruit and a 1% adoption of vegetables. According to simulated results, despite the higher returns, only 9.2% of farmers facing no salinity or salinity lower than 4 dS/m (EC) are likely to adopt polyculture sequences even if the legal restrictions are waived while 14.9% may adopt shrimp farming. In the case of salinity levels higher than 4 dS/m (EC), we expected traditional rice farming, to be replaced by shrimp and polyculture sequences. Nevertheless, market shares of salt tolerant rice remain very high. Only if the legal restrictions are lifted the adoption of aquaculture sequences (sum of shrimp and polyculture sequences) becomes slightly more popular than salt tolerant rice.

Table 4.3.6: Simulated adoption outcomes for the current proposed crop sequences

Crop	Not affected by salinity		Affected by salinity	
	Market shares (%)	Market shares without legal restrictions (%)	Market shares (%)	Market shares without legal restrictions (%)
Rice	34.4	32.3	3.1	3.0
ST rice	43.6	40.7	38.3	36.8
Vegetables	1.0	0.9	19.7	18.5
Fruits	2.4	2.0	2.8	2.1
Shrimp	13.0	14.9	17.1	17.2
Polyculture	5.5	9.2	19.0	22.4

4.3.4 Discussion and policy recommendations

4.3.4.1 Discussion

Earlier studies on salinity responses (Tran et al., 2019, Khong et al, 2020) did not provide comprehensive information on determinants of possible adaptive choices by farmers nor on the possible implications of changes in legal or environmental conditions. Farmers' preferences for aquaculture sequences, when confronted with higher levels of salinity, are in line with the ongoing trend of increased area under aquaculture in Vietnam's coastal areas (Dang, 2020). Our results highlight that apart from the higher investment costs and higher risks (Joffre et al., 2018) associated to aquaculture, this trend is also constrained by the current legal framework. According to Khong et al. (2020), the absence of adequate human capital in terms of skills and education of farmers supports the tendency to stick to traditional rice farming and under moderate salinity conditions a preference for salt tolerant rice varieties is observed. Tran et al., (2019) and Nguyen et al. (2019) furthermore attribute the continued predominance of rice farming, which is supported by the strong preferences for rice farming observed in our CE, to the weaknesses of the local markets to support alternative farming systems and to the legal restrictions for conversion to aquaculture. Our results indicate that without policy interventions, under moderate salinity, farmers may prefer a shift to salt tolerant rice varieties, while at higher levels of salinity they may abandon their fields rather than a transition to aquaculture. Given the high risk aversion of farmers, which was revealed from the current study results, introduction of insurance mechanisms and supportive measures as suggested by Khong et al. (2020) can elicit higher rates of adaptive response by farmers. While previous studies ignored the labour requirement of the adaptive options, our results suggest that the level of effort required for adaptation acts as a deterrent in the adaptive response. This implies the need of supporting mechanization and labour management interventions like subsidized labour for adaptive actions (similar to for example the National Employment Guarantee Scheme of India) (Amjath-babu et al., 2018).

The predicted market shares show that to protect food security of the region, government needs to ensure the availability of salt tolerant rice varieties by promoting the research and development as well as scaling-up initiatives of salt tolerant seed production. In addition, legal measures to allow rice farmers facing very high salinity levels to convert to aquaculture are a necessity to protect livelihoods of farmers. Otherwise, it may lead to abandoning of highly saline farm areas or illegal conversions to aquaculture. Kruse et al. (2020) however argue that a shift to shrimp aquaculture should be preferably confined to areas of higher salinity because it may create path dependencies related to the soil conditions. Their study further calls for alternating rice-shrimp farming as a no-regret strategy for farmers as it better preserves their flexibility when facing lower levels of salinity. Highlighted by Khong et al. (2020), Tran et al., (2019) and Nguyen et al. (2019), other farmer related factors such as financial support (e.g. low-interest loans), education and skills training in addition to legal restriction also influence conversion to aquaculture.

Given that Vu et al. (2018) predict a sea level rise of 30cm by 2050 (increasing the area under salinity threat with around 30000 ha) in Vietnam, planning and supporting the adaptive trajectories to limit the negative impacts on farmers' livelihood and to strengthen the resilience of socio-ecological systems are (Renaud et al., 2015) even more crucial. The results of our study shows that the future scenario needs to be a mosaic of incremental adaptation and transformative options (Nguyen et al., 2019).

