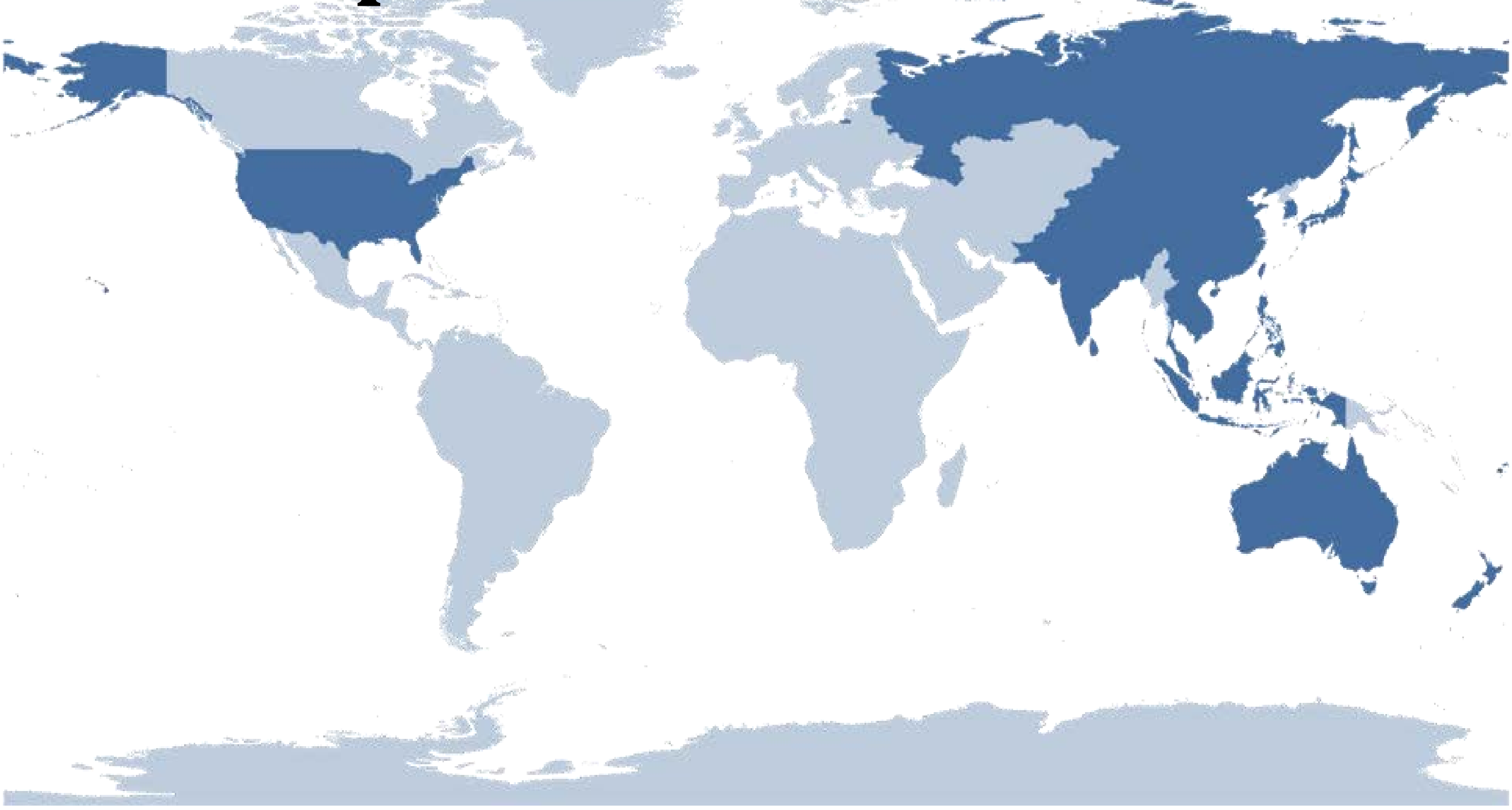
APN Asia-Pacific Network for Global Change Research

FINAL REPORT for APN PROJECT

Project Reference Number: ARCP2011-09CMY- Towprayoon

"Strategic Rice Cultivation for Sustainable Low Carbon Society Development in South East Asia"



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JGSEE The Joint Graduate School of Energy and Environment

CEE PERDO Center of Excellence on Energy Technology & Environment

“Strategic Rice Cultivation for Sustainable Low Carbon Society Development in South East
Asia

Project Reference Number: ARCP2011-09CMY-Towprayoon
Final Report submitted to APN

OVERVIEW OF PROJECT WORK AND OUTCOMES

Non-technical summary

Rainfed rice field in ASEAN Countries occupies an area of 19.8 million hectares which representing 49.2% of the total rice cultivation area of ASEAN. This area is used only 4-5 months per year with single cultivation while for the rest, 8-7 months the land is left fallow. This research work focused on the assessment and identification of strategic rice cultivation practices including rotation with energy crops to contribute to global warming mitigation and adaptation to climate change and enable SEA to develop towards a self-sufficient low carbon society. It was found that energy crop rotation with rice is a good strategy to reduce GHG emissions and contribute increasing soil carbon in the long run. Expansion of this strategy to SEA is not only enabling to enhance the biomass resources for biofuel and bioenergy with no impact to food crops but also to contribute reducing issues of competition between food and fuel crops as well as land use change problem. Moreover this strategic practice may contribute to increasing the potential of carbon sink and moving toward poverty eradication. However, the market of energy crop is a major driver for adoption of this practice and the formulation and implementation of clear policies on renewable energy and biomass utilization is therefore necessary and should be strongly promoted in each SEA country.

Objectives

The overall project objective is to provide scientific information on global warming mitigation and adaptation to climate change in the agricultural sector by improving rice cultivation practices including rotation with energy crops.

To achieve this overall objective, the sub-objectives of the project are:

- To develop sustainable low carbon agriculture in SEA through improved cultivation practices of rice and energy crops (crop rotation),
- To develop long - term field studies to measure, monitor and evaluate the impacts of various cultivation practices on climate change and identify potential adaptive measures and mitigation options,
- To enhance regional capacity of scientists and policy makers in SEA to contribute to sustainable low carbon development of their society.

Amount received and number years supported

The Grant awarded to this project was:
US$ 40,000 for Year 1: 2011-2012
US$ 40,000 for Year 2: 2012-2013

Activities undertaken

To achieve the overall objective of this project, investigations were broken down into 5 major activities as detailed below:

Activity 1: *Review of rice cultivation practices and use of energy crops for rotation in SEA.*
This activity aimed at providing an overview of rice cultivations practices in SEA including potential for rotation with other (energy) crops. Under this activity a report on the state-of-the-art of rice cultivation practices and potential of rotation with energy crops in SEA countries was produced as well as a questionnaire enabling to collect specific information on rice cultivation practices from farmers. Due to limitation of budget and time, the questionnaire survey was performed for the case of Thailand and Indonesia (project collaborator).

Activity 2: *Long-term monitoring of GHG emissions and soil carbon dynamics from rice cultivation and utilization energy crops for rotation*

This activity aimed at comparatively assessing the influence of rice rotation with selected energy crops during the fallow period under well defined cultivation conditions not only on soil carbon cycle or stock but also socio-economic aspects. This assessment aimed ultimately at identifying strategic rice cultivation practices in rotation with energy crops. Under this activity, GHG emissions and soil carbon stock of some current practices of rice cultivation in Thailand were assessed. For long-term monitoring of GHG emissions and soil carbon dynamics, experimental plots with different irrigated short-lived rice cultivation practices were set at the Ratchaburi Campus at King Mongkut's University of Technology Thonburi (KMUTT). Corn and sweet sorghum are the energy crops that were selected for rotation with rice due their short cultivation period, their potential to grow anywhere in the SEA region, their low requirement in water and their ability to serve as feedstock for ethanol production.

Activity 3: *Capacity assessment of GHG emissions and carbon stock from sustainable cultivation practices in SEA*

This activity aimed at assessing the capacity of carbon budget in terms of emissions and carbon stock for rice fields in SEA. To this end, a GIS database of GHG emissions and mitigation options obtained from activity I and II was prepared to serve as input to a GHG emission inventory software program, i.e. ALU software. GIS maps of GHG emissions resulting from existing and alternative cultivation practices were established for Thailand and then replicated to assess the GHG emissions and carbon stock of rice fields in other SEA countries to assess the potentials for reduced GHG emissions (climate change mitigation) for different cultivation scenarios.

Activity 4: *Long-term soil carbon dynamics assessment of sustainable low carbon cultivation using process model*

Long-term soil carbon storage and sequestration may be influenced by the agricultural method followed. The assessment of long-term soil carbon storage and sequestration of the feasible rice-energy crop system was performed under this activity using monitoring and modeling data. Data generated from activity II was used as input to DNDC to analyze the time-series change in carbon storage vs. the corresponding GHGs emissions. Outputs from the model was used to better understand the carbon cycle of cultivated soil system, and the increase of soil carbon storage and soil fertility, which are key criteria for sustainable cultivation.

Activity 5: Knowledge dissemination to scientists and policy-makers in SEA

The objective of this Activity is to build capacity of the scientists and policy-makers in SEA in terms of understanding the strategic approach of sustainable rice cultivation management that would lead to lower GHG emissions while increasing energy crop production. The project closing workshop will be conducted in Thailand with invited participants from selected SEA countries. Emission inventory and carbon storage maps developed from the project under base case and mitigation scenarios will serve as reference information for policy-maker to lay down relevant policies in SEA countries. Long-term soil carbon storage and sequestration will benefit the scientific community to evaluate the potential carbon sink capacity of the SEA region. Results from the dissemination should serve help the analysis and determination of the most appropriate mitigation options and policy measures for developing sustainable low carbon cultivation practices in SEA.

Results

The results achieved from this project can be summarized as follows for each of the main research activities of the project:

Activity 1:

- Overview of state-of-the-art of rice cultivation practices and use of energy crops as potential rotation crops in SEA countries
- Establishment of a database of rice cultivation practices of each country in SEA

Activity 2:

- Production of data related to long-term monitoring of GHG emissions and soil carbon dynamics from specific rice-energy crops cultivation practices based on an experimental site in Thailand.
- Comparative assessment of selected crop rotation practices in term of carbon cycle, economic and social benefits, barriers, best practice issues, etc.
- Identification of feasible sustainable rice-energy crop cultivation practices under well-defined conditions.

Activity 3:

- Production of maps of GHG emissions from rice fields vs. cultivation practices in SEA
- Production of maps of carbon stock of rice fields in SEA
- Development of a database of GHG emissions inventory using ALU software
- Assessment of the Carbon budget of rice cultivation under existing and sustainable practices (i.e. rotation with Corn and sorghum) in SEA

Activity 4:

- Collection of Informative data on long-term soil carbon storage vs. selected rotation crops and cultivation practices
- Comparative assessment of soil carbon sequestration under selected rice-energy crops rotation regime
- Assessment of appropriate cultivation practices as mitigation options for low/reduced carbon emission in the agriculture sector

Activity 5:

- Capacity building of scientists on inventories of GHG emissions and carbon stock as well as process modeling tools
- Capacity building of scientists and policy-makers on mitigation options in the agricultural sector for a low carbon society.

Relevance to the APN Goals, Science Agenda and to Policy Processes

The project objective provided scientific information on global warming mitigation and adaptation to climate change in the agricultural sector by improving rice cultivation practices including rotation with energy crops namely corn and sorghum. This would contribute (1) develop strategic agricultural practices incorporating rice and energy crops in the region, (2) develop field experiments to monitor GHG emissions and soil carbon dynamics of various cultivation practices (3) assessment of national capacity in building an agricultural low carbon society in the region, and hence contributing to climate change adaptation and mitigation for sustainable development. The achievement of these goals should support regional policy-makers in (1) formulating appropriate mitigation options in the agricultural sector, (2) selecting suitable strategic cultivation practices combining rice and energy crop cultivation, and adaptive cultivation practices, and (3) enhancing national scientific and technical capacity in assessing GHG emissions and soil carbon storage of various cultivation practices, which would consequently contribute to Climate Change Adaptation and Mitigation helping reducing regional Vulnerability and leading towards low carbon society development.

Self evaluation

Referring to the initial plan presented in the proposal, the following targets were achieved:

(1) Production of a report on Strategic rice cultivation practices in SEA and rotation with energy crops (main output of activity 1 of the project)

(2) Production of a report on long-term GHG emissions, soil carbon dynamics and socio-economic constrains associated to specific rice-energy crops cultivation practices (main output of activity 2 of the project)
(3) Spatial and temporal distribution of GHG emissions and carbon stock associated to rice paddies in SEA based on ALU simulations (main output of activity 3 of the project)
(4) Assessment of long-term soil carbon storage and sequestration associated to rice paddies and rotation with energy crops using the DNDC Biogeochemistry model (main output of activity 4)
(5) Dissemination of the knowledge generated from the project to scientists and policy makers in SEA during a 3 day-training workshop organized end of May 2013 following completion of all the project activities (main output of activity 5)

Potential for further work

In line with the time and budget available to perform this research work, the activities of this project focused on the assessment of GHG emissions and carbon stock dynamics associated to rice cultivation in rotation with specific energy crops i.e. Sorghum and Corn, for selected countries in SEA. The scope of this research could be further extended to include more energy crops and countries in the region than those focused on in this project. Also, regional simulations using DNDC could be performed (site specific simulations were performed in this research work) to evaluate the implication of strategic rice cultivation practices in rotation with energy crops at a regional scale. This would provide useful information to support low carbon development in the region, contribute to climate change mitigation and overall to more sustainable development.

Publications (please write the complete citation)

(1) A website reporting on the APN project activities and events including downloadable materials produced for the expert meeting (June 2011), training workshop on DNDC (February 2013) and final project workshop (May 2013) of the project are available at: http://www.jgsee.kmutt.ac.th/apnproject.
(2) Electronic copies (USB key) and hardcopies of the workshops' materials organized during the course of the project have been produced and provided to all participants of those events.
(3) Presentation on "Rice Cultivation and Potential Areas for Rotation with Energy Crops in South-east Asia" at the 17th Inter-Governmental Meeting (IGM) and Scientific Planning Group (SPG) Meeting in Jakarta (Indonesia), on 14 March 2012
(4) Two international journal publications and conference papers on the results obtained via this project are also planned to be produced during the period 2013-2014.

References

All the references that were used to support this work can be found at the end of the reports (provided as separate appendices) that were produced for each of the 4 main activities of this project.

Acknowledgments

The APN ARCP program, and the Joint Graduate School of Energy and Environment in Thailand, Mongkut's University of Technology Thonburi, the Bogor Agricultural University in Indonesia and the National Institute for Agro-Environmental Sciences (NIAES) in Japan, are acknowledged respectively for the funding, and the expertise, facilities and equipments provided to perform and successfully accomplish the activities of this project.

TECHNICAL REPORT

Preface

This technical report describes the activities and results obtained as part of the Asia Pacific Network ARCP Project entitled: Strategic Rice Cultivation for Sustainable Low Carbon Society Development in South East Asia.

This 2-year project enabled review current status of rice cultivation practices in the region and potential for rotation with energy crops. It also contributed to identify strategic rice cultivation practices with selected energy crops that would contribute to mitigation of climate change and therefore development of the region towards a low carbon society. The project also enabled to interact with scientists and policy makers in the region of SEA, to share knowledge and raise awareness on the subject of these investigations.

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1. Introduction

South East Asia (SEA) covers an area of 410 million hectares and agricultural land represents about 20% of the total area. Agricultural land has been expanding in SEA over the past decades including but not limited to onto previously forested areas. Such changes in land use reflect actually the development of intensive agriculture, which is a major economic activity in SEA. Of all food crops grown in the region, rice is a major feedstock. On a global basis, according to the Food and Agriculture Organization (FAO), rice plantation covers an area representing about 12.5% of total crop plantation area. This translates in an annual rice production amounting to 659 million tonnes and contributing 164 billion US dollars on the world economy. SEA is the region with the largest area of rice plantation with a coverage representing 30% percent of the world plantation. Maximizing rice yield in this region is therefore essential to increase global food stock. Nevertheless, current climate and energy crisis strongly influence the regional potential for rice production. Temporary or permanent conversion of rice plantation into oil palm plantation and other energy crop plantations has already been implemented in many SEA countries, notably Thailand and Indonesia.

This project addresses strategic rice cultivation practices that would enable to contribute face both climate and energy security issues, by rotating rice with energy crops in order to fully utilize the rice plantation fallow period and hence optimize rice and energy feedstock production. Proposed cultivation practices aim at reducing Greenhouse Gas (GHG) emissions while increasing potential long-term soil carbon stock by optimizing land use change and cultivation practices. Sustainable development is considered in terms of enhancing economic and social benefits while developing a low carbon society to bring down the net GHG emissions and increase soil carbon stock. The overall goal of the project is therefore to identify strategic rice cultivation practices enabling SEA to develop towards a sustainable low carbon society, i.e. reduced GHG emissions, while enhancing the adaptive capacity in the agriculture sector.

2. Methodology

2.1 Overview of the research activities performed in this project

In order to evaluate strategic rice cultivation practices including rotation with energy crops, several a activities were performed in this research work starting with first an assessment of the current status of rice cultivation practices in SEA and potential crop used in rotation with rice. Such information was collected via a literature survey, an expert meeting, and a questionnaire survey that was performed in Thailand and Indonesia. Following this initial assessment, an evaluation of long term GHG emissions and soil carbon dynamics of various rice cultivation systems including rotation with selected energy crops (corn and sorghum) was performed at a specific experimental site in Thailand. Socio-economic considerations regarding such practices were also taken into consideration to eventually come up with possible options for strategic rice cultivation in rotation with energy crops. The experimental data generated from this assessment served as input to the Agriculture and Land Use (ALU) software and the DeNitrification-DeComposition simulations (DNDC) model to investigate GHG emissions, carbon stock and soil carbon dynamics for various scenarios of rice cultivation systems. The simulations were performed first for the case of Thailand where experimental data on GHG emissions and soil carbon measurements had been performed but with the possibility of expanding the simulations to SEA. The overall research framework followed for this research is illustrated in Figure 1.

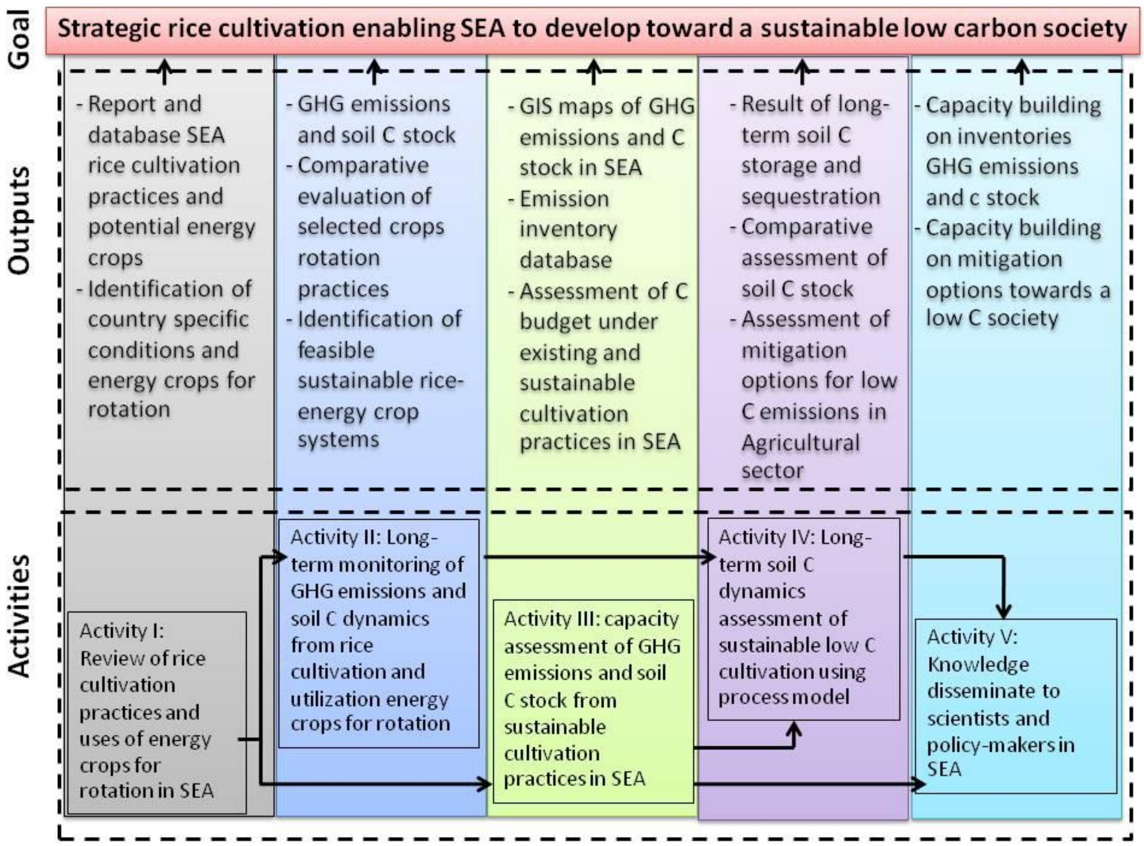


Figure 1 Research Framework

2.2 Status of rice cultivation and rotation with energy crops in SEA

The overall status of rice cultivation including rotation with potential energy crops during fallow periods was reviewed for SEA based on literature survey, information collected from experts in the region as well as a questionnaire survey performed specifically for Thailand and Indonesia (due to constrains of time and budget) to recheck and confirm the information that had been collected from secondary sources. The overall information is available in Appendix 1 in the form of a report entitled "State of the art of rice cultivation practices in South East Asia". The questionnaire that was designed for the survey performed in Thailand and Indonesia is provided in Appendix 2. The programme and presentation materials collected during the expert meeting that was organized during 2-3 June 2011 at JGSEE to gather information on rice cultivation practices in SEA are provided in Appendix 3.

2.3 Long term measurements of GHG emissions and soil carbon dynamics from various rice cultivation systems in Thailand

The paddy fields are important sources of CH_4 as well as N_2O emissions. So it is very important to consider both these GHGs into consideration when investigating mitigation options through appropriate cultivation practices. In this study, field experiments were conducted to understand GHG emissions from rice field as well as rotation with selected energy crops, i.e. corn and sorghum. The study focused on the investigation of GHG emissions under specified conditions and soil carbon dynamics, as well as comparative evaluations of selected crop rotation systems in terms of carbon cycle and its social and economic implications. The full report of these investigations can be found in Appendix 4).

2.3.1 Experimental set up

The field experiments established at KMUTT-Ratchaburi campus in Sub-district Rang Bua, Chombung District, Ratchaburi Province, Thailand. The single rice cropping in rainy season and fallow land in dry season and double rice cropping in dry and rainy season were considered as a rice cropping systems. The rotation cropping system is rainfed rice (Patumthani 1) with selected energy crop rotation which is corn [Suwan 5] and sorghum [Khon Kaen 40].

The experiments were laid out for the years 2010 and 2011 in randomized complete block design (RCBD) with in total eight plots with size 75 m^2 (5 m X 15 m) were established for four crop rotation systems. The rotation systems used in this experiments are 1) Single cropping of fallow land and rain fed rice (RF), 2) Double cropping of corn and rain fed rice (RC), 3) Double cropping of irrigation rice and rain fed rice (RR) and 4) Double cropping of sweet sorghum and rain fed rice (RS) (see Figure 2).