4.3.4.2 **Policy implications**

Currently, Thua Thien-Hue rice farmers showed limited adaptive capacity in the context of increasing salinity. Only a few households have opted for adaptation options and have changed some of their farming practices. Based on the findings of this study, however, we recommend a few strategies to improve the adaptive capacity of rice farmers who are affected by salt intrusion.

The strong dis-preference for high risk adaptation options implies the need for mechanisms that would reduce these risks such as insurance and market mechanisms to increase adoption rates. The current lower preference for rice-vegetables or rice-fruits can be addressed by promoting salt tolerant vegetables/fruits, ensuring their seed availability and better market access. There is a need for public and private research investment in developing salt stress tolerant varieties and seed delivery systems. Given the farmers' preference for rice-rice farming systems, strategies for reducing salinity intrusion (eg: constructing dykes or increasing availability of surface water) by governmental agencies can also influence the risk-return perceptions of farmers concerning different farming options. The other pathway for Govt. agencies in areas of higher salinity is to motivate the complete switchover to transformative adaptation options such as aquaculture. Technology transfer, insurance options, increased availability of finance and waiving of legal restrictions can be the major strategies. Given the importance of farm income in supporting local economy and reducing poverty in the region, these actions are of crucial importance to avoid distress to farm households in the region. Given the large impact of the dispreference for higher investment costs by farmers, there is a need of increasing the investment capacity of farmers. An effective strategy could be the facilitation of land consolidation and abolishing of existing land quotas per household to foster a transition to economically viable farm sizes

(Pedroso et al., 2018), especially in areas of higher salinity. This may support large investments in alternative farming systems including sustainable aquaculture.

In fact, the legal restrictions prohibiting conversion of rice paddies were established to avoid arbitrary conversions, which had resulted in conflicts between rice and aquaculture farmers and inflicted a reduction of productivity of rice farming. Nevertheless, rice plots with strong salinity are no longer available for rice cultivation, and therefore conversion to aquaculture is necessary to avoid wasting land resources and to improve farmers' income. To this end, it is necessary to map areas having higher salinity levels to develop a regional aquaculture conversion plan. A planned transition can avoid unplanned or illegal conversions, which will negatively impact neighboring rice-growing areas. The predicted market shares of aquaculture with and without legal restrictions for salinity affected farms tend to be similar implying that farmers may ignore restrictions when faced with threat to their livelihood. So, the current legal restrictions and land quotas should therefore be carefully reconsidered based on joint planning efforts, taking the local farmers' needs and ambitions into account. According to Khong el., 2019, salinity reduces the land value and adaptive responses can recover the lost wealth by farmers. Hence such planned legal intervention of land size and land use may help in protecting and enhancing the wealth of farming communities in the coastal areas of Vietnam.

4.3.5 Conclusions

Salinity intrusion poses a serious risk to rice cultivation systems in Vietnam, like in many countries in South and South east Asia. However, various adaptation measures can help farmers to deal with the effects of soil salinity. Rice farmers are crucial decision-makers in designing and adopting these various adaptation measures, mitigating the impact of saltwater intrusion. The goal of this study was to use an innovative choice modelling approach to generate information about rice farmers' preferences and motivations for choosing among the portfolio of locally feasible adaptive and transformative options, given the salinity scenario. We also identified the relevant factors governing the farmers' decision on adaptation choices to derive policy lessons. The study also uses the CE as a tool to predict the adoption shares for the considered adaptive options, given different salinity levels and legal framework conditions. The random parameter logit models results clearly showed that the decisions by the majority of rice farmers near lagoon areas in Thua Thien-Hue Province are driven primarily by opportunities to earn a higher margin (return) and that they are currently averse to risks, higher investments, and higher efforts. Farmers showed a significant diversity in preferences leading to offsetting of salinity impacts. In areas with higher salinity levels, waiving the legal restriction on the conversion of rice area to aquaculture ponds could help farmers to cope with the issue. If the legal restriction in adopting aquaculture is not waived, considerable investment in breeding salt-tolerant varieties (rice, vegetables and fruits) with higher performance or reducing the salinity levels in the affected areas, viz. building dykes or surface water irrigation systems, is required, wherever feasible. The predicted adoption rates for ST rice varieties are more than 38%