The black acrylic closed chamber method was used to trap gas emitted from plant and soil into atmosphere throughout the investigation period. Gas samples were taken once a week during day time. The biomass sampling and analysis was done at the same time during harvesting of crop. The samples were collected and dried in the oven for 24hrs at 80°C and then analyzed using nitrogen and carbon analyzer. The amount of carbon in biomass was determined based on the following expression:

$$\text{Carbon in Plant (g C m}^{-2}\text{)} = \text{C element concentration (g C g}^{-1}\text{plant)} \times \text{weight and to the equivalent plant area (m}^{-2}\text{)}$$

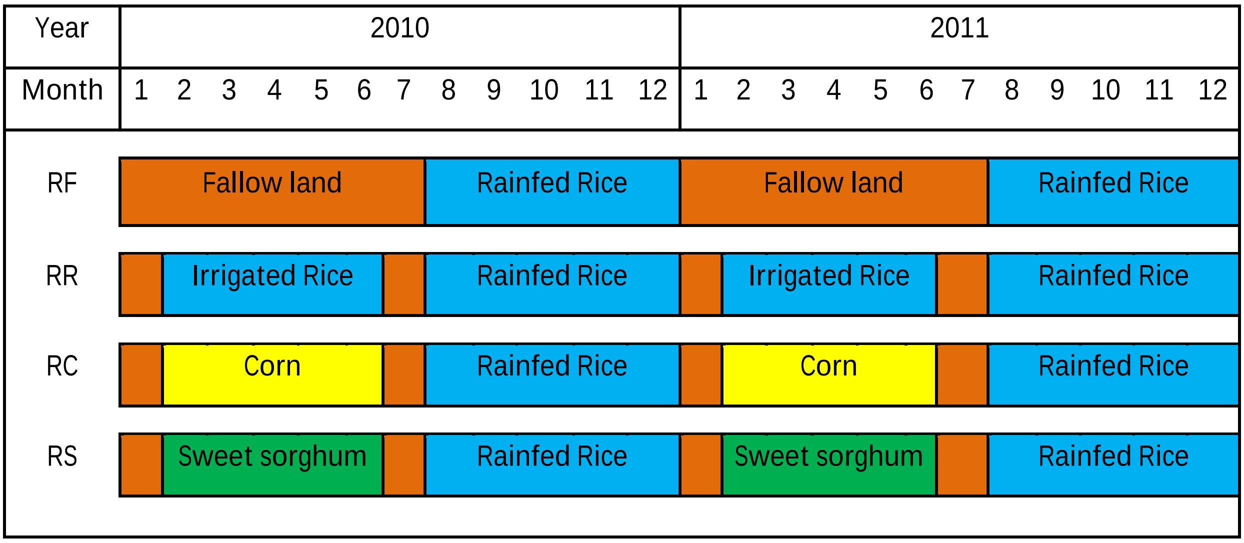


Figure 2 Structure of experiment design

The soil samples were collected from each plot treatment from top layer of soil at a depth 0-15 and 15-30 cm at the day after crop harvesting. The soil organic carbon stocks of each crop were estimated by equivalent soil mass method (ESM) (Lee et al. 2009). According to Nishimura et al. 2008 Soil carbon budget (SCB) can be estimated by integrating the amounts of net carbon supply and removal. Figure 3 and Table 1 show the details of carbon dynamics in experiments and the carbon calculation procedure.

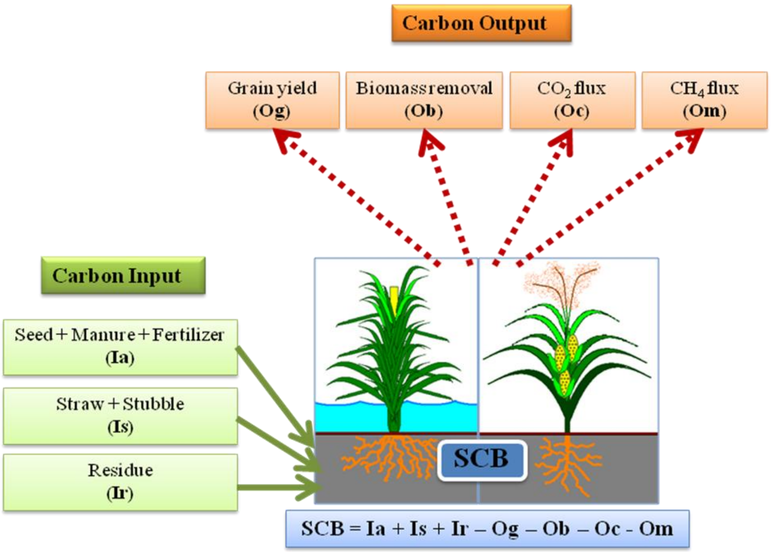


Figure 3 Carbon dynamics in experimental system

Table 1 Terms of carbon calculation

Term	Description
Ia	carbon supplied to the soil by seed, manure and chemical fertilizer
Is	carbon supplied to the soil by straw and stubble incorporation
Ir	carbon supplied to the soil by root residue
Og	carbon removed by grain yield
Ob	carbon removed by crop biomass
Oc	carbon emitted from soil to the atmosphere in the form of CO_2 emission
Om	carbon emitted from soil-plant to the atmosphere in the form of CH_4 emission
SCB	soil carbon budget (g C m^{-2})

2.3.2 Statistical analysis

The one-way analysis of variance (ANOVA) and Duncan's multiple range test ($p = 0.05$) were used to determine the temporal variations of gas fluxes, soil organic carbon (SOC) stock, and Soil carbon budget (SCB) between the rotation of cropping systems (Xiao et al. 2005).

2.4 Assessment of the spatio-temporal distribution of GHG emissions and carbon stock of various rice cultivations systems in SEA

2.4.1 Description of ALU

The ALU program can be used to estimate emissions and removals associated with biomass C stocks, soil C stocks, soil nitrous oxide emissions, rice methane emissions, enteric methane emissions, manure methane and nitrous oxide emissions, as well as non-CO_2 GHG emissions from biomass burning. Methods included in the program are based on guidelines provided by the Intergovernmental Panel on Climate Change (IPCC), as documented in the Revised 1996 IPCC National Greenhouse Gas Inventory Guidelines, and further refined in the 2000 IPCC Good Practice

Guidance on Uncertainty Management in National Greenhouse Gas Inventories, as well as in the 2003 IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry.

2.4.2 Data inputs

The data inputs required to run the model are provided below for the following items (1) Climate and soil data, (2) Rice cultivation area, (3) Rice productivity, (4) Fertilizer N use by rice

(1) Climate and soil data: For all countries of SEA considered (Cambodia, Indonesia, Lao, Malaysia, Myanmar, Philippines, Thailand, and Vietnam) the climate can be considered as tropical moist. For each of the four rice ecosystem considered in these investigations, soil characteristics are same for all SEA countries, and as follows:

- Irrigated rice: high activity clay
- Rainfed lowland rice: low activity clay
- Upland rice: low activity clay
- Flood prone: Wetland mineral

Details about the area of rice cultivated, productivity, and fertilizer N use in SEA countries are derived from IRRI Rice Facts of 2002 and PPI-PPIC ESCAP 2001. See more detail in Appendix 5.

2.4.3 Development of GIS based maps of GHG emissions and soil carbon stock of existing and sustainable cultivation practices

The maps of rice cultivation areas were obtained by overlaying SEA countries land cover maps with paddy field areas derived from satellite information. In order to visualize the change in GHG emissions and soil carbon stock in two different years, e.g. in 2010 and 2030 gridded-maps were developed with a grid resolution of 10-km x 10-km. Potential mitigation options based on different scenarios according to long term field measurement experiments in 2010 (see Figure 2) were assessed using ALU software. The full details of this activity are reported in Appendix 5.

2.5 DNDC simulations of long-term GHG emissions and soil carbon dynamics of various rice cultivation systems

2.5.1 DNDC model Description

The DNDC 9.3 version was used in this study to simulate the field measurements of CH_4, N_2O and CO_2 emissions. The DNDC model under development at the University of New Hampshire since 1992, which is process based simulation model for soil carbon and nitrogen biogeochemistry cycle's (Li et al. 1992a, 1992b, 1994 and 1996). The DNDC is an integration of six sub-models and describes the generation, decomposition and transformation of organic matter and provide as output the dynamics of components of SOC and GHGs (Zhang et al. 2009).

2.5.2 Study area

The field experiments were conducted at Ratchaburi campus of King Mongkut's University of Technology Thonburi, Thailand for the years 2010-2011 to understand the GHG emissions and soil carbon dynamics associated with rice crop cultivation as well as rotation with energy crops (i.e. corn and sorghum) using field observations (see details in Section 2.3).

2.5.3 Data input

The site mode of DNDC model (version 9.3) was used to estimate the soil organic carbon storage and GHG emissions in rice-energy crop rotation. The major ecological factors to drive the model for simulating the GHG emissions from paddy field in rotation with energy crop included three major input parameters that are climate (maximum and minimum temperature and precipitation), soil properties and farm management practices. All input parameters were used to run DNDC model on site mode for the experimental site. The climate data were collected from the Thai Meteorological Department (TMD-Ratchaburi Station), soil physical and chemical properties were collected from laboratory analyses, and farm management data were collected from literature review and personal interviews with farmers (see Appendix 2 for more details on questionnaire survey). The long term simulations from 2011-2030 was conducted using climate data from PRECIS Climate model ECAM4 SRES B2 and using the crop management practices from the second year (2011) of field experiments in Ratchaburi-KMUTT. The information of crop management practices at KMUTT's experimental site for the DNDC model simulations can be found in Appendix 6.

2.5.4 Model validation

The DNDC model results were validated against the measurement data obtained from the field measurements in Thailand. A first validation of the results was done at the occasion of a training event organized during 11-13 February 2013 in Bangkok (see Appendix 7 for the full programme and presentation materials).

At the experimental site in Ratchaburi, the observed GHG fluxes were conducted once per week using a black acrylic closed chamber method (see details in Appendix 4) and then simulated GHGs fluxes were compared with those observed from the field. The model was evaluated using correlation (R^2) and root mean square error (RMSE) coefficients. RMSE is considered as best overall measure of model performance as it summarizes the mean difference in the units of observed and predicted values (Willmott, 1982; Babu *et* al. 2006).

2.6 Dissemination of results to scientists and policy makers in SEA region

A 3 days capacity building workshop was organized during 29-31 May 2013 to disseminate the final project outcomes to scientists and policy makers in the region. At that occasion, the main findings of the project were disseminated to all participants and 2 full days trainings were organized on ALU and DNDC so that the experts can continue this work using their own country's data. Details of the event, including the programme and presentation materials, are provided in Appendix 8.

3. Results & discussion

3.1 Spatio-temporal distribution of GHG emissions and carbon stock of rice paddies in SEA

By using ALU software (see appendix 5), GHG emissions from rice cultivation composed of CH_4, N_2O direct from N in Crop residue, and N_2O direct from synthetic N fertilizer are summarized in Table 2. Indonesia is the first emitting country because of largest area of cultivation, followed by Vietnam where intensification of crop rotation is practiced with up to three crops per year, and Thailand where double cropping is a common practice, especially in the central region and irrigated areas. In each country, the major source of GHGs is N_2O direct from nitrogen in crop residues followed by rice CH_4.

Table 2 GHG Emissions from rice fields vs. cultivation practices in SEA.

Country	GHG Emissions from rice fields vs. cultivation practices in SEA (Gg CO_2-e/yr)			
	Rice CH_4	N_2O direct from N in Crop residue	N_2O direct from synthetic N fertilizer	Total GHG Emissions
Cambodia	7,589	8,782	41	16,412
Indonesia	90,303	143,968	5,810	240,080
Laos	1,540	2,445	56	4,041
Malaysia	6,074	9,833	288	16,196
Myanmar	29,616	41,313	614	71,542
Philippines	33,508	53,120	853	87,480
Thailand	48,510	70,277	2,731	121,519
Vietnam	55,124	85,008	3,625	143,756
Total	272,265	414,745	14,017	701,027

The spatial distribution of GHG emissions from rice cultivation in SEA is illustrated in Figure 4. Individual emission maps of Indonesia, Thailand, Vietnam, Laos and Cambodia can be found in Appendix 5.

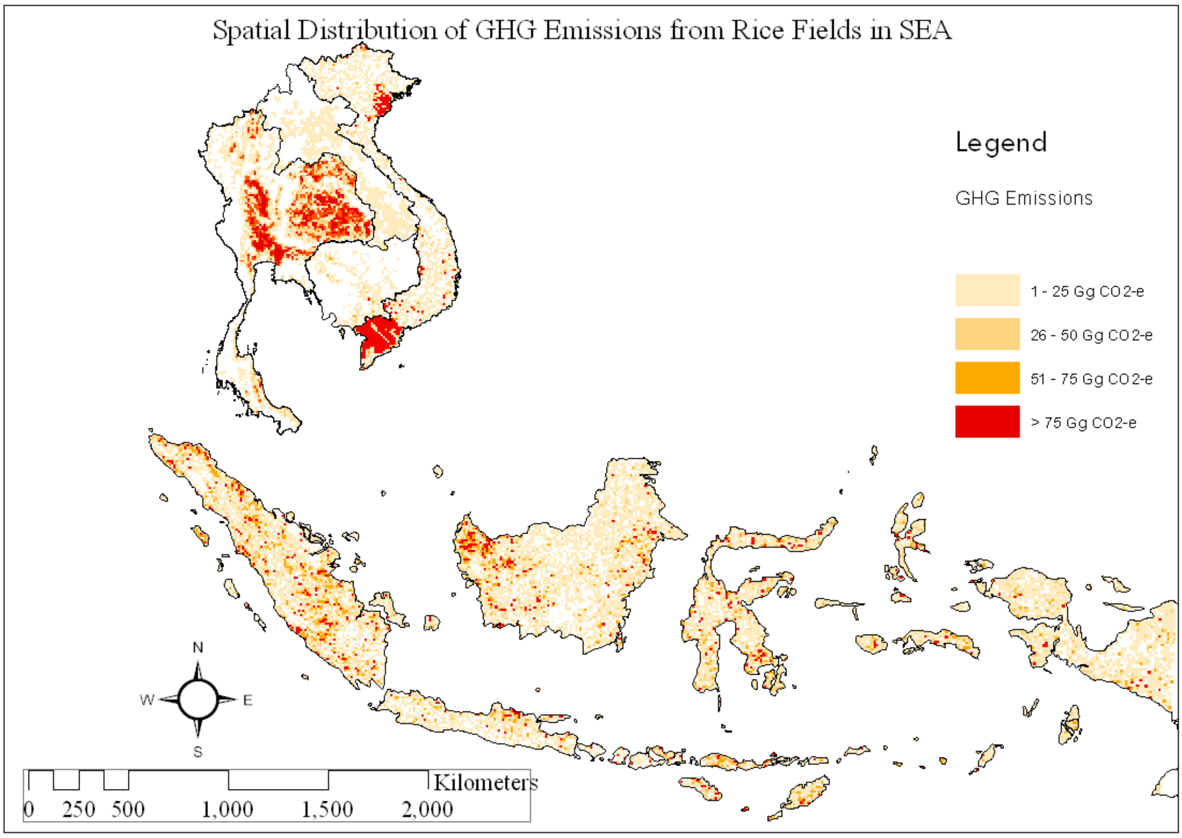


Figure 4 Spatial distribution of GHG emissions from rice cultivation in SEA

The results show that Thailand and Vietnam possess high number of highest GHG emission grids (>75 Gg CO_2-eq per grid) or "hot spot". In Thailand, the areas of "hot spot" cover the central and northeastern regions of the country, while in Vietnam they are observed close to the Red Delta and Mekong Delta. In Cambodia, some "hot spots" appear in the region of Tonle Sap. In case of Indonesia, emission intensity is quite stable throughout the country. Opportunity for mitigation of

GHG emissions from rice field is high in Thailand Vietnam, Cambodia and Indonesia where ‘hotspots’ of such emissions are observed to dominate including via rotation with energy crops.

3.2 Mitigation of GHG emissions

With the field experiments in Ratchaburi province, two major greenhouse gases emitted from energy crop rotation rice field are measured in this study, namely methane and nitrous oxide. In addition carbon dioxide is also observed as an indicator of growth of the crops cultivated. Details of the experiments performed in Ratachaburi can be found in appendix 4. Details of the measurements and results of CH_4, N_2O and CO_2 emissions for the different cropping systems investigated in this study are provided below and results also shown in Table 3.

3.2.1 Methane emissions

CH_4 fluxes were observed to be significantly higher during the rice-growing season but negligible during the fallow land, corn and sweet sorghum growing season (RF, RC, and RS). In all plots of rainfed rice period (2^{nd} and 4^{th} crop), CH_4 fluxes from double cropping of rice were significantly higher than rice rotated with corn, sweet sorghum and fallow land. Field observations indicated that the seasonal cumulative CH_4 fluxes from rice-rice cropping system were 762.26 and 2,960.60 mg CH_4 m^{-2} $crop^{-1}$ in 2010 and 7,043.82 and 2,433.58 mg CH_4 m^{-2} $crop^{-1}$ in 2011, respectively. During crop rotation with corn and sweet sorghum the cumulative CH_4 fluxes of corn were found to vary from -0.38 mg CH_4 m^{-2} $crop^{-1}$ in 2010 to 99.19 mg CH_4 m^{-2} $crop^{-1}$ in 2011 and CH_4 fluxes of sorghum to vary from 105.74 mg CH_4 m^{-2} $crop^{-1}$ in 2010 to 125.42 mg CH_4 m^{-2} $crop^{-1}$ in 2011. The positive emission values of CH_4 are indicative of emissions to the atmosphere while negative values are indicative of absorption into the soil through microbiological oxidation by methanotrophic bacteria (Cai et al. 1997; Nishimura et al. 2008). The results from 2010-2011 show that the selected energy crops (corn and sorghum) enable to reduce CH_4 emissions by 84% and 85% when compared with the double rice cropping system.

3.2.2 Nitrous oxide emissions

Higher N_2O fluxes were observed during fallow period and for corn and sweet sorghum during the growing period possibly because of nitrogen fertilizer application. Some lower N_2O fluxes were observed during the rice growing season. The N_2O cumulative fluxes of RF, RC, RR and RS plots in years 2010-2011 were 57.61, 94.78, 37.18 and 105.43 mg N_2O m^{-2}, respectively. For energy crop cultivation, the highest N_2O emissions for corn and sweet sorghum were found to amount to 299-355 µg N_2O m^{-2} day^{-1} and 268-339 µg N_2O m^{-2} day^{-1}. The energy cropping systems without floodwater produce N_2O emissions through the nitri-denitification process. The cumulative fluxes of N_2O are related to different cropping systems and cropping conditions. The cumulative fluxes of N_2O in 2010 and 2011 for corn and sorghum were found to be 3 times higher than for the double rice cropping system.

3.2.3 Carbon dioxide emissions

CO_2 emissions from this research were determined as the total of plant dark respiration and soil heterotrophic respiration, since the chamber covered the plants while taking gas samples. The CO_2 cumulative fluxes of RF, RC, RR and RS plot in the years 2010-2011 were 404.25, 603.30, 733.93 and 694.39 g CO_2 m^{-2}, respectively. Fertilizer application induced significant increase in the CO_2 fluxes for all crops.

Table 3 Cumulative flux of CH_4, N_2O and CO_2

Crop/Treatment		CH_4 (mg CH_4 m^{-2} $crop^{-1}$)	N_2O (ug CH_4 m^{-2} $crop^{-1}$)	CO_2 (g CH_4 m^{-2} $crop^{-1}$)
1st crop in 2010				
	RF (*fallow*)	-6.09±4.77	19,513.42±427.26	46.81±2.08
	RC (*Corn*)	-0.38±7.06	26,918.14±419.99	97.14±2.88
	RR (*Rice*)	762.26±32.00	2,753.46±77.98	238.23±6.72
	RS (*Sorghum*)	125.42±8.70	32,166.12±661.70	211.33±4.53
2nd crop in 2010				
	RF (fallow→ *Rice*)	784.90±46.68	14,707.65±321.74	134.78±6.19
	RC (Corn→ *Rice*)	849.66±43.03	19,441.81±329.74	144.98±7.48
	RR (Rice→ *Rice*)	2,960.60±136.50	11,233.00±284.05	130.52±7.61
	RS (Sorghum→ *Rice*)	610.73±48.01	18,945.79±439.96	116.29±6.02
3rd crop in 2011				
	RF (fallow→ Rice→ *fallow*)	6.37±3.60	9,816.33±232.45	80.62±1.78
	RC (Corn→Rice→ *Corn*)	99.19±6.59	32,392.20±847.09	203.37±5.22
	RR (Rice→ Rice→ *Rice*)	7,043.82±125.07	7,421.84±157.41	207.98±4.50
	RS (Sorghum→ Rice→ *Sorghum*)	105.74±6.39	38,680.42±826.67	208.48±6.32
4th crop in 2011				
	RF (fallow→ Rice→ fallow→ *Rice*)	1,003.01±45.85	13,569.14±399.76	142.05±5.23
	RC (Corn→ Rice→Corn→ *Rice*)	1,105.52±50.21	16,030.34±382.06	157.82±5.34
	RR (Rice→ Rice→ Rice→*Rice*)	2,433.58±116.06	15,766.58±367.72	157.16±6.86
	RS (Sorghum→ Rice→ Sorghum→ *Rice*)	1,104.60±53.13	15,637.06±536.38	158.30±5.73

3.3 Long term GHG emissions of various rotation crops and rice cultivation systems

In order to forecast the emissions from rotation with energy crops in the next 20 year, the DNDC model was employed as a study tool. Prior to forecast long term emissions, model simulations were performed using the Ratchaburi field measurement data and based and the site mode of DNDC.

3.3.1 Simulation of methane and Nitrous oxide emissions

Seasonal CH_4 emissions from the rotation with energy crops and rice were simulated using the site mode of DNDC (version 93). There are some differences in the daily average CH_4 emission values. DNDC simulations show that the seasonal variations of CH_4 emissions are significantly higher during the rice-growing season but fewer during the fallow, corn and sorghum growing season. Simulated daily average CH_4 emission values range from zero before and after flooding to a maximum of 10.52 kg C ha^{-1} day^{-1} (see Appendix 6).

DNDC simulation shows that the seasonal variations of N_2O emissions are significantly higher during fallow, corn and sorghum growing season. During the rice-growing season, small N_2O emission peaks are observed at the beginning without flooding and harvesting period. In year 2010, N_2O emissions showed high peaks due to tillage and cow manure incorporation. Some peaks of N_2O also occurred as a result of nitrogen fertilizer application. Simulated daily average N_2O emission values range from zero to 0.211 kg N ha^{-1} day^{-1} (see Appendix 6).

Our validation results of field experiment to site mode DNDC model indicated the fair reation of rice-fallow-rice, rice-corn-rice, and rice-sorghum-rice. Results from rice field with continuous plantation (rice-rice-rice) did not represent the good relation (see more detail in Table 2 in Appendix 6). Relation of nitrous oxide between measurement and model simulation is not significant.

3.3.2 Long term simulation of annual methane and nitrous oxide emissions over 20 years

The general condition of rice cultivation in non-irrigated area in Thailand is fallow land in dry season and rainfed rice in wet season, therefore RF (fallow-rice) is the baseline that was used for this research. The 20 years simulation results for predicted annual CH_4 and N_2O emissions in the future for each cropping system are shown in Figure 5. Annual CH_4 emission values are found to be in the range 153.43 - 1,328.49 kg C ha^{-1} $year^{-1}$. In the long term (20 years), rotations with corn and sweet sorghum are found to enable reducing CH_4 emissions by as much as 72% and 80% when compared to double cropping of rice (RR). In addition, the sweet sorghum rotated with rainfed rice showed no significant difference in terms of CH_4 emissions in comparison with the baseline (fallow-rice).

Annual N_2O emissions show a different pattern compared to CH_4 emissions. These are mainly caused by differences in cropping conditions between paddy rice and upland crop. Annual N_2O emission values range from 0.18 to 3.43 kg N ha^{-1} $year^{-1}$. For double cropping of rice (RR) N_2O emissions are observed to be significantly lower due to the flooding conditions of rice cultivation. The N_2O emissions associated to rotation with corn and sweet sorghum (RC and RS) are 4 and 2 times higher than for double cropping of rice, respectively.