when legal restrictions on land conversion are not waived. However, when salinity becomes severe, farmers are well aware that converting rice cultivating land to aquaculture or vegetable options is better than low rice yields or leaving the fields fallow. The simulated adoption outcomes using the choice model shows a 40% share of the farmers adopting aquaculture options under this scenario while the predicted adoption rates are 18% adoption for rice vegetables and 2.1% for rice-fruits sequences. To increase the share of vegetables and fruits, market interventions and the introduction of saline tolerant high-yielding vegetables and fruits would be required.

The results of this study reflect a broad path of agricultural adaptations that can contribute to the wellbeing of coastal dwellers facing formidable challenges, including seasonal weather variation, increasing salinity, legal restrictions and market issues in adapting or transforming to alternative farming systems. Given the potential increase in soil salinity due to the rise in sea level caused by global climate change, the long-term sustainability of coastal farming systems requires a number of appropriate alternative adaptation options in salt-prone areas, such as the planned development of aquaculture zones, the consolidation of farms to economically viable sizes, the creation of market links for alternative crops and the introduction of high-yield, salt-tolerant rice, fruit and vegetables. In addition, risk-reduction mechanisms (e.g. insurance) and investments in research (e.g. salinity-tolerant varieties) could create a more conducive environment for the adoption of alternatives. The capacity of rice-farming coastal households and village communities to adapt in a sustainable way also depends on public investment in structural measures (such as dykes). Therefore, a balanced approach on infrastructure options preventing salinity intrusion and possibilities of adaptation and transformation options to protect or even enhance the income levels of rice farmers is required. Government interventions are the major driver behind the agricultural system changes in Vietnamese deltas (Renaud et al., 2015) and market interventions, legal interventions, infrastructural investments and incentives from government can support a transition to a resilient agro-ecosystem even under the scenario of an extended area affected with salinity in the future. The failure to create a favourable physical socio-economic and legal environment might result in a large number of farmers and agricultural labourers falling into poverty. At the same time, countries like Vietnam need to ramp-up efforts to bring global-level actions to mitigate climate change and limit the potential rise in sea levels. This study showcases how CE methodology can be effectively used to develop comprehensive strategies to deal with salinity intrusion in agricultural fields in deltas that meet the expectations of farming community. It also documents an innovative approach for bridging the knowledge gap to guide policymakers on ways to promote adaptation or transformation measures in any coastal region around the world.

4.3.6 References

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4.3.7 Appendix

Appendix A. Generalized Mixed Logit Model

The results presented in this paper rely on the Random Parameter Logit model that captures heterogeneity in respondents' preferences. Generalized Mixed Logit Models (Fiebig, Keane, Louviere, & Wasi, 2010) extends this specification to account also for heterogeneity in the decision making. This model provides an extension of the Random parameter model by using an individual scaling coefficient σ_i. With β, the mean attribute preference for the population and η_i , the respondent specific deviations from the mean, the extension of the Random parameter Logit model is:

$$\beta_i = \sigma_i \beta + \gamma \eta_i + (1-\gamma)\, \sigma_i \eta_i$$

Where the parameter σ_i gives greater weight to more deterministic choices and smaller weight to more random choices. Then γ is a distribution parameter that moves to or away from the random part of the model, with values between 0 and 1. We estimate two particular special cases such as the GMNL-I (γ=1) and the GMNL-II (γ=0). The results are presented in Table A1. We did not find significant scale heterogeneity. The results however look similar across the models.