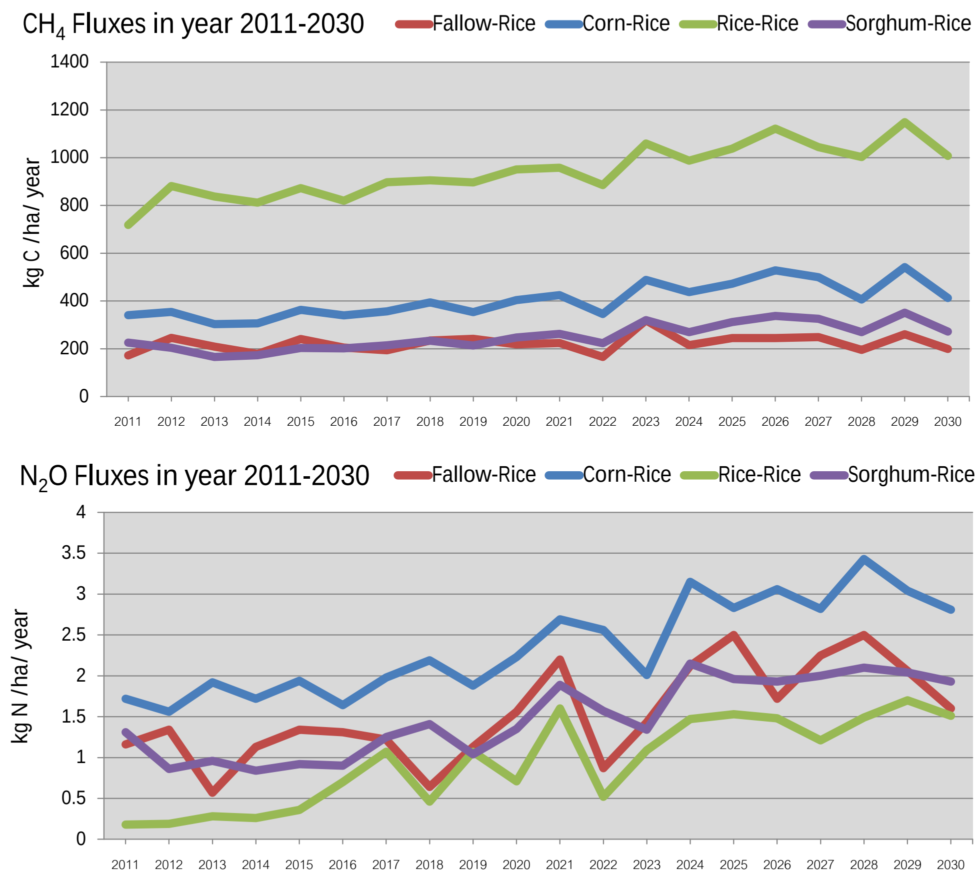


Figure 5 Long term simulation of annual CH_4 and N_2O emissions over 20 years using DNDC model

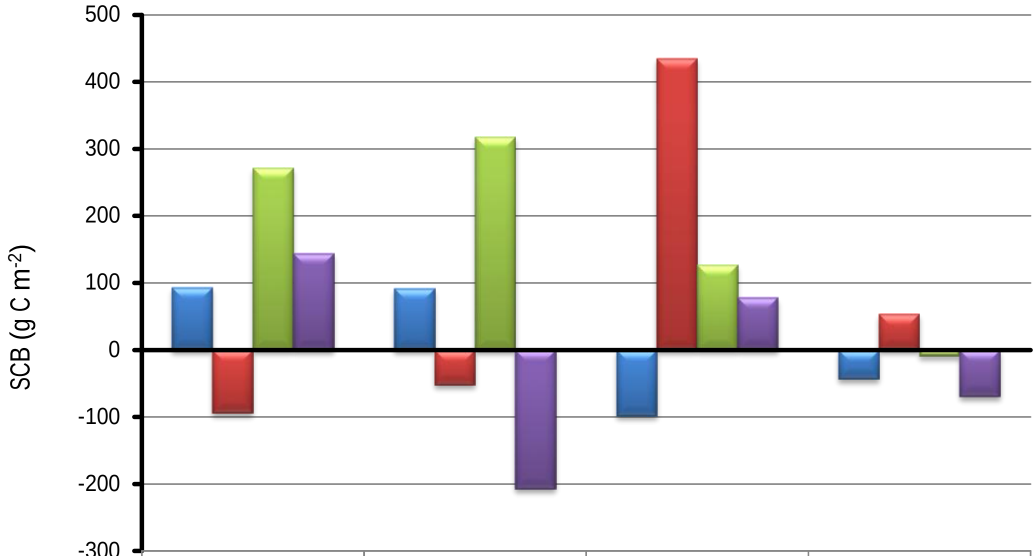
3.4 Enhancing of soil carbon stock in rotation crop rice field

Rotation of rice with corn and sorghum not only shows the GHG mitigation potential it offers but also the impact on organic carbon in soil. In general, soil carbon stock indicates the fertility of agricultural soil. The carbon content in the soil can vary based on cultivation practices. Potential to increase soil carbon stock can be observed by studying the soil carbon budget of each cultivation practice. Soil carbon stock change generally takes place over a long period of time. The ALU program and DNDC software were used to estimate soil carbon stock change in SEA running simulations of corn and sorghum rotation with rainfed rice over next 20 year.

3.4.1 Soil carbon dynamics

Soil carbon dynamics is shown in terms of soil organic carbon (SOC) stock and soil carbon budget (SCB). The SOC stock decreased from the initial soil through the field preparation by tillage. After cropping, SOC generally increased with crop rotation due to an accumulation of roots and organic matter into the soil. The lowest SOC stock was observed in fallow land of RF plot (6.32 Mg C ha^{-1}) whereas the highest SOC stock was found for rotation with corn and sweet sorghum crop with 12.48 and 14.62 Mg C ha^{-1}, respectively. The final SOC stocks at the time of the 4th crop of RR, RC and RS were significantly different (95%) as compared to RF. The double cropping of rice in 1st and 2nd cropping showed a 33 % increase in SOC stock. Nevertheless there were no significant differences among crop activities. These results show the potential energy crop may enable to achieve when used in rotation with rainfed rice to maintain carbon into the soil, as compared to RF.

The SCB is the balance of carbon supply into the soil and carbon removal from soil. The SCB after 1st to 4th cropping ranged from -207 to 435 g C m^{-2} (see Figure 6). Negative values of SCB are indicative of a carbon loss (from the soil). Sweet sorghum in RS plot had the highest C output in the form of sorghum stalk and grain. Manure incorporation in the 1st and 2nd crop had the most important effect on carbon input into the soil. Most of the carbon input for the 3rd and 4th crop was from crop residue incorporation. The highest total SCBs during 2010-2011 was 542.28 g C m^{-2} for RR followed by RC with 415.11 g C m^{-2}, then RF with 150.37 g C m^{-2} and finally RS with -68.72 g C m^{-2}.



	RC	RF	RR	RS
1st crop	93.19	91.37	-98.30	-43.36
2nd crop	-94.28	-51.98	435.46	53.55
3rd crop	272.06	318.36	127.10	-9.29
4th crop	144.14	-207.38	78.02	-69.62

Figure 6 The SCB after 1st to 4th cropping

SCB for the cultivation of rice-corn-rice and rice-rice-rice showed a positive trend of improvement of SOC while no clear results for rice-sorghum-rice and rice-fallow-rice could be observed.

3.4.2 Spatio-temporal distribution of soil organic carbon stock and soil organic carbon stock change in rice ecosystems in SEA

The spatial distribution of soil organic carbon of rice cultivation in SEA using ALU software is illustrated in Figure 7. Individual emission maps of Indonesia, Thailand, Vietnam, Laos and Cambodia can be found in Appendix 5.

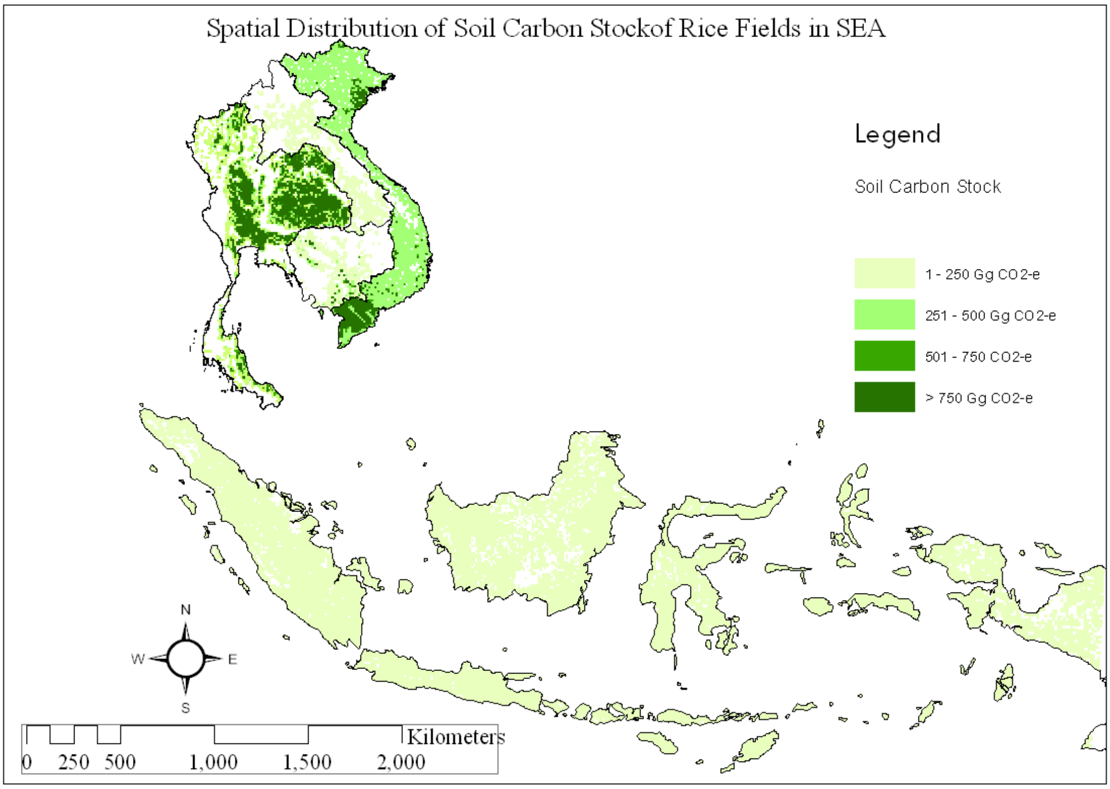


Figure 7 Spatial distribution of SOC stock of rice cultivation in SEA

3.4.3 Soil carbon stock change

Long term simulation of annual soil organic carbon dynamics over 20 years was studied using DNDC model and ALU software. The results of soil carbon stock change over 20 years of the energy crop rotation using DNDC software are illustrated in Figure 8. Similar trends across the crop rotation systems are observed. SOC contents for the crop rotations rice-rice, corn-rice and sorghum-rice are observed to be increasing over the simulated next 20 years. The fallow-rice system is also observed to be gradually increasing. The annual SOC values are ranging from 20,168 to 60,723 kg C ha^{-1} $year^{-1}$. The highest rate of increase in SOC is observed for the double cropping of rice, i.e. 1,957 kg C ha^{-1} $year^{-1}$, as a result of crop residue incorporation into the soil. SOC storage of rice-rice, corn-rice and sweet sorghum-rice are 42%, 33% and 25% higher than the baseline (fallow-rice crop system), respectively (see more detail in Appendix 6).

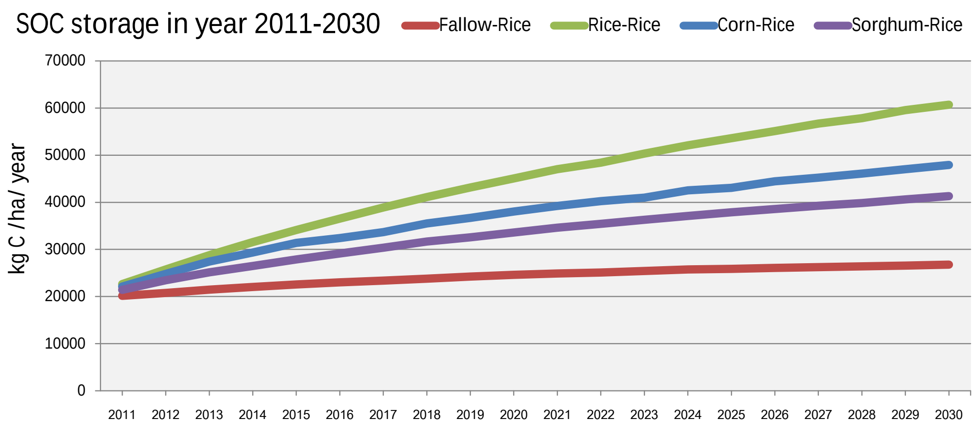


Figure 8 Long term simulation of annual SOC dynamics over 20 years

The soil organic carbon stock change of rice cultivation in SEA was estimated between 2010 and 2030 using ALU software. The results are reported in Figure 9. Thailand is the country with the highest gain followed by Vietnam and Myanmar.

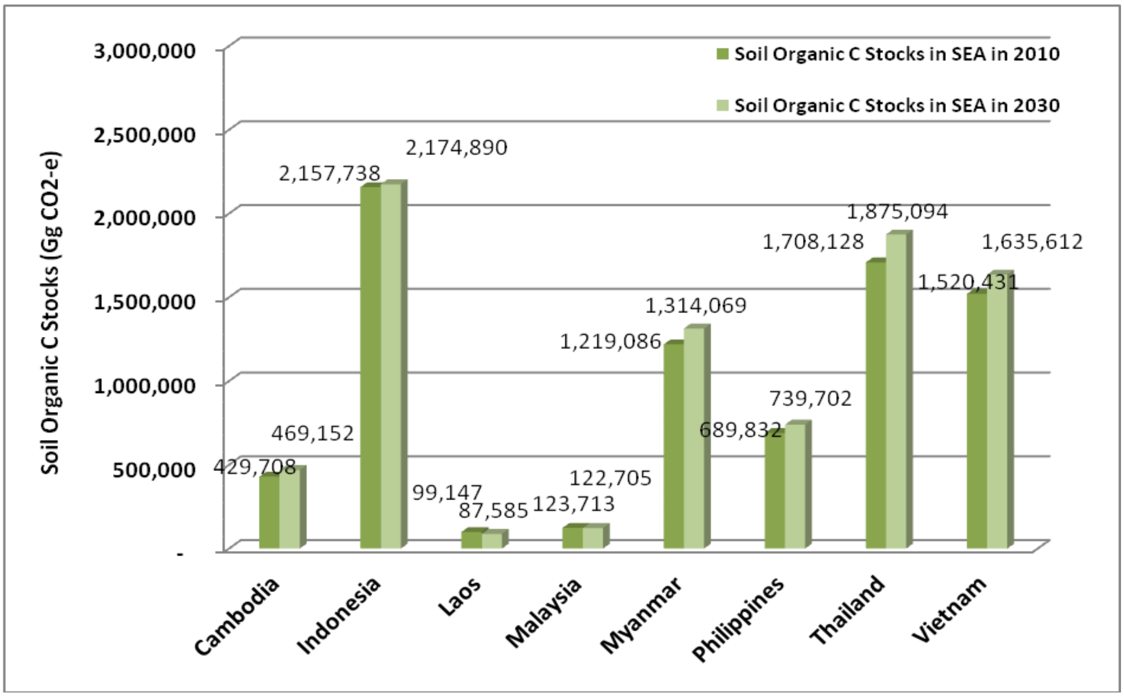


Figure 9 SOC stocks in SEA in 2010 and 2030

From the results, it is observed that scenarios RI, RC and RS contribute to enhance GHG emissions, especially from soil N_2O emissions from nitrogen in crop residues. The soil organic carbon stock change remains the same for the four scenarios because the principal land use is considered in ALU to be rice field for all cases (see more detail in Appendix 5).

The results obtained from both DNDC model and ALU software show that long-term implementation of energy crop rotation using corn and sorghum can contribute enhancing soil organic carbon as compared to having either rainfed or fallow land instead in that period. Results from ALU also show that for almost every country in SEA (except Laos and Malaysia), rice field can act as a carbon sink. We also found that cultivation of rotation crop within the same year with no land use change pattern may need specific GHG and SOC change quantified method. The methodology that relates to land use change cannot reflect this activity clearly.

3.5 Strategies for sustainable low carbon agriculture

Comparative assessment of energy crop rotation practices during the fallow period of rainfed rice field was performed investigating greenhouse gas emission reduction and carbon sequestration as well as economic aspects for the communities involved. The crop rotation systems in this study are corn and sorghum. They present many advantages over monoculture cropping system in different aspect. Both corn and sorghum rotation with rainfed rice can help reduce methane emissions of the next crop rice plantation while the continuous rice-rice cultivation showed higher emissions (see annex 4). In term of soil carbon storage, rainfed rice field rotation with corn showed a better carbon sequestration potential than others (see Appendix 5 and 6). Both corn and sorghum have shown providing economic advantages to farmers in terms of income, particularly rotation of sorghum where yield and price are high. However, this income can vary location wise and country wise due to environmental circumstances.

Rotation with energy crops is a good strategy for low carbon agriculture in ASEAN countries as rice rotation with energy crops not only can help reducing GHG emissions and enhance carbon sink but it can also provide farmers with improved income and an opportunity for job creation at local level. So, in the long term, energy crop may contribute improving the standard of living of farmers providing more stable job and income. However, there is still a need in SEA to improve irrigation facilities for implementation of sustainable rotation practices with energy crop. Also the current status of farming management practices and communications with local farmers are important barriers to overcome for adoption of crop rotation practices.

4. Conclusions

Strategic cultivation: Rainfed rice field in ASEAN Countries occupies an area of 19.8 million hectares which representing 49.2% of the total rice cultivation area of ASEAN. This area is used only 4-5 months per year with single cultivation while for the rest, 8-7 months the land is left fallow. Our result show that sustainable low carbon agriculture through improvement of cultivation practices of rice cultivation in rotation with energy crops during fallow period is a sustainable strategic rice cultivation option to follow for three main reasons. Firstly, in term of environmental aspect, rotation with energy crop in rainfed rice field not only enable to reduce annual GHG emissions but contribute to also increase soil carbon storage in the long term. Secondly, in terms of economic aspect, farmers can obtain more yearly income from energy crops. The total income with energy crop rotation either rotation with corn or sorghum is 1.5 and 1.7 times higher respectively than for the common rainfed cultivation system (see Appendix 4). Thirdly, this strategy can enable to reduce the crisis of land use change and competition between food and energy as these two activities, use the same area for cultivation.

Scientific finding: The amount of annual methane emissions from energy crop rotation in rainfed rice field was found to be close to that of single rice and significantly lower double rice cropping, particularly for the second rice cultivation of the year. In addition, for long term field measurements, rotation with energy crop, was found to enable maintaining soil carbon stock at the same level with that of rice double cropping while a decrease in soil carbon was observed for single rice cropping (rainfed). It was also found that long term application of this practice can benefit carbons storage in soil. The soil carbon budget of energy crop rotation with rice, estimated by input-output assumptions, showed that rotation of energy crop with rice lead to higher carbon storage in soil. These findings are in agreement with the long term projection of soil carbon stock change using DNDC model and ALU software. This confirms that energy crop rotation with rice is a good strategy to increase soil carbon in the long run.

Policy implications: Increasing of soil carbon stock is very important not only in terms of soil fertility but also in terms of carbon sink. IPCC has reported the potential of carbon sink in the agricultural sector particularly in Asia. This study has shown that carbon sink in rice field can be achieved and associated with the appropriate cultivation practices. Types of energy crop to be rotated in rainfed rice field can be different in each country due to physical and ecological characteristics of local rice fields. Corn and sorghum are ideal rotation crops because of their short life and low water consumption as well as conversion potential as biofuel and bioenergy. Other crops that have potential in SEA country include napir grass, sunflower, etc. Expansion of this strategy to SEA is not only enabling to enhance the biomass resources for biofuel and bioenergy with no impact to food crops but also to contribute reducing issues of competition between food and fuel crops as well as land use change problem. Moreover this strategic practice contributes to increasing the potential of carbon sink and moving toward poverty eradication. Nevertheless, the market of energy crop is the major driver for adoption this practice. The formulation and implementation of clear policies on renewable energy and biomass utilization is necessary and should be promoted.

Results' dissemination: Knowledge from this project has been disseminated to ASEAN countries through training workshops. National information on rice cultivation and potential rotation crops was been exchanged and discussed during the first workshop of this project and led to the capacity building of practice implementation, methane and soil carbon estimations and project of soil carbon stock change. The events organized over the course of this project (expert meeting, workshop, training) aimed at providing an opportunity for multilateral communications and exchange of experiences and knowledge among ASEAN participants/experts on rice cultivation practices and rotation crops.

5. Future directions

We found during the activities of the project related to knowledge dissemination that focusing the investigations on Thailand and Indonesia, was not enough to project the potential of carbon sink in rice field in SEA. We found that with the DNDC model and ALU software and the existing data of SEA countries, there is high potential to quantify soil carbon stock change in the region. However, due to time limitation and details of the data acquired, it was not possible to move forward to reach that important information at the level of the region. Nevertheless, a network of ASEAN countries namely, Cambodia, Myanmar, Indonesia, Japan, Vietnam and Thailand has been initiated through this project to carry forward the study of agricultural carbon sink in rice field through rotation with energy crops. This APN project has laid down the foundation for further collaboration on strategic rice cultivation in this region.

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Appendix 1

Report on “State of the art of rice cultivation practices in South East Asia”

EXECUTIVE SUMMARY

Major categories of rice in the world are *Oryza sativa*, *Oryza glaberrima*, and wild rice. *Oryza sativa* originates from Asia. It is planted mainly in Asia although it can also be planted in other regions in the world. *Oryza glaberrima* is found only in Africa. Wild rice can be found naturally in many countries. The *Sativa* species can be generally classified into 3 sub-species: *Indica, Japonica,* and *Javanica*. The *Indica* sub-species are planted mainly in South East Asian countries, except Indonesia which grows the rice sub-species *Javanica*.

South East Asia is a major producer of rice as 30% of the global area of rice is found in that region. This is notably due to suitable topography and climate. SEA countries are generally under the influence of a tropical climate where the weather is hot and humid throughout the year. Topography is a main factor of classification of rice ecosystems divided into upland, lowland, deepwater and coastal rice ecosystems. Upland rice is cultivated in high area i.e. upland, hillside, and farm area known as terrace rice. Since upland rice fully depends on rainfall, upland rice is cultivated with only one cycle per year. The upland rice cultivation can be found in Cambodia, Indonesia, Lao PDR (north), Myanmar (Northern Shan State), Thailand (north), and Vietnam (Northern Mountain (region 1), and Central/Coastal region (Region 3)). Most cultivated areas of rice in ASEAN countries are located in lowland, plain area with water level <1 m. In lowland areas, rice can be planted in large fields easily accessible by farm machines. Floating rice or deep water rice is planted in deep water areas during the cultivation season with water level >1 m. Coastal rice is found nearby the shore e.g. in Indonesia; however, sometimes coastal rice is included under the category of lowland rice. Climate is a factor that classifies rice cultivation into wet and dry season. The wet season of rice cultivation spans over the period May to December while the dry season of rice cultivation is found during January to April. Each country refers to wet and dry season in a different way, for instance, wet season of rice (WS) and dry season of rice (DS) in Cambodia; monsoon rice and summer rice in Myanmar; and major rice and second rice in Thailand. The duration of rice cultivation is 80-180 days depending on the type of rice. The fallow period (time during which the land is empty) is usually found during January to April in rainfed areas because there is not enough water to cultivate rice so farmers grow alternate plants i.e. watermelon, mungbean, garlic, and so on. These alternative crops will be planted if there is enough water. However, in irrigated areas, rice can be cultivated during the dry season relying on water resources supplied via irrigation. In this case, there are few or no alternative crops planted there.

Cultivation practices of rice in SEA do not differ much. Rice cultivation starts with land preparation, planting, water management during growth, farm management of young plants using fertilizers/ lime/ pesticides/ herbicides, and harvesting. However, the production of rice depends on the cultivation practice followed in a particular area since land preparation up to harvesting as well as soil fertility (soil organic carbon). Higher production of rice can improve the socio-economic status of rice farmers. Details of rice cultivation process in SEA are briefly provided below.

Land preparation is an important process to increase oxygen into soil and reduce inputs of herbicides. Firstly, the land is plowed roughly by animal or machine to turn over, dry, and mash straw and weed into the soil. Animal labor is usually provided by cows or buffalos. Machines for plowing can be tillers or tractors. Then harrowing is done to level the land, remove weeds, and make soil cracking. The machine used for harrowing is composed of a rotary harrow for puddling attached to a small-size tractor. Farmers plow the land 1-2 times and harrow 2-3 times for each cultivation.
In SEA, there are two main planting methods: broadcasting and transplanting. These methods consist of many sub-methods, mainly related to the preparation of seeds before planting. The most popular method used differ from one country to another and even between regions of a same country depending on economic, labor, and climate conditions. The ancient traditional method is

transplanting. In this technique, rice seeds are transplanted before moving to the plantation phase in the prepared land. For the transplanting method, the rice survival percentage is quite high since rice is grown before planting. Since low amount of seed is used it is a low cost method. This method is suitable for various climate conditions as the already grown rice can better resist to changes in climate conditions. However, this method is quite labor intensive and therefore suitable only in countries/regions where such labor can be found i.e. northeast of Thailand, small farms in Cambodia, most areas in Lao PDR, 80% of rice farms in Myanmar, and traditional farmers in Vietnam. Broadcasting is another popular method of rice cultivation for large scale production purposes (economic purpose). Contrary to the transplanting method, this technique requires little labor but needs a large amount of seed due to low survival percentage. Therefore, new methods have been developed using pre-germinated rice before seeding. New transplanting method have also been developed and promoted by FAO called Parachute Rice Transplantation, which can be found in every country in SEA. Parachute is a technique of tossing rice seedlings, uprooted from plastic trays containing soil balls into the paddy field. The advantage of this new method is the reduced labor force required for transplanting.

Management of water level during growth is done in lowland rice to produce high yield of rice. Lowland rice is cultivated in water level <1 m, and mostly found for water level in the range 2-30 cm. The purpose of flooding is to control weeds/residues and to feed rice. In Java, Indonesia, the period of flooding is 1-130 days. Young rice is planted in low water level 2-5 cm flooded for 1-14 days. After that, water level is increased to be 10, 15, 20 or 30 cm. In Thailand, the Rice Department suggested that the water depth for broadcasting should not exceed 5 cm from planting to tillering, and not exceed 10 cm after tillering. The suitable depth of water for transplanting rice should not exceed 20 cm.