Table 4.3.A1: Results of the Generalized Mixed Logit Model

		GMNL-I				**GMNL-II**			
		GMNL-I		*GMNL-I with interaction with salinity*		*GMNL-II*		*GMNL-II with interaction with salinity*	
Variables		*Coefficient*	*S.E.*	*Coefficient*	*S.E.*	*Coefficient*	*S.E.*	*Coefficient*	*S.E.*
Mean estimates									
Production costs (million VND[!])		-0.873***	0.09	-0.892***	0.11	-1.663***	0.16	-1.189***	0.21
Risk	**low**								
	medium	-2.116***	0.23	-2.088***	0.25	-2.432***	0.30	-2.862***	0.45
	high	-3.575***	0.34	-4.740***	0.48	-4.591***	0.48	-6.483***	0.83
Effort	**low**								
	medium	-2.424***	0.27	-2.401***	0.28	-2.980***	0.36	-3.047***	0.38
	high	-4.002***	0.45	-4.011***	0.52	-4.408***	0.55	-5.046***	0.80
Returns (million VND[!])		0.453***	0.07	0.449***	0.07	0.469***	0.09	0.495***	0.10
Legal restriction		-3.704***	0.42	-5.133***	0.66	-4.139***	0.51	-6.406***	0.97
Crop	**Rice**								
	Rice – ST rice[#]	2.301***	0.31	2.329***	0.42	2.280***	0.52	3.82***	0.59
	Rice – vegetable	-4.635***	1.09	-2.527***	0.91	-1.53	0.99	-4.085***	1.29
	Rice – fruit	-1.205	0.76	-2.689***	0.94	-1.885	1.19	-6.108**	2.94
	Aquaculture	13.443***	1.35	7.964***	1.63	16.719***	1.79	7.063***	2.71
(Interaction with high salinity, binary variable EC > 4 = >1)									
Rice – ST rice x EC > 4				-1.936**	0.79			-1.798*	1.08
Rice – vegetable x EC > 4				6.357***	1.19			7.561***	1.15
Rice – fruit x EC > 4				5.158***	0.98			5.655***	2.65
Aquaculture x EC > 4				16.62***	1.82			20.633***	2.28
Standard deviation estimates									
Production costs (million VND[!])		0.678***	0.06	0.670***	0.07	1.054***	0.09	1.233***	0.16
Risk	**low**								
	medium	0.688*	0.37	0.060	0.39	0.19	0.38	0.515	0.44
	high	0.140	0.74	1.192**	0.49	1.709***	0.57	3.272*	1.81
Effort	**low**								
	medium	1.233***	0.42	0.444	0.46	2.949***	0.61	1.616	1.01
	high	1.388**	0.56	1.837***	0.56	2.332***	0.67	0.909	1.18
Returns (million VND[!])		0.066***	0.02	0.037	0.03	0.042*	0.03	0.242***	0.04

Legal restriction		0.945	0.89	2.008*	0.66	0.907	0.88	5.775***	2.07
Crop	**Rice**								
	Rice – ST rice#	6.08***	0.51	7.206***	0.67	8.935***	0.84	9.838***	1.11
	Rice – vegetable	14.968***	1.54	11.511***	1.10	18.215***	1.88	18.538***	4.63
	Rice – fruit	7.582***	1.16	6.551***	0.87	14.628***	2.16	13.781***	2.86
	Aquaculture	2.838***	0.68	4.488***	0.85	5.222***	0.93	10.288***	2.07
τ		0.302	5.70	0.417	7.63	0.546	9.38	0.759	34.54
γ		0.67	12.81	0.670	12.26	--		--	

Table 4.3.A2: Soil salinity classes according to the crop response to salinity

Soil salinity class	Soil salinity	Conductivity of saturation extract (dS/m)	Effect on crop plants
1	Non-saline	0-2	Salinity effects negligible
2	Slightly saline	2-4	Yields of sensitive crops may be restricted
3	Moderately saline	4-8	Yields of many crops are restricted
4	Strongly saline	8-16	Only tolerant crops yield satisfactorily
5	Extremely saline	>16	Only a few very tolerant crops yield satisfactorily

(Source: Abrol et al. 1998; FAO, 1988)

Table 4.3.A3: Crop characteristics for the simulation of adoption rates of various sequences

Crop	Returns (in thousands of VND[!])	Production costs (in thousands of VND[!])	Risk	Effort	Legal restriction
RICE	2002.5	1241	Low	Low	No
ST RICE	2002.5	1483	Medium	Low	No
VEGETABLES	1126	2363	Low	Medium	No
FRUITS	3792	4445	Low	Medium	No
SHRIMP	20260	28188	Medium	Medium	Yes
POLYCULTURE	18679	23679	Medium	Medium	Yes