Chemical fertilizers are applied in paddy fields in most SEA countries, especially for rice cultivated via modern method. For traditional farming in mountainous areas organic fertilizers are still mainly applied. However, organic farming is being promoted in many countries as a mean to recover good soil texture and fertility. Lime is applied to the paddy field to adjust pH as chemical fertilizers leads to acidic conditions formation in soil. Chemical herbicides and pesticides are applied in most paddy fields since seeding and before harvesting to control weeds/insects and increase yield. However, the cost of chemicals (fertilizers, herbicides and pesticides) is high leading to reduced net income for farmers.

The harvesting of rice can be performed either manually or by machine. Manual harvesting is done using sickle, a simple tool consisting of curved blade set on a short wooden handle. In SEA, harvesting machines are mainly use in lowland areas easy of access.

Rotation crops are planted in paddy fields during the fallow period and with enough water for cultivation. The rotation crops are legumes, fruits, and vegetable. Only few areas see energy crops planted as alternate crops in paddy fields. Most rotation crops are found in non-irrigated paddy fields where rice is only cultivated once a year since in irrigated areas rice can be cultivated 2-3 times/year so that farmers can grow rice continuously without any alternate crops.

Rice cultivation practices in SEA countries are not so different since they are located in a region that is characterized by similar weather conditions and topography. Hence, strategic practices of rice cultivation in rotation with energy may apply similarly for several countries in SEA, enabling the region to develop more sustainably while enhancing the adaptive capacity in the agricultural sector.

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CHAPTER 1 INTRODUCTION

1.1 Background

According to the Food and Agriculture Organization (FAO) for the year 2007, global rice plantation area covers 12.5% of total crop plantation area. The world annual production of rice amounts to 659 million tonnes and contributes 164 billion US dollars on the world economy. South-East Asia (SEA) is the region with the major rice plantation area covering 30% percent of the world plantation area. Maximizing rice yield in this region is essential to increase global food stock. However, the current climate and energy crisis strongly influence the regional production of rice.

JGSEE (Thailand) in collaboration with the Bogor Agricultural University (Indonesia) and the NIAES (Japan) are involved in a 2 years APN-ARCP funded project on Rice Cultivation for Sustainable Low Carbon Society Development in SEA. In this project strategic rice cultivation practices enabling to address both climate change and energy security issues, are investigated. These are performed by considering rice rotation with energy crops in order to fully utilize the rice plantation during fallow period and therefore optimize rice and energy feedstock. The proposed cultivation practices considered in this work aim at reducing GHG emissions while increasing potential long-term soil carbon stock by optimizing land utilization and cultivation practices. Sustainable development will be considered in terms of enhancing economic and social benefits while developing a low carbon society to bring down the net GHG emissions. The overall goal of the project is to identify strategic rice cultivation practices enabling SEA to develop towards a sustainable low carbon society while enhancing the adaptive capacity in the agriculture sector.

1.2 Objective of this report

This report aims at providing information on the state of the art of rice cultivation practices in SEA. Countries focused on in SEA are Cambodia, Indonesia, Lao PDR, Myanmar, Thailand and Vietnam. The information provided in this document was retrieved from literature review, questionnaire surveys (Thailand and Indonesia) as well as from SEA experts of the above listed countries when gathering at the occasion of an expert meeting on “State-of-the-Art of Rice Cultivation Practices in South-East Asia” that was organized by JGSEE during 2-3 June 2011 in Bangkok.

CHAPTER 2 STATISTICS OF RICE CULTIVATION IN SOUTH EAST ASIA

Statistics of rice cultivation covered in this chapter include information on harvested area, production, yield, and import/export of rice for SEA countries including Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand, and Vietnam. The period cover is from 1961 to 2011 and the information obtained mainly from the Food and Agriculture Organization (FAO) of the United Nations (UN).

2.1 Harvested area

The area of rice harvested in SEA during 1961-2011 is presented in Figure 1.

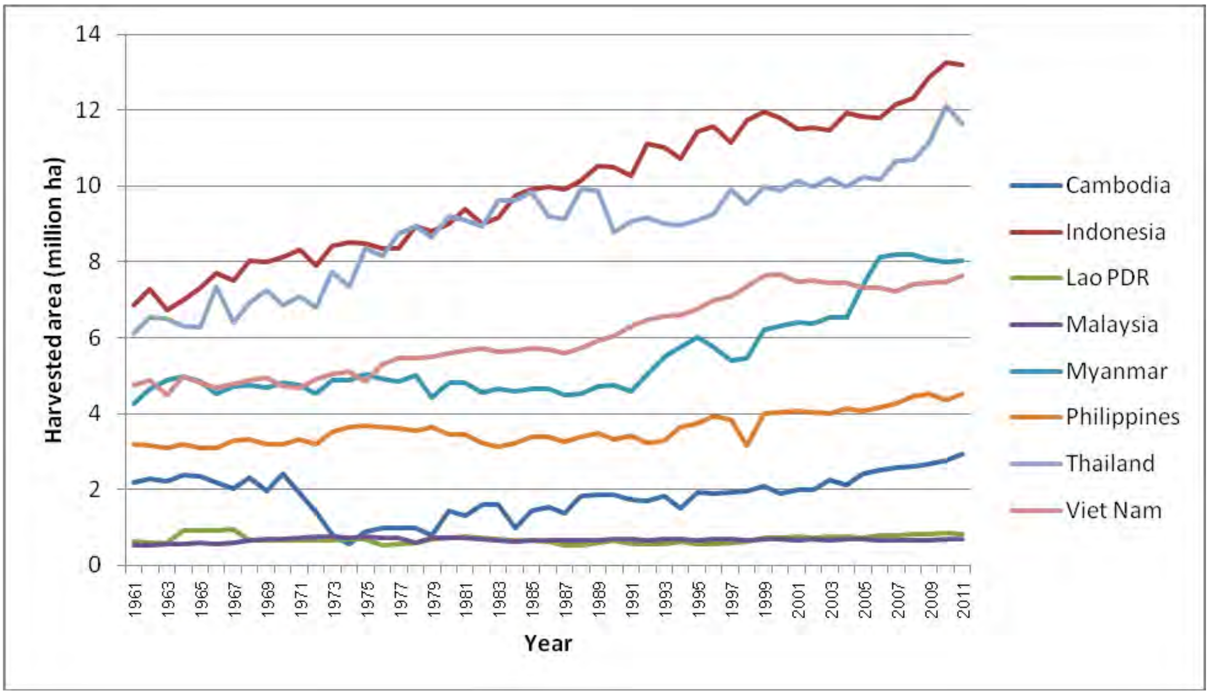

Figure 1 Statistics of harvested area of rice during 1961-2011.
(FAO, 2012)

From Figure 1, it is observed that the area of rice harvested for most SEA countries has been increasing over the years, except Malaysia and Vietnam. The largest area of rice harvested is found in Indonesia. Thailand comes in second position. The smallest areas of rice harvested are found in Lao PDR and Malaysia.

2.2 Production

Rice production during 1961-2011 is presented in Figure 2.

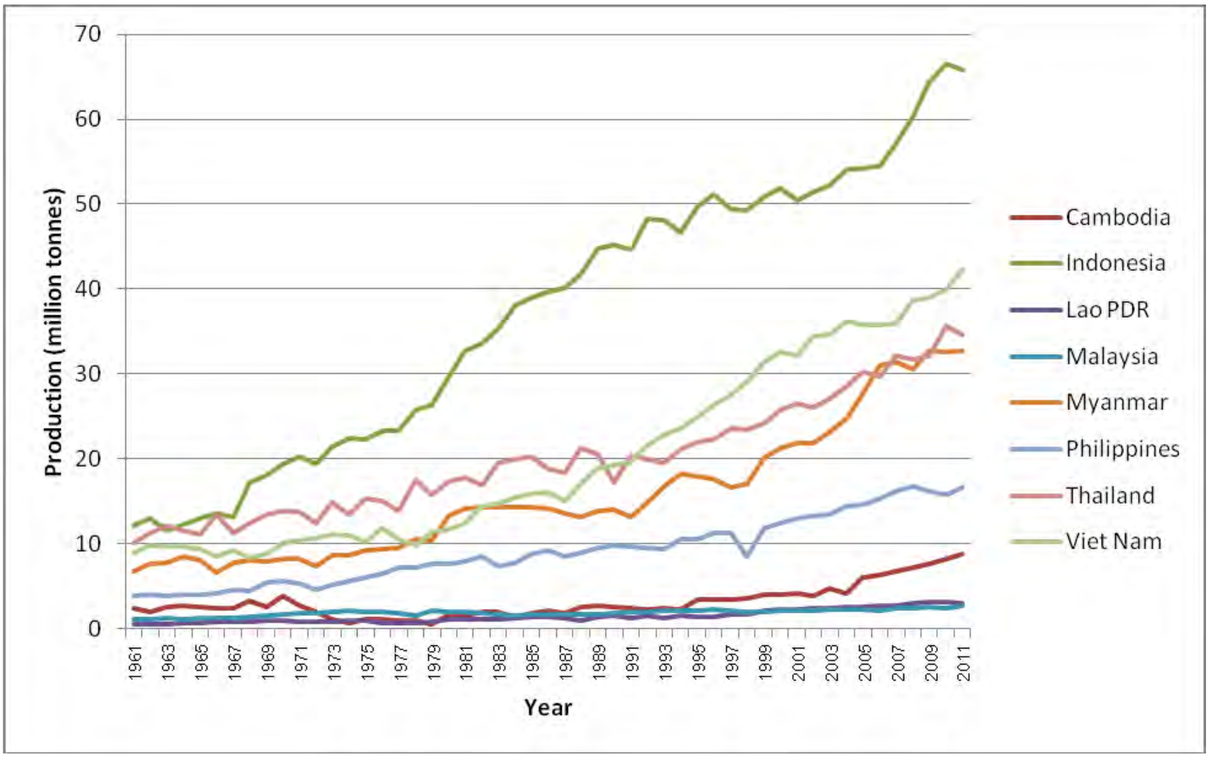

Figure 2 Statistics of rice production during 1961-2011.
(FAO, 2012)

From Figure 2, it is observed that the production of rice has been increasing in every country in the region, especially in Cambodia where rice production over the period 2001 to 2011 has increased by 75%. Main factor of rice production is climate situation. El Niño/La Niña caused drought and flood damage at paddy fields and had a result in decreasing of rice in these years.

2.3 Yields

The evolution of rice yields in SEA countries during 1961-2011 is presented in Figure 3.

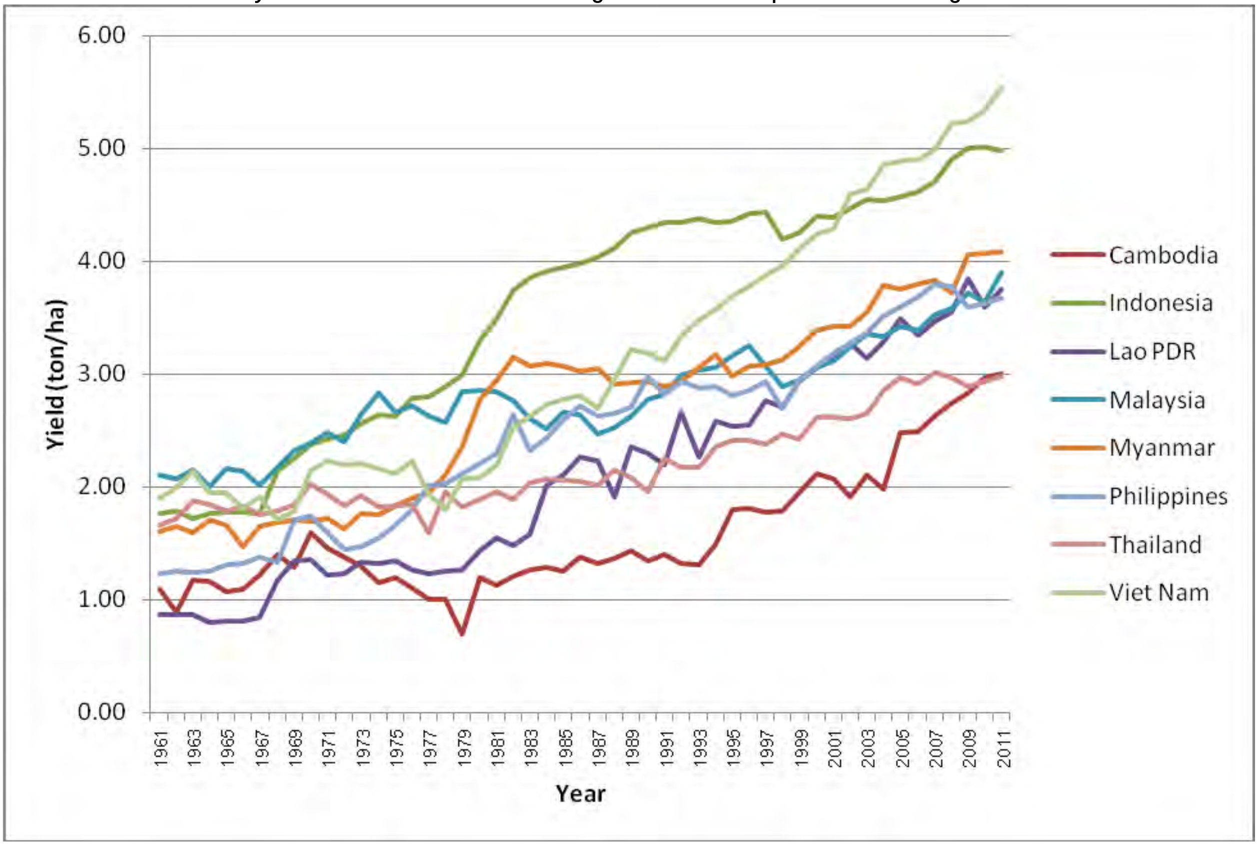

Figure 3 Statistics of rice yield during 1961-2011.
(FAO, 2012)

From Figure 3, it is observed that the yield of rice production has been steadily increasing for all countries in SEA. Yield of rice in Vietnam is increasing sharply since 1991 because of development in rice varieties and irrigation system.

2.4 Import/export

Details of rice import/export over the period 1961-2008 are presented in Figures 4-5.

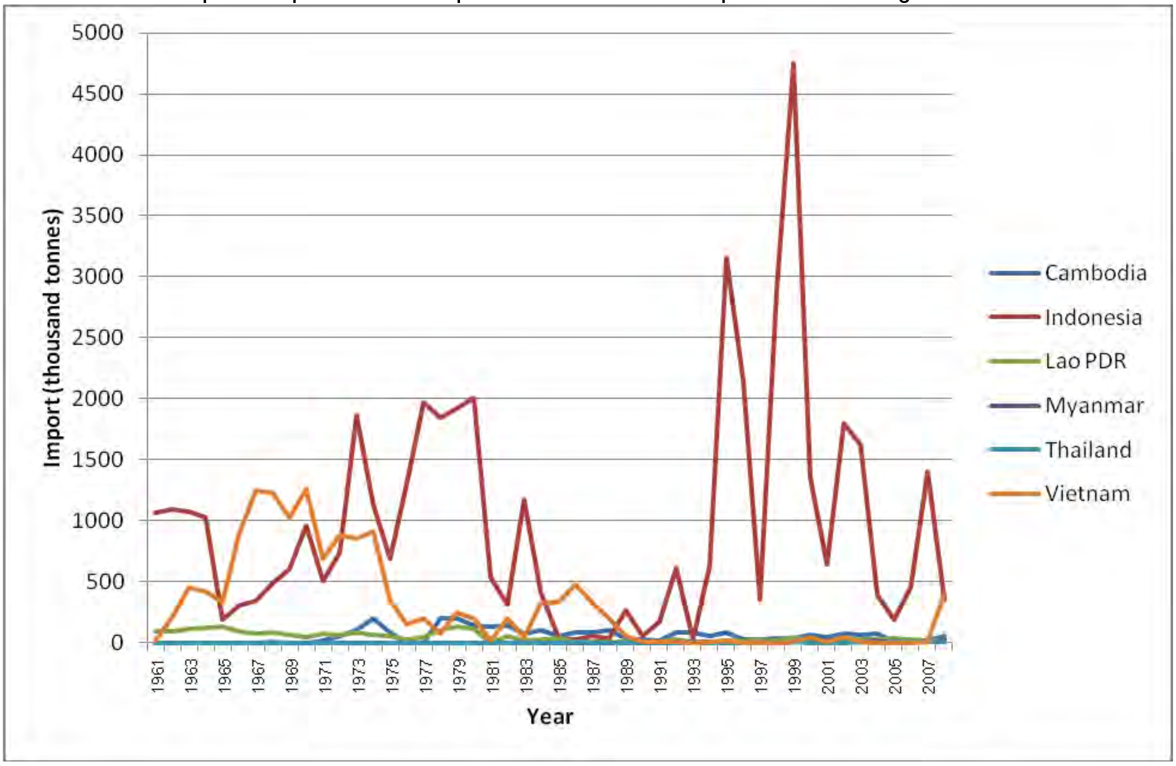

Figure 4 Quantity of rice imported during 1961-2008.
Source: Food and Agriculture Organization of the United Nations (IRRI, 2013)

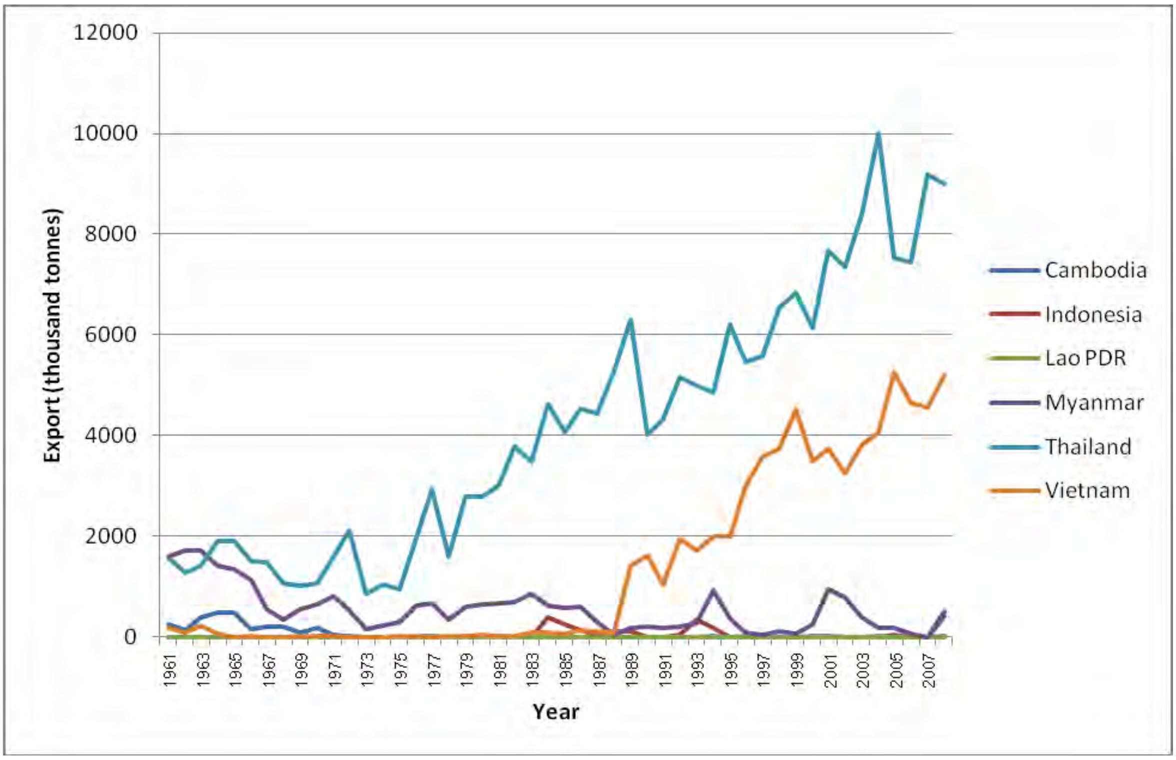

Figure 5 Quantity of rice exported during 1961-2008.
Source: Food and Agriculture Organization of the United Nations (IRRI, 2013)

From Figure 4 and 5, it is observed that the major importer of rice in SEA is Indonesia and the major exporters of rice are Thailand and Vietnam. From Figure 1 and 3, the largest area of rice cultivation is in Indonesia, which is also one of the countries among those in SEA having the highest yield and highest production of rice; however, in this country rice production is not sufficient to satisfy the national demand for consumption. Consequently, the amount of rice imported in Indonesia is the highest among all SEA countries.

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International Rice Research Institute, 2013. World Rice Statistics. [online] Available at http://ricestat.irri.org:8080/wrs/

CHAPTER 3 COUNTRY REPORTS ON RICE CULTIVATION PRACTICES

3.1 Cambodia

Cambodia is an SEA country covering a land area of 181,035 km^2. The border of Cambodia is surrounded by Thailand to the north and west, Laos to the northeast, and Vietnam to the east and southeast. West of Cambodia is 443-kilometer coastline along the Gulf of Thailand. Climate is dominated by the annual monsoon cycle with its alternating wet and dry seasons. Four annual seasons in Cambodia are classified into November–February (cool and dry), March-May (hot and dry), June-August (hot and wet), September-early November (cool and wet). The country consists of a low-lying central plain surrounded by uplands, low mountains, Tonle Sap (great lake), and the upper part of the Mekong River. The area around Tonle Sap is a plain that is flooded about 2,590 km2 during the dry season and expanding to about 24,605 km2 during the rainy season. Planted areas of rice are located mainly in the plain areas of Tonle Sap and in the southern part of the country (Wikipedia, 2012).

3.1.1 Rice varieties

Species of rice in Cambodia is *Oryza sativa* the same as in other countries in SEA. In Cambodia, there are 38 crop varieties released: 33 for rainfed lowland and irrigated land, 2 for upland, and 3 for deepwater. The 33 species in rainfed lowland and irrigated are categorized into 9 early duration, 5 medium duration insensitive, 6 medium duration sensitive, 5 medium duration aromatic, and 8 long duration sensitive. New rice varieties are developed that are tolerant to environmental stress i.e. tolerant to 10-12 days water submergence (CAR9, Phka Romduol and Phka Romdeng), tolerant to 7-10 days water submergence (CAR6, Phka Romchek and Phka Romeat), tolerant to moderate drought (CAR3 and CAR4), moderately resistant to brown plant hopper (IRKesar, Kru, Chul'sa and CAR12), and resistant to stripe stem borer (Kru, IR72, Sen Pidao and IR66). Local rice varieties are Neang Malis (similar to fragrant Thai Jasmine rice), Neang Khon, Phka Khnei (another fragrant variety, phka meaning "flower"), Neang Minh (long grain rice), Romdul, Bonla Pdao, Sen Kro Ob, Sen Pi Dao (Wikipedia, 2011), Neang Sor, Champa Meas, and Phka Malis (ACI and CamConsult, 2006). Medium-water rice and deep-water rice varieties (accounting for 80% of lowland rice) is exclusively traditional (FAO, 2002). Grain yield of rice grown by various methods is presented in Figure 6.

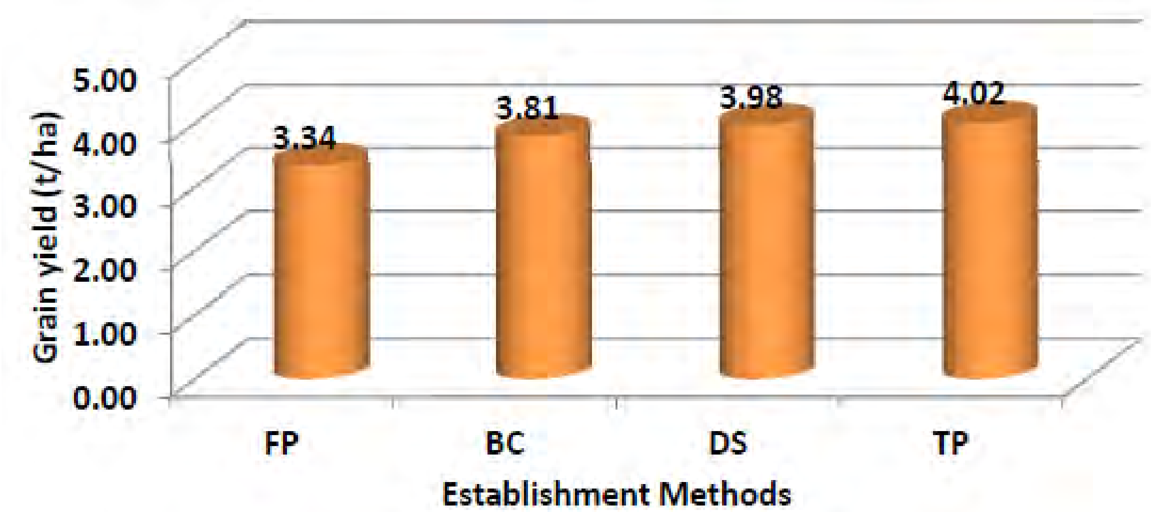

Figure 6 Grain yield of rice grown by various methods.
(FAO, 2002)

FP: farmer's own practice (BC 60 kg/ha, no weeding), BC: broadcasting (60 kg/ha), DS: drum seeder (60 kg/ha), TP: transplanting (2-3 seedlings/hill, 20 days, 20x20cm).

3.1.2 Rice ecosystems

In Cambodia paddy fields cover an area of 1,377,100 ha and paddy field with palm trees cover an area of 1,309,200 ha (FAO, 2002). Water resources for rice cultivation in Cambodia are from precipitation, irrigation and groundwater. Rainfall is mainly from the South-West monsoon during the period of mid-May to November. The greatest amount of rainfall occurs between June and August (WFP, 2009). The total area of irrigated paddy field is 407,000 ha.

Rice in Cambodia is mainly cultivated in low land areas because geography of the country is mainly plain area (WFP, 2009). Rice ecosystems in Cambodia, as elsewhere, are influenced by rainfall/flooding patterns, soil suitability and the country's topography. The International Rice Research Institute (IRRI) has defined four main rice ecosystems (see Figure 7), three wet seasons and one dry season. For the wet season, rice is cultivated in upland or mountainous areas (1.9%), rainfed lowland (80.2%), and deepwater/floating areas (3.4%). During the dry season (14.5%), the rice is fully irrigated. As a result, Cambodian rice growing ecosystems can be grouped into the following four broad categories: (1) rain-fed lowland rice or wet season rice, (2) deepwater or floating rice, (3) rain-fed upland rice or Chamkar rice, and (4) dry season irrigated rice.

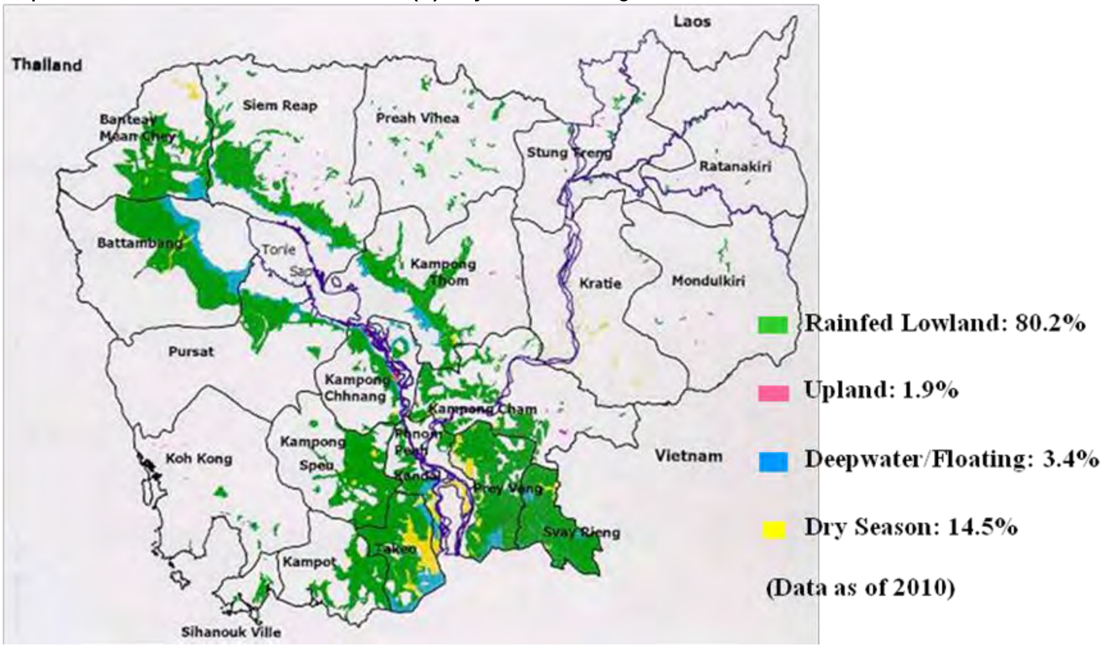

Figure 7 Ecosystems of rice cultivation in Cambodia.

Details for each rice ecosystem are as follows:

1) Rain-fed lowland rice: Rain-fed lowland rice represents 80.2 percent of the total annual rice cropping area of Cambodia. It is characterized by flat bounded rice fields, which depend almost entirely on rainfall or surface runoff for their water supply. The varieties grown by farmers in the rain-fed lowlands are dependent on factors such as local traditions and practices and water depth in the fields. In the higher fields, where the water depth is 15-20 cm, short duration (fast growing) varieties are normally grown, while in the lower fields, where the water depth is 20-60 cm, medium and long duration varieties are normally grown. In general, farmers tend to match the variety of rice to the availability of water in the area (WFP, 2009).
2) Deepwater or floating rice: Deepwater or floating rice covers an area representing 3.4% of the total area of rice cultivated in Cambodia. It is grown where the water depth exceeds about 80 cm (up to 400 cm) in flooded areas around the Tonle Sap and in depressions along the Mekong River, mainly in Kampong Thom, Kompong Cham, Prey Veng and Takeo

provinces. Most deepwater crops are dry seeded in April/May with seeds germinating at the onset of the raining period. The depth and duration of flooding depend on local rainfall conditions and/or the height of the Mekong River. Areas may remain flooded for three to six months (FAO, 2002).

3) Rain-fed upland rice: The area under rain-fed upland rice cultivation accounts for 1.9 percent of Cambodia's total annual rice cropping areas. Upland rice areas are unbounded fields in the mountainous and rolling hill areas of Cambodia (Mondulkiri, Rattanakiri, Kratie, Koh Kong, Kampong Cham and Kampong Thom). In the shifting cultivation areas of the Northeast of Cambodia upland rice is an integral part of the "chamkar farm". Ethnic minority groups in these areas practice this type of cultivation almost exclusively. Permanent upland rice production is commonly practiced by Khmers where a field of rice is grown annually either on its own or as an intercrop or in rotation with other upland crops. It is important to note that shifting cultivation (also known as swidden agriculture), a common practice of clearing and utilizing a plot of land for 1-5 years and then clearing another plot of land for cultivation, is associated with burning also termed "slash and burn", and responsible for the destruction of thousands of hectares of forest (WFP, 2009).
4) Dry season irrigated rice: Dry season rice covers 14.5% of the total area of rice cultivated in Cambodia. This type of rice can be grown either as a fully irrigated crop at the end of the wet season, or in flood recession areas, normally with supplementary irrigation. Dry season rice is also now being planted in deep flooded areas in place of the more risky and lower yielding floating rice grown in the wet season. Under these circumstances supplementary irrigation is normally provided. Mostly modern varieties are used, and yields are significantly higher than for the wet season crops (FAO, 2002).

Seasons of harvest including areas, yields, and production for all types of rice ecosystems considered in Cambodia are presented in Table 1.

Table 1 Rice harvested areas by water resources, Cambodia 1999

Season	Rice Type	Harvested Area (ha)	Sowing	Harvesting	Yield (tonne/ha)	Production (tonne)
Wet season	*Upland*	48,138	May	October	1.4	67,393.2
	Rainfed *Lowland*:					
	- early	371,553	May	end October	1.6	594,484.8
	- medium	838,237	May/June	December	1.8	1,508,827.0
	- late	529,495	June/July	January	1.7	900,141.5
	Deepwater	56,569	April/May	Feb/March	1.3	73,539.7
Dry season	Irrigated & recession	233,000	Jan/Feb December	April February	3.04	708,320.0
TOTAL		2,076,992				3,852,706.2

(FAO, 2002)

Cultivation of rice in Cambodia is increasing. In 2010, the total harvested area was expanded to be 2.80 million ha, a 3.84% increase as compared to 2009.

3.1.3 Land preparation

Cambodian farmers use animal to prepare land and cultivate rice. Animal types are cows and buffalos. Seeding is done manually by broadcasting, transplanting, and using some equipment to facilitate planting, i.e. drum seeding method.

3.1.4 Planting methods

In Cambodia, although traditional cultivation practices dominate, new cultivation methods are being researched and slowly introduced in the country.

Traditional methods: In Cambodia, there are two planting methods: transplant and broadcast (direct seeding). Transplant method is used in small farms while broadcast method is used in large farms (Koji, 1995).

New management of rice cultivation method (System of Rice Intensification): Dr. Koma, the director of the Center for Studies and Development of Cambodian Agriculture (CEDAC), first tried SRI methods in 1999. In 2000, 28 farmers participated in the SRI experimentation. Due to the early successes of SRI, the Cambodian government, especially the Minister of Agriculture, H.E. Chan Sarun, officially started endorsing and promoting SRI in 2005. Since then, SRI has been promoted in all provinces of Cambodia. Subsequently, SRI was included in the National Strategic Development Plan (NSDP) for 2006-2010 to raise productivity in the rice sector, and then in the revised NSDP for 2009-2013 (SRI-Rice, 2011).

3.1.5 Fertilization

Farmers use Urea and DAP chemical fertilizers (100 kg/ha) for increasing the yield of rice and to improve soil quality. Various types of chemical fertilizers are provided on the market. The common kinds of chemical fertilizers farmers use in Cambodia are Urea, DAP, 16-20-0, 15-15-15 and 16-16-8-13s. The List of chemical fertilizers that were imported in Cambodia in 2002 is provided in Table 2.

Table 2 List of chemical fertilizers imported to Cambodia in 2002

No	Common Name of Chemical	Origin of fertilizer	Imported Quantity (tons)
1	Amm Nitrate	Singapore	150.50
2	DAP	Thailand	9,616.00
3	NP	Thailand	2,735.00
4	NPK	Thailand	1,348.00
5	Urea	China, Vietnam	3,482.50
6	Other Fertilizers	Thailand, Vietnam and USA	26,332.00

(ACI and CamConsult, 2006)

Recommended rates of nutrients application for rainfed lowland rice based on soil types are reported in Table 3.

Table 3 Recommended rates of nutrients application for rainfed lowland rice based on soil types

Soil types	Recommended rate of nutrients (kg/ha)		
	N	P	K
Prey Khmer (Psamments)	28	4	33
Prateah Lang (Plinthustalfs)	50	10	25
Bakan (Alfisol/Ultisol)	75	13	25
Koktrap (Kandic Plinthaquult)	73	15	25
Toul Samroung (Vertisol/Alfisol)	98	15	0

(Vang, 2001)

3.1.6 Use of pesticides and herbicides

There are more than 400 trade names of pesticides/herbicides in Cambodia, most of which are imported from Thailand and Vietnam. Purposes of chemical utilization are to remove/restrict fungi, insects, rodents, and weeds (Ministry of Environment, 2004).

3.1.7 Harvesting method and management of rice residues

Most rice is harvested manually although in some areas machines are used to harvest rice.
Common practice of rice residues management include moving straw out of the field to serve as animal feed about 60%-75% and leaving the remaining fraction of rice residues, i.e. mainly stubble, in the field. Medium maturity rice, Phka Rumduol, has a straw dry matter weight of about 10 t/ha. The 75% removal of it is equal to 7.5 t/ha which is equivalent to the removal of 38 kg N/ha, 5 kg P/ha, and 90 kg K/ha (Vang, 2011). Open burning of rice residues in the field is intensively performed during the dry season.

3.1.8 Rotation crops

Rotation crops introduced to farmers are legumes e.g. mung bean, soybean, and sesbania, used to improve soil structure and fertility (nutrients) for improved rice yield. Four mung bean varieties have been released: CARDI Chey, CMB01, CMB02, and CMB03. Other rotation crops include maize and watermelon.

Major limitations in double cropping systems are the lack of reliable rainfall for early season rice; risk of soil water saturation for early season mung bean; and lack of water for the establishment and subsequent growth of mung bean. Examples of good practices to reduce risk and maximize yields for the wet season rice crop are early planting of mung bean to reduce risk of soil water saturation. Dry season mung bean needs to be planted as soon as possible after harvesting of wet season rice. There is possibility of shifting plantation dates by growing wet-season rice earlier to accommodate dry season mung bean or later to accommodate early-season rice. Characterization of rainfall patterns is important to assist with the evaluation of risks inherent to different cropping systems. The risk of crop loss can be reduced by availability of supplementary irrigation and also increases the value of double cropping (Sarom, 2007). As water resources are limited, there is a study to indicate suitable amount of water for rotation crops (mungbean and peanut) in Cambodia, as reported in Table 4.

Table 4 Effect of furrow irrigation frequency on grain yield and water use efficiency (WUE) of mungbean and peanut grown after WS rice (ACIAR-07 Project)

Irrigation Frequencies	Water use (mm)	Grain yield (kg/ha)	WUE (kg/ha/mm)
Mungbean			
Every 3 days	250	985	3.94
Every 6 days	216	1044	4.84
Every 9 days	177	686	3.87
Mean	216	899	4.16
lsd (5%)	-	168	0.75
Peanut			
Every 3 days	285	720	2.52
Every 6 days	244	812	3.33
Every 9 days	211	649	3.08
Mean	249	749	3.01
lsd (5%)	-	114	0.48

Lsd = the least significant difference

From Table 4, maximum grain yield is presented when frequencies of irrigation are every 6 days, using 216 mm water for mungbean cultivation and 244 mm water for peanut cultivation.

3.1.9 Soil organic carbon

Soil organic carbon and soil properties of major rice soils for the lowland category are presented in Table 5.

Table 5 Properties of major rice soils for lowland in Cambodia

Soil Groups (Local name)	Area	Sand	Silt	Clay	pH	Org. C	Total N	Olsen P	Exchangeable Cations (cmol/kg)			
	(%)					(g/kg)	(g/kg)	(mg/kg)	K	Na	Ca	CEC
Prateah Lang*	28	50	37	13	4	2.9	0.3	0.4	0.08	0.55	1.2	3.71
Krakor & Kbal Po**	28	18	34	48	5.9	9.1	1	4.6	0.24	0.62	6.68	15.1
Bakan*	13	35	49	16	5.8	6.6	0.6	1	0.09	0.51	1.75	4.84
Prey Khmer*	11	73	22	5	5.6	4.7	0.5	1.3	0.04	0.05	0.61	1.45
Toul Samroung*	10	28	29	42	5.5	8.8	0.9	3.1	0.17	0.29	7.1	16
Koktrap*	5	36	41	23	4	10.9	1.1	2.6	0.1	0.25	1.13	8.09

Note: Type of landscape: *Old colluvial/ alluvial; ** Krakor & Kbal Po

From Table 5, The SOC is quite high as compared to Thailand where rain-fed rice field soil contains 4.73±1.85 g/kg, similar to soil group Prey Khmer in Cambodia. CARDI classifies N, P, and organic C of soil samples in the Cambodian Soil Database, which is presented in Table 6.

Table 6 Classification of N, P, and organic C of soil samples in the Cambodian Soil Database

Soil properties	Classifications				
	VL	L	M	H	VH
Total N (%)	<0.05	0.05-.15	0.15-0.25	0.25-.50	>0.50
% of soil	63	34	3		
Olsen P (mg/kg)		0-7	7-15	>15	
% of soil		88	5	7	
Organic Carbon (%)	<0.06	0.06-1.00	1.00-1.80	1.80-3.00	>3.00
% of soil	1	86	11	2	

VL-very low, L – low, M – medium, H – high, VH – very high

3.1.10 Socio-economic status of rice farmers

There is a gradual shift in Cambodia of moving from subsistence-oriented to commercial oriented production systems with improved enabling environments including rice export policies, contract farming, rice mills (large scale), seed suppliers, and marketing and market information access.

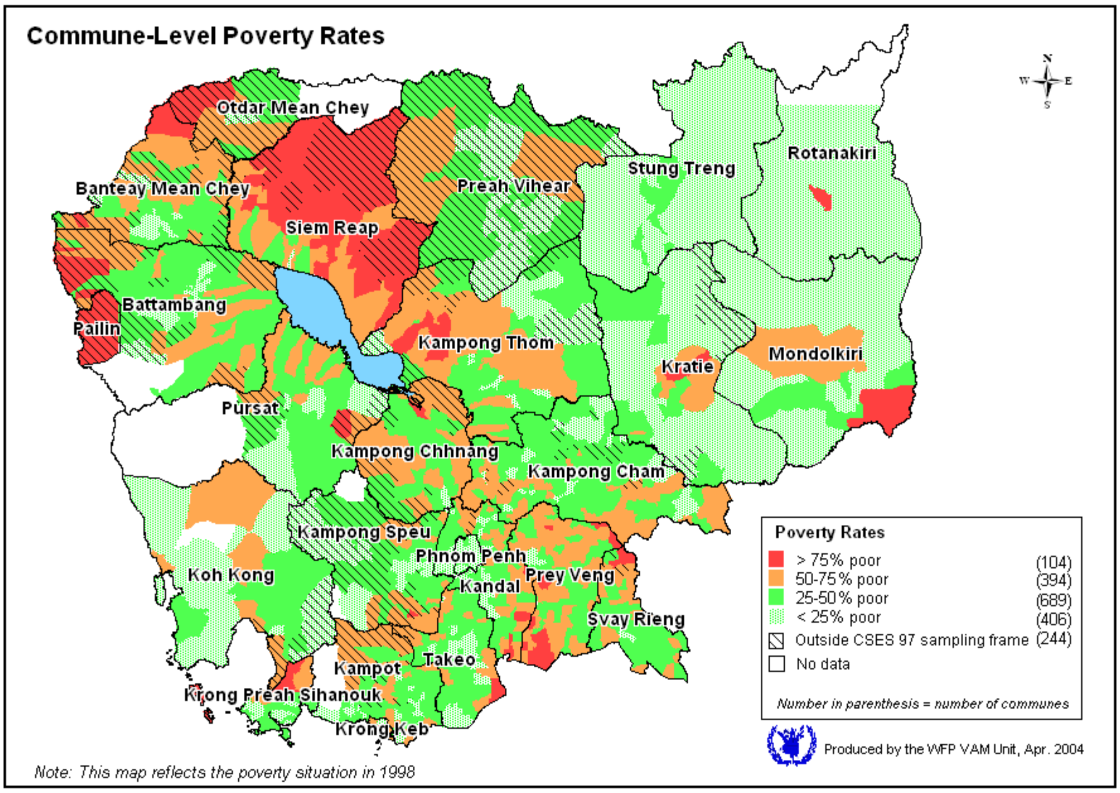

Figure 8 Poverty situation map in Cambodia, 1998.

Cambodian farming systems are largely subsistence oriented and most agricultural activities are based on low inputs and rain fed production systems centered on paddy rice production. As shown from Figure 8, in spite of Cambodia having achieved rice self sufficient and even an exportable surplus, the rice-based farming systems are characterized by low income. The typical farmer growing paddy gets an income per hectare ranging between $100 and $200 per year. With little diversification into other crops and agricultural activities and with an average landholding size of 1 hectare, poverty is pervasive (Agrifood Consulting International and CamConsult, 2006).

According to the 2004 Cambodia Socio-Economic Survey (CSES), 35 percent of Cambodian population or about 4.6 million individuals are estimated as living below the poverty line. Of this group, approximately 2.6 million live in extreme poverty facing food deprivation (WFP, 2009).

3.1.11 Summary

Rice in Cambodia is mainly cultivated in low land areas and the area of rice plantation has been continuously increasing over the years representing 90% of the total agricultural area used in the country. Rice cultivation practices in Cambodia rely mainly on labor but new technologies are being introduced. This is notably the case for harvesting which is slowly becoming mechanized although still marginal. Rice intensification methods following successful experimental trials are now being endorsed and promoted by the Cambodian government. Such methods have been included since 2006 in the National Strategic Development Plan. Since most paddy fields in Cambodia are located in rainfed areas, there is substantial potential for the cultivation of alternate crop in paddy fields to maximise output per unit area of land. This opens opportunities for the introduction of energy crops as rotation crops. This option to would not only enable Cambodia to take a step developing toward a low carbon society in the agricultural sector but also to improve the welfare of rice farmers who are still subsisting on low income.

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3.2 Indonesia

Indonesia consists of 17,508 islands, but about 6,000 islands are inhabited. These islands are scattered over both sides of the equator. The largest ones are Java, Sumatra, Borneo (shared with Brunei and Malaysia), New Guinea (shared with Papua New Guinea), and Sulawesi. The borders of Indonesian lands are shared with Malaysia on Borneo, Papua New Guinea on the island of New Guinea, and East Timor on the island of Timor. The maritime borders of Indonesia are shared across narrow straits with Singapore, Malaysia, the Philippines, and Palau to the north, and with Australia to the south. The capital city is Jakarta, located on Java, which is the largest city, followed by Surabaya, Bandung, Medan, and Semarang. Location of Indonesia is on the edges of the Pacific, Eurasian, and Australian tectonic plates so it consists of numerous volcanoes and frequent earthquakes. There are at least 150 active volcanoes in Indonesia. As Indonesia is lying along the equator, it is characterized by a tropical climate, with two distinct monsoonal wet and dry seasons. The climate is highly humid, averaging about 80%, and slightly varied temperature, 26–30 °C, throughout the year. Annual rainfall in the lowlands varies from 1,780–3,175 millimeters, which is lower than in mountainous regions that vary up to 6,100 millimeters, particularly in the west coast of Sumatra, West Java, Kalimantan, Sulawesi, and Papua receiving the highest rainfall (Wikipedia, 2012). The main islands of Indonesia consist of Java, Sumatera, Sulawesi, Kalimantan, Bali and Nusa tenggara. In 2008, the total wetland area was 8.01 million ha, 29% of which is located in Java, 41% in Sumatera, 11.6% in Sulawesi, 12.6% in Kalimantan, 5.4% in Bali, and 0.8% in Nusa tenggara. These wetlands are located for 62.5% in irrigated areas and 37.5% in non irrigated areas. Indonesia is ranked 3rd in the world regards to total rice production, but is also ranked the world's 7th largest rice importer. Rice is cultivated in both lowland and upland elevations throughout the country- irrigated lowland rice-mainly in Java and also in Sumatra and Sulawesi, rainfed upland in Bali, and combination between upland and lowland area. Indonesian rice harvested area covered 12,147,637 ha, located in every island. The three islands contributes about 89% of total national rice production- Java (5,179,231 ha), Sumatra (1,865,354 ha), and Sulawesi (1,255,392 ha) (FAO, 2007).

3.2.1 Rice varieties

Major species of rice in Indonesia is *Oryza sativa* (*Javanica*). From 1943 to 2007, 190 rice varieties in wet land were released and 30 rice varieties of dry land were released. The varieties mostly cultivated are:

- IR-64: Way Apo Buru, Memberamo, Cisokan
- Ciherang: IR42, Cisadane, Cibogo
- Ciliwung: Widas and IR 66.

The rice varieties mainly produced in Indonesia based on the area cultivated are presented in Figure 9.

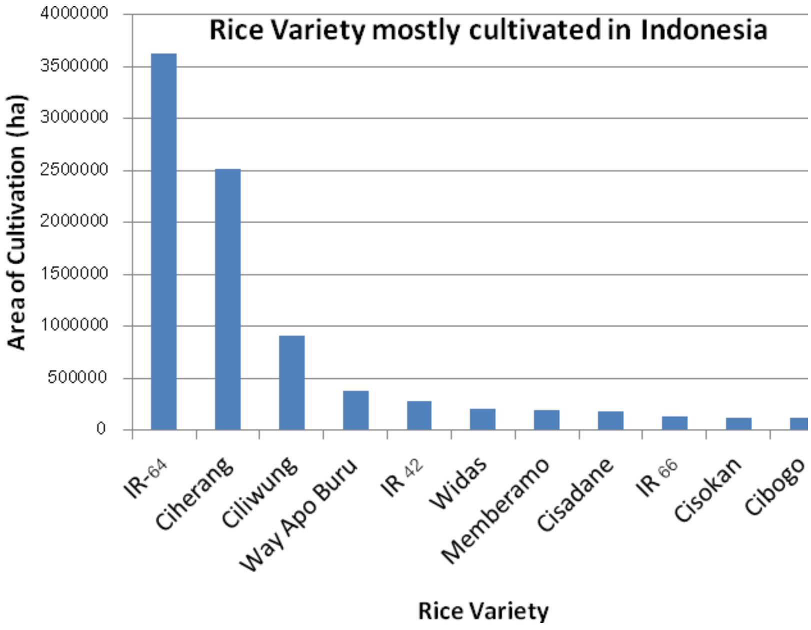

Figure 9 Cultivated area of major rice varieties in Indonesia.

The three main rice varieties cultivated in Indonesia are IR 64 (31.4%) followed by Ciherang (21.8%) and Cilwung (8%). The rice yield is 0.004-20 tonnes/ha. From the questionnaire survey in Java, rice varieties name “Ciherang” and “IR64” were planted in many areas in Java. The average yield of Ciherang was 4.36±1.99 tonnes/ha (0.004-7 tonnes/ha) and IR64 was 2.53±3.71 tonnes/ha (0.14-16 tonnes/ha).

3.2.2 Rice ecosystems

The main ecosystems of rice cultivation in Indonesia are presented in Table 7.