Table 4.3.A4: Crop characteristics for the simulation of adoption rates of sequences, affected by salinity

Crop	Returns	CostsProduction	Risk	Effort	Legal restriction
RICE	2002.5	1241	Medium	Medim	No
STL	2002.5	1483	Low	Low	No
VEGETABLES	1126	2363	Medium	Medium	No
FRUITS	3792	4445	Medium	Medium	No
SHRIMP	20260	28188	Medium	Medium	Yes
POLY CULTURE	18679	23679	Medium	Medium	Yes

[!] VND: Vietnamese Dong (1 USD = 22,740 VND)

5 Conclusions and recommendations

5.1 Conclusions

To sum up, this dissertation demonstrates a set of empirical analyses of salinity impact on rice production and various adaptive strategies with adoption potential for rice farmers. It provides information about impacts of salinization at different levels. Using household survey data I explored the impacts of salt-water intrusion in rice fields at various levels of salinity and analyzed adaptation measures to different salinity impact levels. The empirical analyses were performed by using regression models and CEs. The results of the regression models showed that increasing salinization has a negative impact on rice production and is a significant threat to rice farming. The yield and efficiency of rice production is significantly lower in fields with soil salinity greater than 4 dS/m. These findings point out the need for a rearrangement of rice varietal portfolio on plots with salinity level less than 8 dS/m. This may help farmers to optimize varietal portfolios in order to achieve higher profits and to increase profitability without increased production risks and based on available resources. The portfolio rearrangement should consider both reorganizing suitable rice varieties, currently known and used in the area, and applying new salt-tolerant varieties to improve rice yield and rice production efficiency. For salinity levels not suitable for rice farming; I analyzed other solutions based on the experience of innovative rice farmers, experts' opinions and own analysis of cost-benefit. The CEs method was used to build a framework for the behavioral assessment of rice farmer's decisions regarding adaptation measures. The study considers rice farmers as a key component in the evolution of rural innovations based on their preferences and the interaction with the levels of salinity. Beckford (2002) (8) highlighted that farmers' views must be taken into account when accessing the usefulness of their innovations.

It is to be noted that there is a lack of studies addressing the issue of salinity by collecting primary empirical data from farmers own fields under their own field management conditions (63). Therefore, I found it pertinent to carry out research involving farmers in the field to understand not only the impact of salinity on rice production in multiple perspectives but investigate the farmer's preferences to adopt. There is the need for evidence-based and empirically derived information to support adaptation measures against salinity under local conditions (1448). Meeting these requirements, in my dissertation, I collected data from rice farmer households, used information and innovations from farmers that could help them to adapt to saltwater intrusion based on available local resources.

5.2 Recommendations

On the basis of the results of this dissertation, useful recommendations for local authorities can be developed to enable better decision making in adapting to salinization in the coastal areas of the central Vietnam.

Role of agricultural cooperatives

Agriculture in Vietnam and Thua Thien-Hue province generally is characterized by small family households that are organized in cooperatives. About seventy percent of rice households in my study sample cultivated rice area less than 0.5 ha that are divided into several dispersed small plots. This dispersed and small scale agriculture poses challenges to the adaptation to new conditions (e.g. Trough production specialization or product diversification) and the adoption of innovations (e.g. new technologies, new rice varieties, etc.), especially in dealing with salinity adaptation and the increase of production and of high-quality products (27; 41; 64).

Agricultural cooperatives in Vietnam are the suppliers and buyers of most agricultural inputs and outputs. They also support farmers in the acquisition of knowledge about new technologies and are also the social core of rural communities. In addition, agricultural cooperatives also provide technology for field works, transporting and they also provide loans. Therefore, cooperatives are determining factors in coping strategy to environmental stressors including salinity. They also need to be included in all adaptation strategies in Vietnam’s rural areas. In my study case, it is necessary to increase cooperatives’ awareness about suitable adaptation options to increasing soil salinity. According to the empirical results and field experience, agricultural cooperative officials need to be educated and trained about the significance of varietal portfolios and adapting crop sequences for different levels of salinity. The training and guidance that cooperatives provide to rice producers could help to increase rice productivity, reduce production costs, bring higher profit to members in the linkage with market and importantly adapt to increasing salinization.