Table 7 Rice ecosystems in Indonesia

No.	Ecosystem/ rice soil types	Distribution (%)
A	Lowland	55
B	Highland	17
C	Complex (Combination between A and B) 1. Vertisols (Grumusols) (Sub ordo Aquert, udert, and ustert) 7% 2. Ultisols and Oxisols (Red yellowish podsolic) 4% 3. Alfisols (Red yellowish Mediteranean) 4% 4. Newly opened rice field: Ultisols (red yellowish possolic) 10% 5. Newly opened rice field: Oxisols 1%	28
	Total	100

As shown in Table 8, the three main ecosystems of rice cultivation in Indonesia include lowland, upland, and complex (combination between lowland and upland) areas. Rice is cultivated mostly in lowland areas, which account for 55% of the total area of rice cultivation in the country (total area of rice field in Indonesia 11.7 million ha).

Table 8 Seasonal rice crop calendar in Indonesia

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
normal rice plantation in west Java (2 cycles/year)												

Land preparation
Rice Cultivation

3.2.3 Land preparation

The traditional preparation of land using Tajak, a traditional long sickle, is performed 3 weeks before planting. One week before planting, dead weeds are removed from the field (Kartaatmadja et al., 2004). Recently from a questionnaire survey performed in Java (145 questionnaires), it was found that about 93% of rice fields are prepared using machines while the remaining are prepared manually using working animals (7%). The animals used for land preparation are essentially buffalos (2 to 7 years old). Each family owns 2 to 4 buffalos. The cost of land preparation is in the range of 70,000-5,000,000 Rp/ha. However, the cost for land preparation using machines was found to be lower than those using animals.

3.2.4 Planting methods

The result of the questionnaire survey showed that a 100% of rice in Java is planted by broadcasting of pre-germinated rice seeds. The time spent for seeding is 1 to 60 days. The size of the plantation for one family is in the range 0.02 to 40 ha. However, most farmers own 0.25 to 3 ha of land and the time spent for seeding is in the range 1 to 4 days or 20 to 30 days (Figure 10). Laborers spend about 6-10 hr/day on the field. The cost of planting (Rp/ha) depends mainly on the number of laborers (Figure 11).

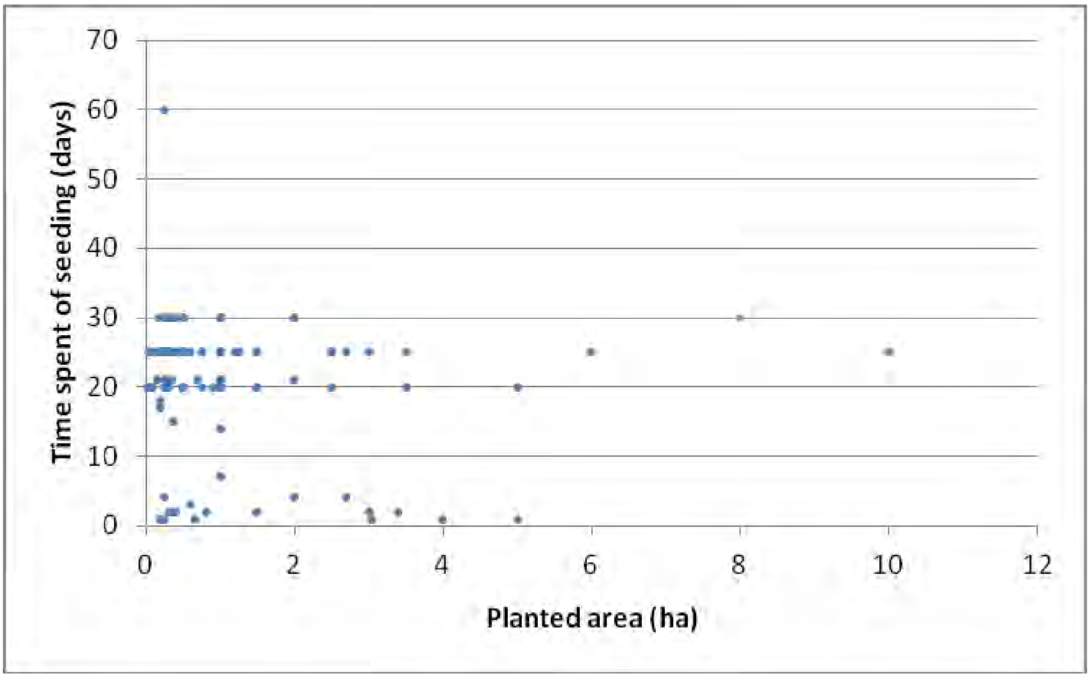

Figure 10 Correlation between the time spent for seeding and plantation area.

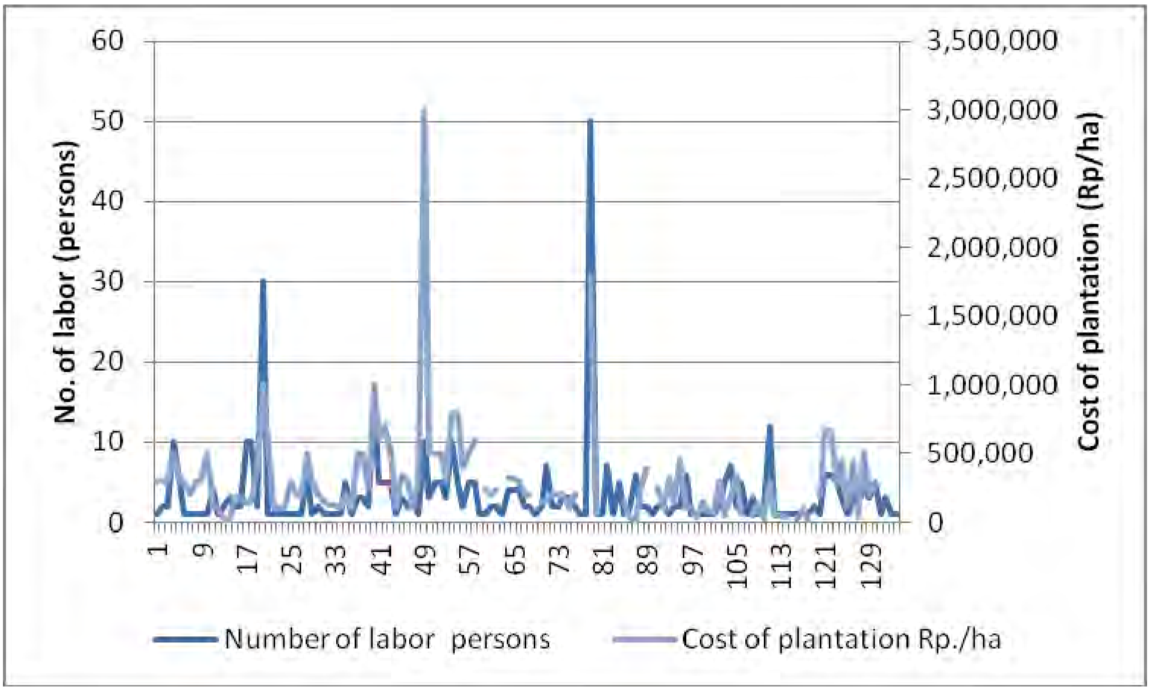

Figure 11 Cost of plantation and number of labor for planting.

3.2.5 Water management during growth

As shown in Figure 12, major water resources for rice cultivation in Java include irrigation (43%), natural water, i.e. canals/rivers (19%), groundwater (16%), man-made ponds (15%), direct rain (6%), and others, i.e. drainage systems and wells (1%).

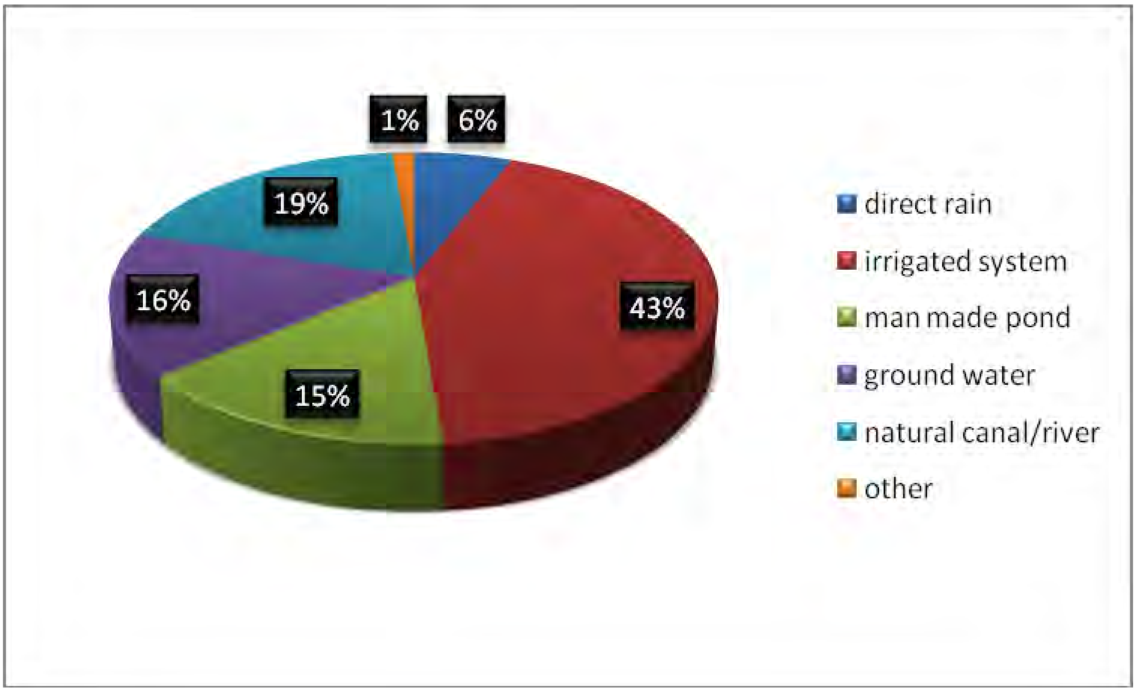

Figure 12 Major water resources for rice cultivation in Java, Indonesia.

From Figure 13, it is observed that alternative water resources for rice cultivation in Java are mainly from direct rain (68%), and other sources including groundwater (18%), natural sources, i.e. canals/rivers (7%), irrigation (5%) and man-made ponds (2%), respectively.

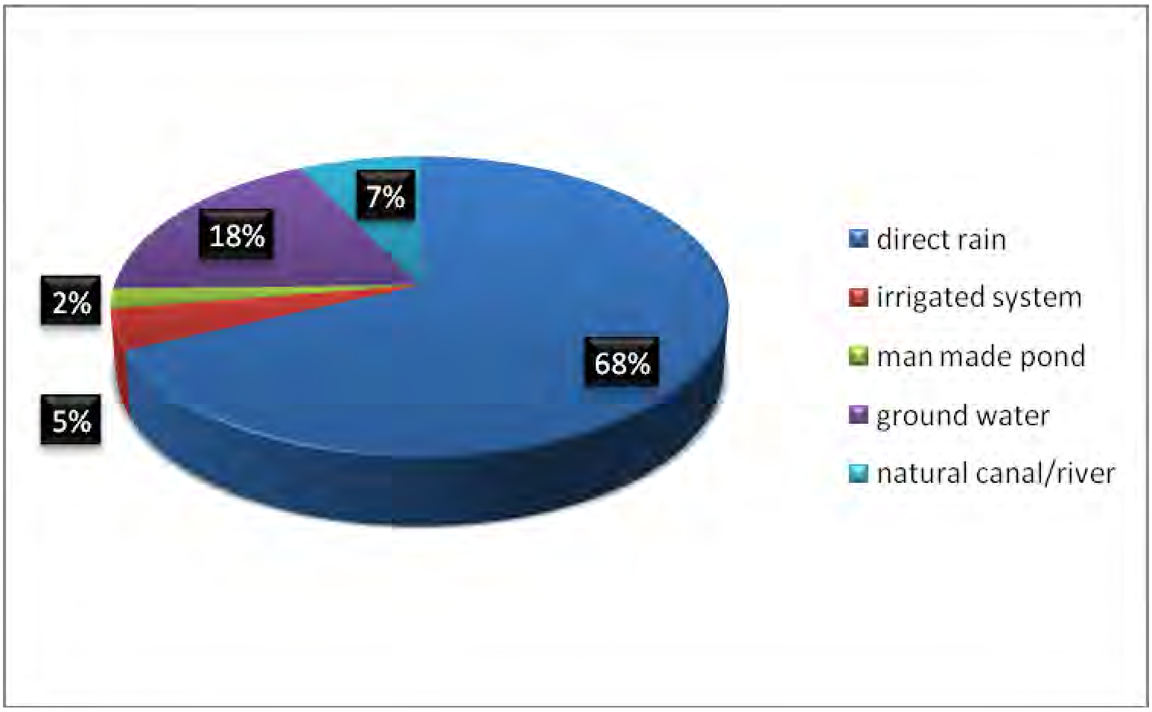

Figure 13 Alternative water resources for rice cultivation in Java, Indonesia.

Although there can be various water management methods used during the plant growth, mainly water is drained into the rice field immediately after planting or 1-2 weeks after planting. The number of water inlets into the field is in the range 1 to 4 times. The depth of the water is about 2 to 30 cm. In the rice fields that drain water into the field 4 times usually contained water depth 5 cm for 3, 7, or 14 days.

3.2.6 Fertilization

The results of the questionnaire survey in Java showed that the types of fertilizers applied in rice fields consist of Urea (N source), TSP (P source), Ponska, Dasar, Kujang, Pusri, ZA (grow faster), KCL (more fertile), and NPK. The Urea type is applied to render leaf greener. Ponska type is applied to increase grain weight. The KCL type is applied in small amount in fertile areas about 1to 5 kg/ha. All farmers apply fertilizers in their farms. The amount used depends on soil fertility, with three main ranges of application as follows: 1-25 kg/ha (Karawang, Sukabumi, Cianjur, Ngawi, Sragen), 50-300 kg/ha (Wanagori, Wonagiri, Sukoharjo), and 100-800 kg/ha (Ngawi, Bojonegoro, Malang). Although rice fields are located in the same area, different amounts of fertilizer applied in the field were found in Ngawi, i.e. 2-6 kg/ha and 100-800 kg/ha. The price of fertilizer is mostly in the range of 1,700-3,500 Rp/kg. The number of laborers working in the field ranges between 1 to 6 persons. Labor wages are in the range 15,000-50,000 Rp/kg of fertilizer. The average labor cost is 27,938±5,146 Rp/kg. Most laborers were found to be hired for 25,000-30,000 Rp/kg of fertilizer. The highest wage was found in Ngawi and Sukoharjo.

3.2.7 Liming

In Java, it was found that 89% of the 145 surveyed families apply lime in their rice field. The amount of lime applied ranges between 2 to 600 kg/ha. The largest amount of lime applied in the field was found in Bojonegoro with 400 to 600 kg/ha. The price of lime ranges between 340 to 50,000 Rp/kg. The price of lime in Bojonegoro is quite high, about 17,000 to 20,000 Rp/kg. Labor cost associated with liming is in the range 20,000 to 30,000 Rp.

3.2.8 Use of pesticides and herbicides

Farmers apply pesticides in most areas of Java. The results of the questionnaire survey indicate that 90% of 145 families apply pesticides in their farms. However, herbicides are applied only in 39% of cases. Pesticides are used 1-10 times per cycle but mostly used 1-2 times per cycle. Most pests found in rice fields are grasshoppers, mouse, and larva. There are various types of pesticides used in Java, i.e. Spontan, Furadan, Dupont, Rizotin, Pastak, Reagen, Muradan, Furadan, Ponska, Baygon, Decis, DDT, Mipsin, Rejotine, Siodan, Culakron, Topdar, Naga, Buprosida, Aplaud, Top Dor, Sonio, Bioveet, Virtaco, Sherpa, Firtaco, Starban, Ariffo, R-cabas, Darmabas, Sekor, Akodan, Lotsa, Bassa, etc. Their price varies between 5,000 to 50,000 Rp/kg. Application of pesticides is done since planting up to 90 days after plantation. Pesticides are diluted 0.03-60 times before being applied and require 1 to 10 persons. Labor costs are in the range 7,500-48,000 Rp (mostly between 20,000-40,000 Rp).

Herbicides are applied 1-2 times per cycle, but in some fields are applied 6-7 times per cycle.. Examples of herbicides include: Satrund, Sida Up, Mitsilindo, Satio, Logeram, Dras, Gramaxon, sakrun, Ali, Noxon, Mesulindo, Sherly, Bio up, Dilar, Ally, Obat, Karevo, Indomin, Tigul, Tarmin, Round Up, Rambasan, Adroson, Gramason. The price of herbicides ranges between 5,000 to 160,000 Rp). They are applied since the date of planting until 15 days after planting. The number of labor for applying herbicides is 1-5 persons, which cost 15,000-40,000 Rp (most 25,000 and 30,000 Rp).

3.2.9 Harvesting methods and management of rice residues

From the questionnaire survey in Java, rice is harvested both by manual (65%) and machine (35%). Rice height at harvested date was 50-120 cm. Stubble height was 5-50 cm. The machine cut rice at 15-30 cm height above ground.

Most residues remain on the field following harvesting. From the questionnaire survey out of the 143 farmers, it was found that 76% leave the residues on the field, 15% are removing the residues from the field, and 9% remove only a fraction of the residues from the field. For the fraction of residues remaining on the field, it is totally burned for 19% of the 143 surveyed farmers. The main reasons for burning are: to prepare the land (71% of cases), fertilize the land (17% of cases), remove pest (6% of cases), and remove weeds (6% of cases). Rice residues are mainly burnt in the afternoon, i.e.72% of the cases. For another 26% of the cases, it is burnt in the morning and the remaining 2% at night. Most farmers use rice residues for soil amendment (69%), mulching (19%), animal feed (6%), as media for mushroom cultivation (3%), or fertilizer (3%). Utilization of rice residues is presented in Figure 14.

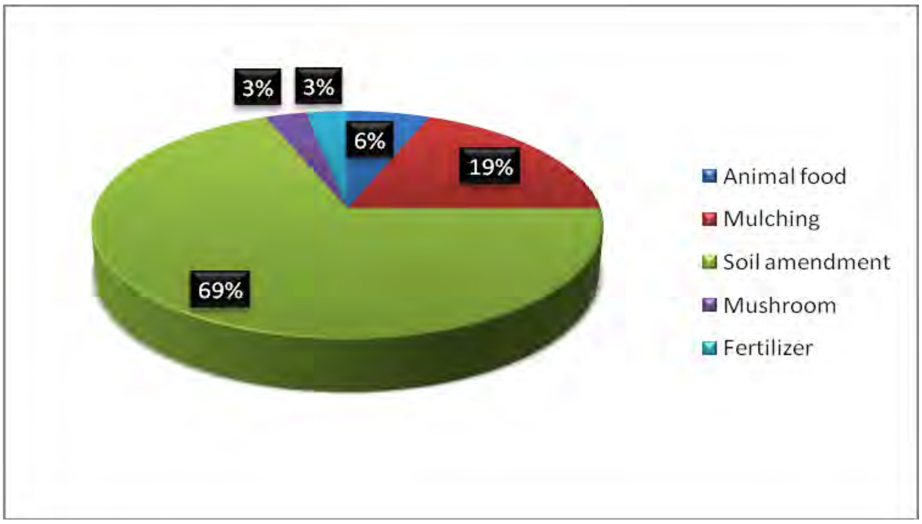

Figure 14 Utilization of rice residues.

3.2.10 Rotation crops

After harvest, some farmers continue planting with a next crop immediately. The fallow period in Java lasts for one week to four months. During the fallow period, farmers plant legumes (soybean, peanut, mungbean, string bean), and corn. The results of this questionnaire survey is in good agreement with information obtained from Lombok (an island in West Nusa Tenggara province) where crops such as soybean, peanut, mungbean and corn are reported to be commonly grown in rotation with rice crops, without fertilizer (Wangiyana and Cornish, 2002).

However, most farmers do not plant crop rotation (79%) because their farms are located in irrigated areas (43%) or in areas with good access to water resources i.e. manmade pond, ground water, canal/river, drainage system (51%). Hence, a next cycle of rice can be cultivated immediately after harvest of the previous rice crop. The low fraction of crop rotation found in Java from the questionnaire survey is result is in good agreement with the information gathered from APN expert meeting, as presented in Figure 15.

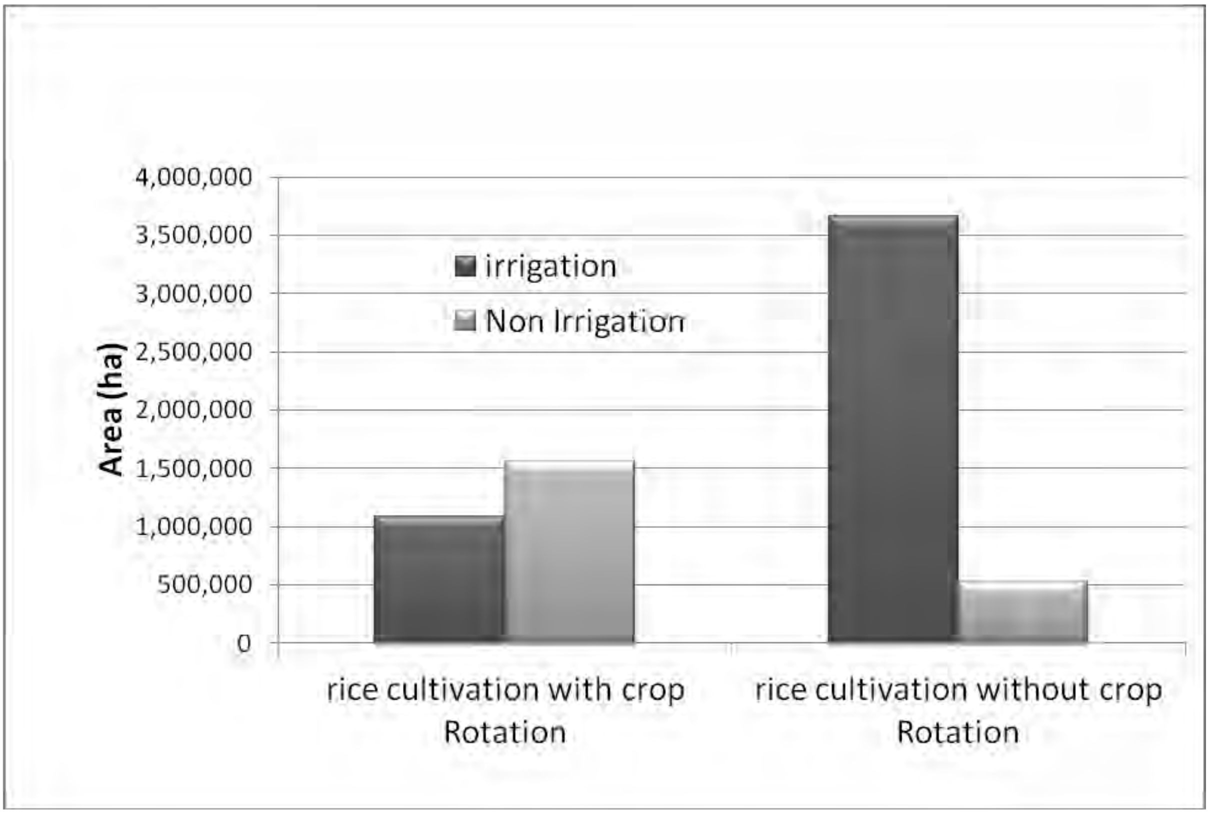

Figure 15 Total area of rice cultivation with and without crop rotation in Indonesia. (Rusmana, 2011)

3.2.11 Soil organic carbon

Soil organic carbon in lowland areas in Indonesia where rice is grown is presented in Table 9.

Table 9 Soil organic carbon of soil in lowland areas in Indonesia

Level	Soil organic carbon (%)	Fraction (%)
Low	<2	73
Medium	2-3	23
High	>3	4

(Rusmana, 2011)

Most areas contain low soil organic carbon levels due to the intensive weathering process, high rainfall and temperature, land use change, and inappropriate management practices. In west Java, soil carbon sequestration was compared between organic and conventional rice cultivation in the top 10 cm soil layer (Komatsuzaki and Syuaib, 2010). The results are presented in Table 10.

Table 10 Comparison of soil carbon sequestration in west Java, Indonesia

	Soil Bulk Density (g mL^{-1})	Carbon content (%)	Soil carbon storage (Mg ha^{-1})
Organic	0.88	2.89	25.0
Conventional	0.80	2.22	17.6
Significance	Not significant	1%	5%

(Komatsuzaki and Syuaib, 2010)

The profile of soil carbon content for organic and conventional rice cultivation in the top 30 cm soil layer is presented in Figure 16.