Soil testing and rearrangement of rice varietal portfolio

Farmers often do not know the salinity level of their fields. But salinity has large impacts on rice production with a large variability in yield of various varieties. Proper soil testing can also help in the reduction of excess use of chemical fertilizers resulting in lower input costs and higher income of farmers (61). I, therefore, recommend salinity tests in the rice field at the start of every cropping season, especially before rice cultivation in the dry season and for fields with known salinity problems. The early determination of the salinity level can improve the choice of rice varieties and avoid wastage from re-sowing on those rice plots where high salinity levels lead to crop failure. I recommend an investment on salinity meters for the field at the level of cooperatives and make it one of the input services provided to farmers. The authorities and agricultural projects play an important role in credit supporting as well as technical training for cooperatives and farmers.

Salinity measurement encourages suitable application of rice variety response to salinity levels. Traditional rice varieties include KD18, HT1, TH5, X21, Xi23 and others should be planted on plots that have no salinity intrusion or low salinity level (2-4 dS/m). For moderately saline soil (4-8 dS/m), farmers should plant salt-tolerant varieties (ML48, RVT) or try saline tolerant rice varieties that have been successfully tested/applied in other regions.

The list of salt-tolerant varieties is diverse from number of successful experiments in the fields of the Central Coast region. For instance, a set of salt-tolerant rice varieties collected from Cuu Long Delta Rice Research Institute (CLRRI) has been successfully tested in dry and wet seasons during 2012-2013 (18). In another trial, a set of so-called Green Super Rice varieties (GSR) has been successfully tested in Thua Thien Hue province in two crops during 2013-2014 (19).

The cooperatives play an important role in timely provision of technology and information to farmers and could be the key to a sustainable intensification of rice production coping with climate change. Soil testing and the possibilities of a portfolio of varieties should be made available to cooperative leaders and could be professionally conducted by the cooperatives on fields suspected for higher salinity levels.

Resources use and management

Under the contexts of sea level rise and climate change, saline water should be considered as a useful resource rather than a constraint because it can support the production of large amounts of natural fish suitable for well-developed aquaculture systems. By this “living with salinity” approach, risks can be reduced through diversification of products and income sources (9). The surveys informed that some rice fields are abandoned in the dry season due to high salinity level (from level 4 (8-16 dS/m) and are no longer suitable for irrigated cultivation. Legal restriction is also one of the main reasons of rice field’s fallow. I suggest converting saline areas of rice fields permanently to aqua cultivation instead of abandoning these areas in the dry season. As the results of the CE show, the removal of legal restrictions on the conversion of rice-growing land to aquaculture ponds creates and motivates the opportunity for rice farmers to achieve higher profit margins and avoids the waste of resources. Additionally, salinity measurement in the study area demonstrated that adjacent areas usually have approximately the same salinity. Therefore, I recommend identifying the adjacent rice areas with high salinity levels over years that are on a regular basis abandoned during the dry season and convert these areas into permanent aqua culture fields. Small and dispersed rice plots of different households in this high saline level need to be consolidated to larger plots for efficient aqua cultivation. This will help to develop the conserved ecosystem and avoid conflicts from uneven conversion of rice farming to aqua farming on different dispersed plots. The mobilization of households to boldly convert rice-to-aquaculture areas in a comprehensive and collaborative manner is necessary. Once again the important role of agricultural cooperatives is shown in connecting and unifying the members as well as linkage with government relating to efficient resource use and management.

Irrigation and production planning

The result from descriptive statistics showed that the cooperatives only meet the irrigation needs of 60% of rice plots (15). Farmers indicated in individual conversations that cooperatives should invest in water pumps used for irrigation during the dry season, if possible supported by the government or in association with other private companies. At the same time, the development of other soft measures such as the adjustment of the cropping calendar (shift the seeding time) or diversifying cropping patterns based on water resources availability are necessary.

Coordination between actors of the agricultural sector

It is important to have collaboration and coordination between related stakeholders including Department of Agriculture and Rural Development, Department of Irrigation, Center of Hydrometeorology in terms of data sharing (analyzes and forecasts) and communication in order to have better sluice gate operation plans as well as seasonal calendars for farmers to reduce the vulnerability to salinity problem. We suggest that priority should be given to short-term adaptation measures such as the rearrangement of rice varietal portfolios for rice farming. For rice areas that are no more suitable for rice farming, the local authority should consider saline plots as resources and make use of it through combination of soft and hard adaptive measures, though focusing on hard measures as dyke development to prevent salt water intrusion is important.