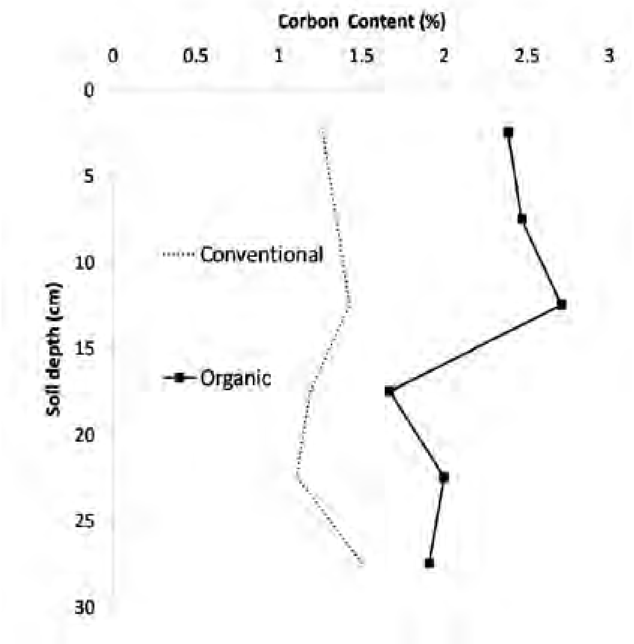

Figure 16 Profile of soil organic carbon at 30 cm soil depth from the surface.
(Komatsuzaki and Syuaib, 2010)

Measurements of soil organic carbon (SOC) were conducted at 2.5, 7.5, 12.5, 17.5, 22.5, and 27.5 cm depth from the surface. From the top soil, the SOC was gradually increased until a level of soil depth at 12.5 cm, then the SOC start to decrease gradually; however, the SOC is increased again at the depth below 22.5 cm. Content of soil organic carbon is found to be higher at any depth of soil for organic rice than conventional rice.

3.2.12 Socio-economic status of rice farmers

The study of Sukristiyonubowo et al. (2011) compared the cost and revenue of three rice cultivation systems: conventional, semi, and full organic rice farming in Sragen District, Central Java Province, Indonesia in October 2008. This was performed via field visits of individual farms by conducting interviews without questionnaires. The results of the socio-economic aspects investigated are presented in Table 11 and 12.

Table 11 Cost and revenue of three different rice farming systems: conventional, semi, and full organic rice farming in Sragen District, Indonesia for the dry season 2008 (not including family labors)

No.	Parameter	Conventional (Rp/ha/season)	Semi organic (Rp/ha/season)	Fully organic (Rp/ha/season)
1.	Production cost			
	Labor cost:	4,700,000	2,540,000	2,340,000
	Land preparation	1,200,000	800,000	600,000
	Planting	800,000	600,000	600,000
	Fertilization	200,000	-	-
	Weeding	800,000	600,000	600,000
	Pest and disease control	200,000	40,000	40,000
	Watering	1,500,000	-	-
	Harvest		500,000	500,000
	Agricultural input cost:	2,300,000	160,000	60,000
	Mineral fertilizers	2,200,000	100,000	-
	Organic fertilizer	-	-	-
	Commercial pesticides	100,000	-	-
	Bio pesticides	-	30,000	30,000
	Scorr	-	30,000	30,000
2.	Total cost	7,000,000	2,700,000	2,400,000
3.	Revenue	15,000,000	15,000,000	16,800,000
4.	Benefit	8,000,000	12,300,000	14,400,000
5.	B/C ratio	1.13	4.55	6.00

Note: the labor cost for fertilization in semi and fully organic systems were included in land preparation.

From Table 11, B/C ratio is benefit per production cost. The production cost is the sum of the labor cost and agricultural input cost and benefit is the difference between the revenue and the production cost. The differences among conventional, semi, and full organic rice farming consist of water resources, fertilizers, and pesticides. In the conventional system, farmers applied chemical fertilizers and commercial pesticides, and used irrigated water. For semi organic rice systems, there were no chemical inputs, application of some commercial pesticides and inorganic fertilizers, and use of water from springs or deep wells. For full organic systems, there were no inputs of inorganic fertilizers and commercial pesticides, and only spring water was used as water resource.

Table 12 Cost and revenue of three different rice farming systems: conventional, semi, and fully organic rice farming in Sragen District, Indonesia for the dry season 2008 (including family labors)

No.	Parameter	Conventional (Rp/ha/season)	Semi organic (Rp/ha/season)	Fully organic (Rp/ha/season)
1.	Production cost			
	Labor cost:	5,000,000	3,330,000	3,240,000
	Land preparation	1,200,000	800,000	700,000
	Planting	800,000	800,000	800,000
	Fertilization	300,000	-	-
	Weeding	900,000	800,000	800,000
	Pest and disease control	300,000	200,000	140,000
	Watering	1,500,000	-	-
	Harvest	-	700,000	800,000
	Agricultural input cost:	2,300,000	160,000	60,000

No.	Parameter	Conventional (Rp/ha/season)	Semi organic (Rp/ha/season)	Fully organic (Rp/ha/season)
	Mineral fertilizers Organic fertilizer Commercial pesticides Bio pesticides Scorr	2,200,000 - 100,000 - -	100,000 - - 30,000 30,000	- - - 30,000 30,000
2.	Total cost	7,300,000	3,460,000	3,300,000
3.	Revenue	15,000,000	15,000,000	16,800,000
4.	Benefit	7,700,000	11,540,000	13,500,000
5.	B/C ratio	1.05	3.34	4.09

Note: the labor cost for fertilization in the semi and fully organic systems was included in land preparation.

The results of cost shown in Table 12 are in range with the results obtained from the questionnaire survey. However, these values are located towards the upper bound of those found from the questionnaire survey. The study of Sukristiyonubowo (2011) simplified the calculations using the common labor cost of Rp 20,000 IDR/day, which is similar to that found from the questionnaire survey performed in Java. The selling price of rice is Rp 2,500 (semi-organic) and 2,800 (fully organic) IDR/kg, while that found from the questionnaire is in the range Rp 3,500 to 4,500 IDR/kg in Sragen. However, total revenue from Tables 11 and 12 is in the same range as that obtained from the questionnaire survey. Using the exchange rate of 1 US dollar = Rp 9,000 IDR (Reference), based on results from Table 12, the net benefit made by Indonesian farmers is in the range 889 to 1,600 USD/cycle. From the questionnaire results, it was found that for 2-3 rice cycles/year Indonesian farmers make a benefit of 1,778 up to 4,800 USD/year.

3.2.13 Summary

Major species of rice in Indonesia is *Oryza sativa* (*Javanica*) which is different from other countries in Southeast Asia *Oryza sativa* (*Indica*). Major varieties of rice in Indonesia are IR-64 and Ciherang that cultivated in many areas in Java. The main islands of Indonesia consist of Java, Sumatera, Sulawesi, Kalimantan, Bali and Nusa tenggara. Rice ecosystem consists of lowland 55% of total paddy field, highland 17% of total paddy field, and complex (combination between highland and lowland) 28% of total paddy field. The lowland are located for 62.5% in irrigated areas and 37.5% in non irrigated areas. Farmers prepare land manually but modern method as chemicals are used for fertilizer, herbicide, and pesticide. Harvesting is done mostly by manual and some of them are done by machine. After harvest, most rotation crops are planted in non-irrigated area, while rice is continued planting immediately in most irrigated paddy field. Indonesian farmers make a benefit of 1,778 up to 4,800 USD/year.

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3.3 Lao PDR

Lao PDR is an SEA country covering total area of 236,800 km^2 with a land area of 230,800 km^2. It is surrounded by China in the north, Thailand in the west, Vietnam along the north and east border, and Cambodia in the south. As the borders of Lao PDR are enclosed by other countries, the country does not have any coastal area. In terms of topography, Lao PDR is composed mainly of rugged mountains, some plains, and plateaus. Most mountain areas are found in the eastern part of the country near Vietnam, and some are found northwest near the northern part of Thailand. The plateaus are located in the north, i.e. the Xiangkhoang Plateau, and south, i.e. the Bolaven Plateau. There are three seasons in Lao PDR, consisting of rainy, cold, and hot. The wet season lasts from May to November and is followed by the dry season from December to April. In the dry season, winter is from December to February and summer is from March to April Paddy fields are located mostly in non-irrigated areas, representing approximately 90 percent of the total rice area in the country. Therefore, rice is essentially sown in the early part of the summer season relying for water on the monsoon rainfall. Irrigated areas are located in lowland areas along the Mekong River. There farmers can cultivate double-cropping of rice during the dry season (Wikipedia, 2013).

3.3.1 Rice varieties

Primitive upland cultivars (*Oryza sativa L.*) in northern Laos are classified into 106 japonica, 16 indica, two intermediate, and eight heterozygous cultivars. The japonica cultivars are characterized by glabrous hulls and sticky grains. Only two out of 16 indica cultivars are glabrous. The heterozygotes are generated by out-crosses between japonica and indica cultivars in upland fields. The intermediate type is the progeny of such heterozygotes. Genotypic frequencies differ between populations collected from upland fields along roads and along a branch of the Mekong River. Such differences are caused by different origins of these two populations. In this report, isozymes are indicated as valuable markers to recognize the cultivars to be of independent stack (Ishikawa et al., 2002).

In 1990-1991, IRRI surveyed and located 73 local varieties of rice planted in Lao PDR, which 85-90% of the rice cultivars grown are “glutinous varieties”, commonly RD6, RD8 and RD10; and non-glutinous varieties Khow Dok Mali 105 (Thai origin). The most popular varieties are RD10 because of their large seeds and good eating characteristics and are particularly good for cultivation during the dry season under irrigated conditions (IRRI, 1996). Roder et al., (2006) indicated that there are over 3,000 different varieties of rice recorded in Lao PDR. New varieties have been developed to enhance yield and capture high quality traits. Two popular new varieties are Thasano1 (TSN1) and Thadokkham1 (TDK1). Other new rice varieties are presented in Table 13.

Table 13 Improved Rice Varieties, Lao PDR

Name	Year Released	Major Positive Traits
TDK 1	1993	High N response, good tillering, resistance to most biotypes of brown plant hopper and to rice leaf diseases
TDK 2	1993	Moderately resistant to leaf blast, bacterial leaf blight, BPH, gall midge, and stemborer
PNG 1	1994	Good grain quality, moderate yield, broad adaptability, maturity at 125–130 days, and resistance to blast
PNG 2	1995	Moderately resistant to brown spot, flowering in mid-October
TDK 3	1997	Good grain quality, resistance to rice diseases and suited to favorable rain-fed lowland
TDK 4	1998	Good grain quality, high N response, suited to medium fertile and saline soils

Name	Year Released	Major Positive Traits
TSN 1	1998	Good grain quality and high N response, best suited to fertile soils
NTN 1	1998	Good grain quality, 130 days maturity, resistance to blast
TDK 5	2000	Good grain quality, maturity at 125–130 days, plant height 95–115 cm, resistance to blast, bacterial leaf blight

Note: NTN = Namtane, PNG = Phone Ngam, TDK = Thadokkham, TSN = Thasano
(Bestari et al. 2006)

Two major groups of modern rice varieties were released in Lao PDR after 1990. The first group consists of the Lao-IRRI modern rice varieties (LMVs) developed by the joint Lao-IRRI research programs. From Table 13, nine varieties developed specifically for Lao conditions have been officially released. These are glutinous varieties selected for good quality, high yield potential, and suitability to saline and low fertility soils. Some are also resistant to common insects and diseases such as brown planthopper, gall midge, stemborer, leaf blast, bacterial leaf blight, and brown spot. However, the traditional varieties, i.e. Hom Nang Nouane (HNN) and Kai Noy Leuang (KNL), have continued to be cultivated because of their fragrance and softness of their grains after cooking; whereas, new developed varieties TDK1 and TNS1 are not fragrant (Boualaphanh et al. 2011).

3.3.2 Rice ecosystems

Main categories of paddy fields in Lao PDR include rain-fed lowland (lowland wet season), irrigated lowland (lowland dry season), and rain-fed upland areas (upland wet season). There is no deep water rice ecosystem in Lao PDR. The area of rice cultivated for each ecosystem over the period 1976-2004 is presented in Figure 17.

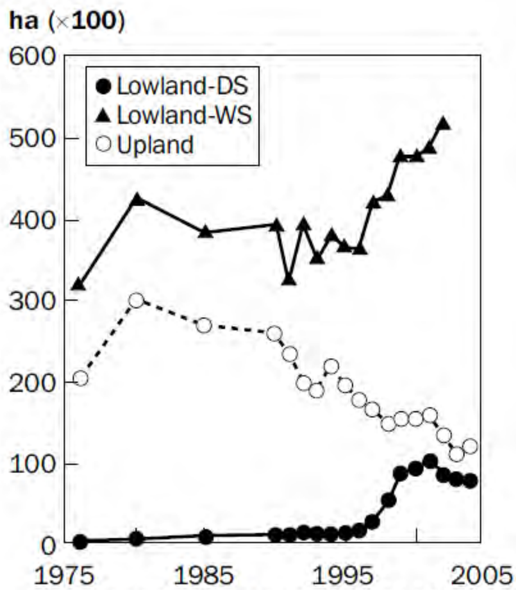


Figure 17 Ecosystem of rice cultivation in Lao PDR in the lowland and upland environments from 1976 to 2004.
Note: DS = Dry season, WS = Wet season
(Schiller et al. 2006)

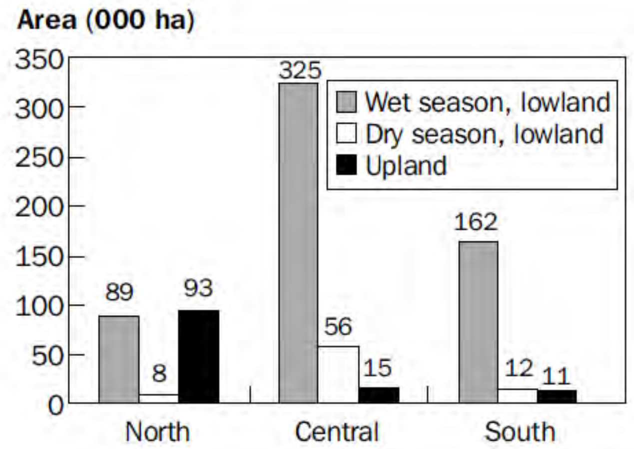


Figure 18 Area of each rice ecosystem by region.
(Schiller et al. 2006)

Most paddy fields in Lao PDR are located in rain-fed areas, 90% of total paddy areas, which are classified into lowland and upland. In non-irrigated areas, rice is sown during the wet season so the cultivation of rice in non-irrigated areas is called wet season rice. Rice can be cultivated in irrigated lowland areas during the dry season because there are enough water resources available via irrigation system.

Upland rice is rice cultivated in hilly areas mostly in the northern part of the country where natural vegetation has been replaced. Since irrigation is not available in such areas, rice is therefore planted only once during the wet season. The farming system of upland rice is referred to as shifting cultivation since farmers are to clear the initial natural vegetation present in such areas, i.e. forest or grass, via slash and burn before planting the new rice crop. As compared to other rice cultivation systems (lowland rice), shifting cultivation (upland rice) is characterized by a long agricultural production cycle. This is due to the slash and burn activities practiced to clear and prepare the land for rice plantation (see Figure 18).

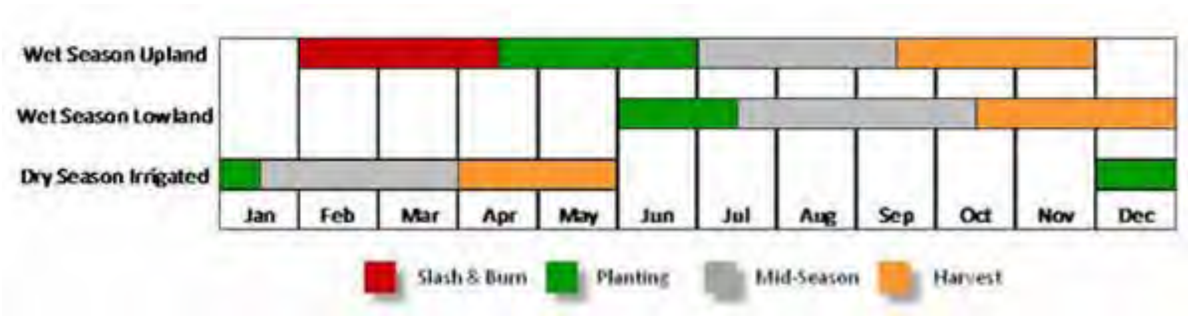
In 1990, the area of upland rice accounted for 40 percent of the total area of rice sown in Lao PDR, i.e. 245,877 ha, with up to 1 million farmers following the slash and burn farming system practice. But over the years the trend of lowland rice cultivation has been increasing while that of upland as been steadily decreasing. The areas of rice cultivation and production for each region of Lao PDR for the year 2004 are presented in Table 14. Lowland wet season rice corresponds to the main area of rice cultivated in each region of Lao PDR. Lowland dry season rice is mainly located in the central region of the country. Rain-fed rice in the lowlands dominates rice cultivation in the country. About 75% of the area cultivated (576,000 ha) and 78% of the production (about 2 million tonnes) originates from this ecosystem. Rain-fed upland rice accounts for over 15% of the total area of rice. Almost 50% of the rice grown in the Northern region originates from the rain-fed upland rice ecosystem (Bestari et al. 2006).

Table 14 Area and production of rice by region of Lao PDR, 2004

Region	Rain-fed Lowland (%)		Rain-fed Upland				Irrigated lowland (%)	
			Upland (%)		Shifting cultivation (%)			
	Area	Production	Area	Production	Area	Production	Area	Production
Northern	46.84	63.97	25.67	17.44	23.23	12.70	4.28	5.90
Central	82.03	79.82	1.94	1.08	1.76	0.79	14.26	18.30
Southern	84.55	87.32	5.10	3.13	0.70	0.36	6.65	9.19
Lao PDR	74.71	78.13	8.53	5.09	6.78	3.26	9.98	13.51

(Ministry of Agriculture and Forestry, 2004)

Table 15 Seasonal rice crop calendar in Lao PDR (USDA-FSA, 2011)



The most important areas of rice cultivation in Lao PDR are located in Savannakhét province, a lowland irrigated area along the Mekong River. Production of rice in this province accounts 22 percent of national rice production. Dry season lowland rice is mainly cultivated in Savannakhét province and Vientiane (prefecture) accounting for 25% and 20% of total lowland dry season production, respectively. Wet season lowland rice is found in plain areas of central through south regions, and few areas in valley bottoms of the north region. Savannakhét and Champasak provinces produce rice from wet season farming and account for 23% and 15% of total wet season lowland rice production. About 40% of rice production in wet season upland rice is harvested in Houaphan, Louangphrabang, Oudômxai and Oudomxay, provinces which are located in the Northern region where rice is cultivated under shifting cultivation systems (USDA-FAS, 2011).

3.3.3 Land preparation

The main fields are initially plowed about 2 to 4 weeks before transplanting. Just prior to transplanting and when the soil is flooded, the field is plowed again and puddled using a harrow. In sandy soils, land preparation must be done immediately before transplanting because the soil settles fast and it becomes difficult to transplant (Linquist and Sengxua, 2001).

No-till system has been studied by Dupin et al. (2009) in upland area, northern Lao PDR, because of erosion problem from tillage in slope area. Shifting cultivation was originally a no-till farming system because weeds were few and could be controlled by hand pulling and cutting, nowadays tillage is part of the rice cultivation system (Dupin et al. 2009). The three main stages of land preparation are as follows:

1) few weeds are hand pulled after being allowed to grow
2) A small curved hoe is used for superficial tillage to prevent cause severe yield reduction from weeds
3) A medium size hoe is used for deep tillage to prepare the land for sowing

Land preparation for rice cultivation is also done using handheld tractors in lowland areas. This method is not popular because most farmers still prepare the land without machine. According to FAO (2007), only 1,080 agricultural tractors were available in Lao PDR in 2007. This is a much smaller number than for neighboring countries, that is 4 times lower than in Cambodia (1,855 tractors), 150 times lower than in Thailand (220,000 tractors) and 204 times lower than in Vietnam (162,476 tractors). The use of tractors is not applicable for upland areas on sloping land under shifting cultivation system (Gansberghe, 2005a).

3.3.4 Planting methods

Most rice is planted by transplanting. The period of wet-season rice typically begins in May or early June at the start of the monsoon rainfall with the planting of the rice nursery. Following sufficient rain, the seedling nursery is prepared by plowing and puddling using a harrow. This is often done by buffalo but increasingly small handheld tractors are being used (enough water is required to make the soil soft enough to plow, especially for buffalos) (Schiller et al. 2006). The number of buffalos per planted area is shown in Figure 19.

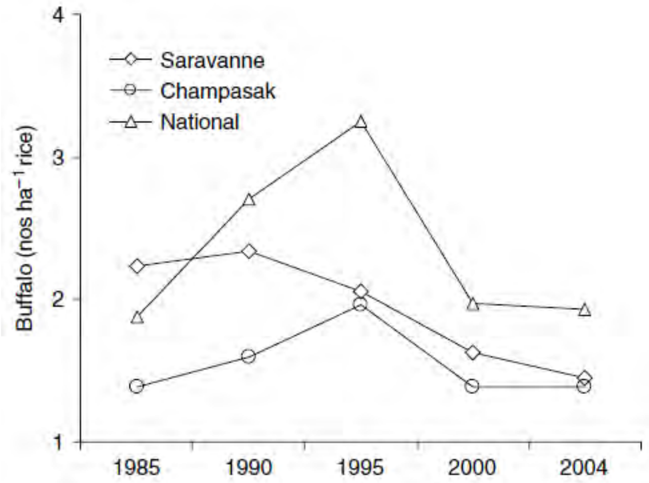


Figure 19 Number of buffalos per hectare of lowland rice in Suravanne and Champasak province in Lao PDR.
(Roder et al. 2006)

The average number of working animal labor for rice cultivation in lowland area is 1-2 buffalos per hectare. Some farmers plant rice by broadcasting. Rice seeds are presoaked for a day or two before sowing. The seeds are broadcasted immediately after puddling. Nurseries occupy a small area (5–10% of the total area to be planted) and are usually fenced to protect them from livestock. Seedlings grow for about 30 days in the nursery, although farmers may transplant at any time from 25 to 40 days or longer depending on rainfall. Sufficient rainfall is required to plow the main field and prepare for transplanting (Schiller et al. 2006).

3.3.5 Water management during growth

Rice cultivation in irrigated lowland areas is grown in every region of Lao PDR in bunded fields with ensured irrigation for one or more crops a year. Farmers generally try to maintain 5–10 cm of water ("floodwater") in their fields. Both irrigated and rainfed lowlands fields are predominantly puddled (harrowing or rotavating under shallow submerged conditions). Upland rice is grown under dry land conditions (no ponded water) without irrigation and without puddling, usually in non-bunded fields (Barker et al., 2007). Although Lao PDR is not faced with problems of flooding that could result from wet-season rainfalls, dry-season water management (irrigation and drainage) is very difficult to achieve under the irrigation conditions available in Lao PDR (Schiller, 2004). Irrigation systems are developing only thanks to the investments provided by the Laotian government and some other countries, i.e. Kuwait to support export to their countries (Chaophrayanews, 2010).

3.3.6 Fertilization

In rainfed areas, soil improvement is mainly achieved by applying manure and rice husks and slight use of chemical fertilizers. Fertilizers are mainly applied in upland paddy because these areas are less fertile when compared with rainfed and irrigated lowland paddies, except traditionally rice grown under slash-and-burn systems with long fallows that can restore soil fertility (Saito et al., 2006).

Inorganic fertilizer inputs in lowland rice cultivation have been increasing rapidly over the past decade, but still below 20 kg/ha. The most popular nutrient sources are still rice straw and manure from buffalo and cattle. Roder et al. (2006) studied fertility management and found the most promising inputs and strategies to optimize yields in organic rice production systems are (1) optimizing use of locally available nutrients, mostly from manure, crop residues and weed biomass, (2) N addition through green manure and legumes growing in rotation and (3) additions of P through guano or rock-phosphate.

3.3.7 Use of pesticides and herbicides

The use of pesticide in Lao PDR is low. The insecticide is used in most lowland rice areas, but at a very low level. As a result, the arthropod communities in the rice environment of Lao PDR have remained relatively undisturbed. The seeds are sometimes mixed with the pesticide before germination to protect against pests. (Schiller et al, 2006). Chemical herbicides and pesticides are not used in rainfed area and traditional slash-and-burn area with long fallows that reduce insect and weed pressure (Saito et al., 2006).

In Lao PDR, weeding is done manually so more labor is required-about half of the annual labor requirement. Frequency of weeding depends mainly on the length of the previous fallow. A farmer may weed the field two to five times. Labor maybe members of the household or exchange labor among farmers for weeding. If weeding is done by members of the family, weeding needs to be done almost every day to provide adequate weed control, especially in areas where the fallow period is short. In the case of group weeding, a single field can be weeded in a few days. In hilly area or sloping fields, farmers weed by walking up the slope and in this sense they prefer steep fields, as they bend over less while weeding (Schiller et al. 2006).