5.3 Implications

This dissertation will be of interest to other rice growing developing countries with low-lying coastal areas. Given the general lack of studies on impact assessment of salinity in the developing countries, I hope that the analyses presented here will raise awareness. I suggest initiating detailed and location-specific assessments of potential impacts of salinity changes on rice farming in coastal area. Such estimates may encourage the development of alternative options for coastal communities exposed to imminent salinity risks. In addition to the above findings, the present study implied a set of limitations of the empirical analyses and an outlook for future research.

Limitations of the present study

Statistical analyses of regression models were performed by using only cross-sectional data collected during the dry and wet crops seasons of 2015-2016 (In article I and article II). The empirical data supported the impact analysis of salinity and the evaluation of adaptation options. We could, however, not assess the impact of climate change in this context because of the lack of panel data.

The technical efficiency of rice production at household level was computed using cross-sectional data collected using a Stochastic Frontier (Parametric Frontier technique) approach, while overall efficiency is the product of the technical efficiency which is estimated in this dissertation and allocative efficiency which is still missing. The dissertation does not presents Data Envelopment analysis (Non-parametric Frontier Technique) to calculate compare the results of two approaches in order to examine whether there are any substantial differences in the efficiency estimates derived in terms of productive efficiency.

The models considered salinity levels (presented by EC measurement) as important variables in the relationship with other inputs influencing rice output. However, there is still no consideration of other negative impact factors (other environmental economical-social factors) simultaneously with salinity intrusion. Thus, it is not easy to answer where is the tolerant threshold for rice plots to define each stage and apply suitable adaptations.

Regarding the rice varietal portfolio we recommended, our results did not go into spatially specific recommendations for each field. For example, the portfolio analysis showed that in non-saline level (0 - 2 dS/m) the variability of rice production could be minimised by up to 72% using a mix of the X21 and KD cultivars without indicating the specific displacement in area. These limitations are caused by data protection issues and a limited collaboration of related stakeholders.

In the behavioral research on rice farmers, the CE model (article III) cannot be used with too many attributes and too many levels of each attribute leading to possible omitting of attributes which could have an impact on rice farmers' decisions. Each rice farmer was asked to choose their most preferred alternative from a set of crop sequences with predefined attributes including salinity. However, a few of the respondents did not have saline plots that might have caused imaginary decisions that are not tied to the adaptation to saline intrusion.

Outlook for future research

Though our results indicated a relationship between increasing salinity and rice farming, more relevant variables, especially other environmental factors that may have an impact on rice production should be considered in future research. Additionally, analysis of panel data of salinization for rice and other crops could improve the analysis and allow spatially explicit recommendations and the identification of trends over time.

In efficiency assessment, implementation of comparative analysis between parametric (DEA) and non-parametric (SFA) frontier techniques as an integration of the two types of approaches through two-step models is necessary (56). This comparison should indicate the trade-off between DEA and SFA, that is, something is sacrificed for something to bar-gain complementally rather than direct competitors (25). An additional investigation of allocative efficiency and a cost-benefit study may be conducted for more insights. The existing inefficiency in allocating resources of rice production in Thua Thien-Hue province may also be investigated in future studies.

Future studies may also investigate why majority of the rice farmers prefer to stick with the traditional seed varieties in spite of lower yields and lower salt-tolerance.

With further researches it is important to identify and classify vulnerable groups to climate change in different levels. Identifying such groups will help to conduct in depth interviews with vulnerable groups and this will provide effective and efficient solutions to their vulnerability issues. Of course, the comparison between two vulnerable and non-vulnerable groups is also interesting for researchers.

Finally, to apply the suitable adaptations for each vulnerable groups and each ecological local area, it should be investigated in how far coordination and collaboration between farmers, cooperatives and other stakeholders could be improved to adapt better to spatiotemporal variability in soil salinity. It is equally important that the local government should formalize, facilitate, and scale up collaborative networks to accelerate rural innovations on a larger scale and benefits the wider farming communities (77).

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