3.3.8 Harvesting methods

Duration of harvesting season in Lao PDR is September to November. Harvesting begins in early September with the early-maturing varieties; whereas, late-maturing ones are usually harvested by then end of October; and some varieties are harvested in November. Harvesting is done manually. The harvest is bundled and left in the field for a few days to dry. Spikes are left on top of the stubble and straw to dry or placed on an elevated pole or rack. Dried rice is often stored for a short period in the field before threshing by pilling the cut rice neatly into a large round stack. The spikes are placed in the middle of the stack to protect them from rain and rodents. Traditionally, threshing is done manually, which can be found in isolated area of Lao PDR. Nowadays, threshing is becoming increasingly mechanized by combine harvester in lowland area (Schiller et al. 2006).

3.3.9 Management of rice residues

Large quantities of rice straw left after the harvest are used as substrates for the cultivation of straw mushroom. Although the cultivation process is very simple and productive, knowledge of how to cultivate mushroom is limited so training is provided by the government officials through supporting international agencies such as UNDC, FAO, and JICA (Tapingkae, 2005).

After rice is harvested, water buffaloes and cattle graze in paddy fields, except in irrigated lowland fields that are also cultivated in the dry season. Rice husks are utilized as organic amendment for soil improvement.

3.3.10 Rotation crops

The rice fields where rotation crops are used are shifting cultivation systems, which are classified into 2 sub-groups: (1) Rotational, and (2) Pioneering. Rotational shifting cultivation is the most common type in Lao PDR. For this type, farmers keep their villages in the same place but shift their cultivated plots according to a crop/fallow cycle that depends upon several factors. In pioneering shifting cultivation systems, farmers moved their whole village settlements from one site to another after several years, mainly because the nearby forest had become exhausted (Gansberghe, 2005b). The main crops used for rotation include legumes, vegetables, and corn.

3.3.11 Socio-economic status of rice farmers

Contract farming is emerging as a promising tool to facilitate market linkages and provide the necessary supports to enable small farms to shift to commercial production. An ADBI research work by Setboonsarng et al. (2008) looked at the effects of rice contract farming on welfare of farmers in Lao PDR. It used data from a household survey of 332 contract farmers and 253 non-contract farmers. The results of the survey are presented in Table 16.

Table 16 Commercial production: Revenue, cost, and profit

Variables	Contract farming	Non-contract farming
1. Household Characteristics		
No. of farmer members	5.88	5.61
No. of family members older than 16	4.52	4.03
Percentage of females in family	49	49
Total land (ha)	2.48	1.72
Monthly consumption expenditure per person (1,000 kip)	144	147
2. Commercial Production		
No. of households	296	72
Size of commercial area planted (ha)	1.11	1.43
Percentage of planted area harvested	98	99
Revenue (1,000 kip/ha)	5,237	3,527
Rice price (kip/kg)	1,587	1,344
Yield (kg/ha)	3,272	2,603
Cash cost (1,000 kip/ha)	2,251	1,778
Cash cost (kip per kg of rice production)	1,290	936
Ratio of hired labor cost in total cash cost (%)	32	45
Profit (1,000 kip/ha)	2,924	1,751

(Setboonsarng et al. 2008)

From the above table, it is observed that contract farmers earn significantly higher profit than non-contract farmers. Under the contract, farmers receive an average price of 1,911 kip/kg for organic Japanese rice. For other varieties of rice, there is no significant difference of price between contract and non-contract farmers. Due to the premium price for Japanese rice, the average price of rice for contract farmers is 1,587 kip/kg and for non-contract farmers is 1,344 kip/kg. In Table 16, the revenue is presented per unit of area. The average size of holdings in the Lao PDR is 1.62 ha. In the south, the area on average is 2.02 ha, which is above the national level. Champasack province has the biggest average farm size of 2.17 ha. This is followed by Saravane with 2.07 ha, Vientiane Municipality with 1.96 ha, Sekong with 1.91 ha, Oudomxay with 1.87 ha, Luangprabang with 1.79 ha, Borikhamxay with 1.77 ha, Vientiane province with 1.76 ha, and Savannakhet with 1.61 ha. The smallest average farm size of 0.87 ha is in Phongsaly province (FAO, 2008). Material cost for contract farmers are also higher than for non-contract farmers as presented in Table 17.

Table 17 Material cost of commercial operation for contract and non-contract farming

Variables	Contract		Non-contract	
	1,000 kip/ha	Kip/kg	1,000 kip/ha	Kip/kg
Total material cost	1,474.00	852.00	920.00	462.00
Seed cost	283.00	192.00	81.00	41.00
Seed price	-	2,842.00	-	1,913.00
Fertilizer cost	814.00	528.00	429.00	272.00
Fertilizer price	-	3,347.00	-	3,231.00
Pesticide cost	0.31	2.78	0.33	1.67
Irrigation cost	180.00	107.00	137.00	74.00
Rental machine	136.00	82.00	166.00	71.00

Note: kip/kg of rice production
(Setboonsarng et al. 2008)

Although they have higher costs than non-contract farmers, contract farmers are compensated by higher yields and price premiums. As a result, contract farmers are significantly more profitable than farmers outside the contract, earning an average of 2,924,000 kip/ha of rice field, compared with the 1,751,000 kip/ha earned by non-contract farmers.

3.3.12 Summary

Ecosystem of rice in Lao PDR can be classified into irrigated lowland, rainfed lowland, and rainfed upland. There is no deepwater rice in this country. Species of rice planted in Lao PDR are *Indica* and *japonica*, as well as intermediate species between both types. Upland rice is planted via traditional methods that rely mainly on labors and organic materials. New technologies, such as machine for land preparation and product harvesting, are being slowly introduced for lowland rice cultivation but are still marginally used. For upland rice, following harvest, rotation crops such as legumes, vegetable, and corn can be used during the fallow period. In recent years, there has been a rapid expansion of contract farming in Lao PDR and such a scheme has been found to be particularly beneficial for farmers with relatively poor performance. It is an effective development tool to increase the incomes of smallholder farmers in rural areas where market failure is prevalent. Also contract farmers are more likely to diversify production into other commercial crops or livestock, leading to increased incomes and more secure livelihoods. The contract arrangement thus appears to be effective in facilitating the transition of small farmers from subsistence to commercial production thereby reducing poverty in rural areas with limited market development.

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3.4 Myanmar

Myanmar covers a total land area of 678,500 km^2 and is bordered northwest by Bangladesh and India, north and northeast by the Tibet and China and southeast by Lao PDR and Thailand. The country has also 1,930 kilometres of coastline along the Bay of Bengal and Andaman Sea in the south and southwest directions. Climate of Myanmar is influenced by location and topography that generates diversity of climate conditions. Effect of monsoon classified climate of Myanmar into three seasons: summer (March to mid May with average temperatures 43°C in central region, 36°C in northern Myanmar, and 29-35°C on the Shan Plateau), rainy season (mid-May to end of December, with most Upper Myanmar averages about 890 mm or 35 inches, and in Lower Myanmar about 5,080 mm or 200 inches), and winter (November to end of February, average temperature 20-24°C and hilly areas with an elevation over 3,000 feet below 0°C). Myanmar is a mountainous country. The highest point is called Hkakabo Razi and is located in Kachin State, with a maximum elevation of 5,881 m above sea leavel. In the north, at the border between Myanmar and China the Hengduan Shan mountain is found. Mountain ranges run north-to-south from the Himalayas, such as the Rakhine Yoma, the Bago Yoma, the Shan Hills and the Tenasserim Hills. The mountain chains divide Myanmar into three river systems, which are Irrawaddy, Salween (Thanlwin), and Sittaung rivers. The Irrawaddy River is the longest river, nearly 2,170 kilometres long, and flows into the Gulf of Martaban. Fertile plains exist in the valleys between the mountain chains. The majority of the population lives in the Irrawaddy valley, which is situated between the Rakhine Yoma and the Shan Plateau. Major areas of rice production are located in Ayeyarwady Region, the rice bowl of Myanmar (Wikipedia, 2012).

3.4.1 Rice varieties

Rice varieties are developed to increase production yield. Varieties of rice are classified into monsoon and summer season.

Table 18 Rice varieties and yield (t/ha) in Ayeyarwaddy Region

Rice Variety	1994-95	2003-04
Monsoon Season		
High yield variety	2.64 (67%)	2.57 (83%)
Traditional varieties	1.70 (33%)	2.24 (17%)
Summer Season		
High yield variety	2.07 (96%)	3.06 (100%)
Traditional varieties	1.14 (4%)	-

HYV = high yield variety

Significant increase in grain yield was found in modern varieties so that such varieties were widely used by all farmers. Farmers tend to increasingly use modern varieties (high yield varieties). In year 2003-04, fraction of planting new varieties was 83% of total rice planting in monsoon season. In summer season 2003-04, farmers grew only the modern varieties for 100%.

Comparing between the years 1994-1995 and 2003-04 for all varieties, there was an average 39% increase in rice yields indicating an improvement in the management of rice cultivation by farmers.

3.4.2 Rice ecosystems

Rice ecosystems in Myanmar can be classified into irrigated areas, favorable rainfed areas, drought prone areas, deepwater/submerged/salt affected areas, and upland areas. As observed from Figure 20, most paddy fields are located in favourable rainfed areas and irrigated areas. Few upland areas can be found in Myanmar.

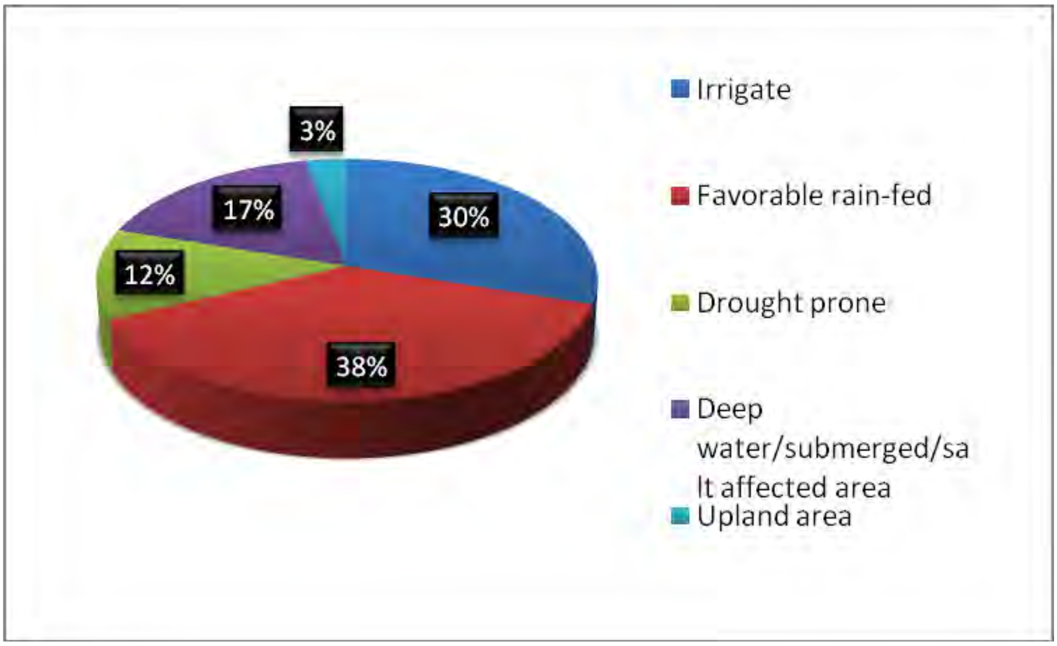

Figure 20 Rice Ecosystems in Myanmar (%).
(Swe, 2011)

Since 1993, the rice area in Myanmar has expanded sharply as a result of new areas being cultivated for summer rice. The increase in summer rice area and increased yield of rice has resulted in significant increase in rice production, as illustrated in Figure 15.

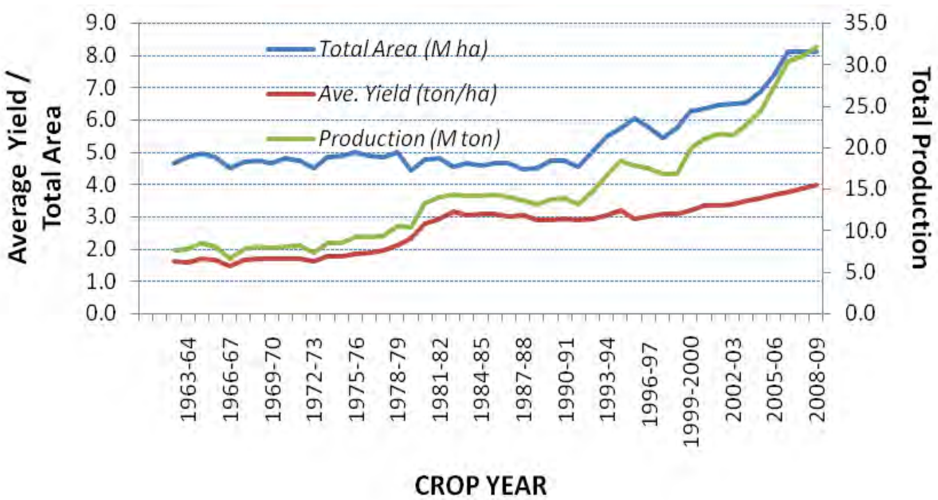

Figure21 Total area, average yield and total production of rice (1963-2009).
(Swe, 2011)

As observed from Figure 21, as of 2009 rice fields in Myanmar covered a total area of more than 30 Million ha as compared to 20 Million ha in 1990. The yield of rice also increased from about 3 tonnes/ha in 1990 to 4 tonnes/ha in 2009 (it was about 1.5 tonnes /ha in the 60s). Hence rice production in the country since 1990 has quadrupled reaching in 2009 about 32 Million tonnes. Seasonal rice crop calendar of various rice ecosystems is presented in Table 19.

Table 19 Seasonal rice crop calendar in Myanmar

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Myanmar: sing rice, rainfed												
Myanmar: double rice, irrigated												
Myanmar: lower part of Myanmar, rainfed												
Myanmar: middle part of Myanmar: rainfed												
Myanmar: middle part of Myanmar: irrigated												
Myanmar: Shan States, hilly regions												

Land preparation

Rice Cultivation

In rainfed area, farmers can cultivate rice once a year in rainy season during June to December in lower part of Myanmar, and August to January in middle part of the country and hilly areas; whereas, rice can be cultivated throughout the year in irrigated areas. However, some irrigated areas cultivate once a year i.e. Middle part of Myanmar.

3.4.3 Land preparation and planting methods

Preparation of land in Myanmar is done by tillage, approximately 70% of which is performed using working animals and the remaining 30% by machine. Transplanting is the main method used, with about 80% of the total area of rice being transplanted in the country. Direct seeding can be found in double rice growing area for around 20% (areas where rice can be planted more than one time per year). Another method of rice planting is dry seeding, which is performed in a few areas in the dry central part of Myanmar.

3.4.4 Water management during growth

Management of rice field via the system of rice intensification (SRI) and alternate wet and dry rice (AWD) have been introduced into the existing farming systems for mitigation of greenhouse gases (CH_4 and N_2O) emissions from rice fields. These systems have been introduced since the year 2000 but are still not so popular in Myanmar. Setting a good drainage system is a necessity which enables in a rice field to increase oxygen and methane oxidation. In addition, some findings showed that controlled irrigation may reduce N_2O emissions. There are many new constructions of reservoirs and dams in Myanmar. Irrigation facilities have been installed over the last two decades with about 228 large and small rural dams.

Nowadays, many farmers in dry areas are facing risks of crop failures due to insufficient water for crop production. So the government has been making efforts to promote irrigation by constructing new dams and river water pumping stations, and renovating old village reservoirs and tanks. Water could be extracted from rivers through pump stations. Farmers need then to use pumps to distribute water into their rice fields.

3.4.5 Fertilization

Fertilization is classified into monsoon and summer season. Details of the fertilizers used for either season are presented in Tables 20-21.

Table 20 Fertilization during monsoon season in Myanmar

Fertilizers applied	1994-95 (Monsoon)		2003-04 (Monsoon)	
	% of Farmers	Grain Yield (kg/ha)	% of Farmers	Grain Yield (kg/ha)
Urea only	6	2,191	22	2,575
Urea+FYM	32	2,566	29	2,631
FYM only	28	2,212	25	2,445
Others	21	2,745	5	2,746
No Fertilizer	13	1,075	19	2,178

Table 21 Fertilization during summer season in Myanmar

Fertilizers applied	1994-95 (Summer)		2003-04 (Summer)	
	% of Farmers	Grain Yield (kg/ha)	% of Farmers	Grain Yield (kg/ha)
Urea only	41	2,254	75	3,001
Urea+FYM	19	2,901	12	3,666
Others	12	3,482	13	2,822
No Fertilizer	28	1,403	-	-

Monsoon season: As shown in Table 20, an increase in the number of farmers not applying fertilizers is observed over the 2 periods of study. Yields of rice are noticed to be lower in areas where fertilizers are not applied but to have increased from 1994-95 to 2002-03. Also it is noticed that a majority of farmers apply a combination of urea & farmyard manure which enables to achieve the highest yield of rice recorded.

Summer season: It is observed from Table 21 that in 2003-2004, all farmers applied fertilizers. It is also found that over the period 1994-1995, the highest yields of rice were attained when urea was applied in combination with farmyard manure and others and lowest yields were obtained when no fertilizers were applied. Over the period 2003-2004, highest yields were achieved when urea was applied in combination with farmyard manure or with urea only. Also it is noticed that farmers apply more fertilizers for summer rice than monsoon rice.

Naing et al. (2008) surveyed rice production in Myanmar over the period 1998-2002. The rate of N applications during the rainy season decreased from 95 kg N in 1998 to 35 kg N in 2002 with an increasing number of farmers having stopped the application of N-fertilizer. Overall, application rates were considerably higher in Upper than in Lower Myanmar (see Figure 22). Trends in P and K application are the same in the Upper Myanmar whereas in Lower Myanmar the rates are always low.

A majority of farmers do not use farmyard manure, or only apply it at a low rate of 2 to 4 tonnes/ha in addition to or as a substitute for chemical fertilizers. The highest rates of fertilizer application are observed in the Mattaya and Patheingyi Townships for the year 2001 and in Kyaukse and Pyinmana for the year 2002; all townships were in the Upper Myanmar with irrigation facilities. In both years, most farmers applied both chemical fertilizers and farmyard manure to the seedbed at rates higher than those applied to transplanted fields. Farmers believed a heavy fertilization of the nursery would result in healthier seedlings, and would be more effective than spreading small amounts of manure over a larger area.

The recommended rates of chemical fertilizer were 56 kg/ha N, 13 kg/ha P, and 20 kg/ha K.

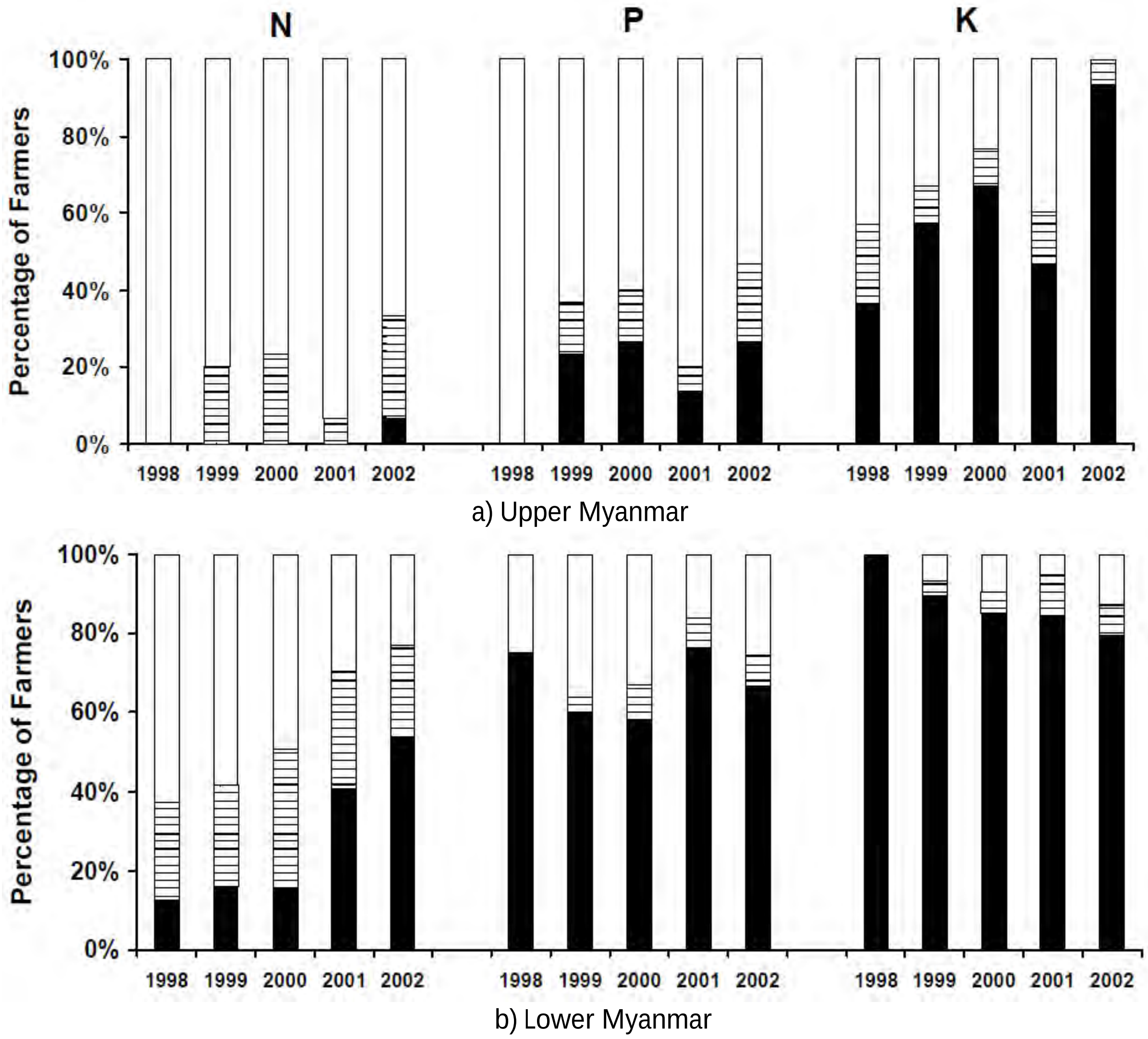

Figure 22 Percentage of farmers applying chemical fertilizer.
Note: Applied chemical fertilizer recommended rate (white sections), less than the recommended rate (striped sections) or none (black sections) in the wet season between 1998 and 2002 in a) Upper and b) Lower Myanmar.
(Naing et al. 2008)

3.4.6 Use of pesticides and herbicides

Hand weeding is the method most often employed for weed control as it keeps useful weeds for animal and human nutrition. Although a variety of herbicides for rice cultivation are available on the market, but too expensive for regular use.

In Myanmar very few pests are found in rice field. The most common rice pests are stem borer (Scirpophaga incertulas), rice gall midge (*Orseolia oryzae*), Jassid (*Nephotettix apicalis*) and rice ear bug (*Leptocorisa spp.*) There are some pests found in some areas but the levels of their infestation are low, except for the gall midge. Formerly, the rice gall midge was not a major rice pest in Myanmar. However, the abnormally heavy rains of the 2002 rainy season favoured the spread of the rice gall midge in those areas. The outbreak was found to have started in the seedbed before moving into the paddies (Naing et al., 2008).

3.4.7 Harvesting methods and management of rice residues

Combine harvester is not commonly found in Myanmar. Most rice fields are harvested manually. Hence short stubble is left in the field while long straw is moved out of the field. Then threshing is performed using machine thresher. Rice straw is mainly used for cattle feed. There are only few cases of residue burning to clear land for the next crop

3.4.8 Rotation crops

Cropping patterns of rice field are presented in Table 22.

Table 22 Major cropping patterns and share of cultivated area in crop year 1994-95 and 2003-04

Cropping Patterns	1994-95 (%)	2003-04 (%)
Rice - Pulses	35	34
Rice - Fallow	13	18
Fallow - Rice	11	8
Fallow - Pulses	11	14
Rice - Rice	11	3
Rice - Oilseed	7	9
Fallow - vegetable	1	7
2 Rice - Fallow	2	0
Others	9	7
TOTAL	100	100

"Lowland Rice-based Ecosystems in Nyaungdon Township of Ayeyarwaddy"
(Swe, 2011)

Rice-Pulses are the most predominant cropping pattern occupying a large share of the cultivated area. Rice-Rice cropping pattern decreased from 11 to only 3 percent during 2003-2004. There is an increase in cultivated area following the Rice-Fallow and Rice-Oilseed observed during 2003-2004. Double rice cropping during the monsoon season was no longer followed in 2003-2004. After rice harvesting, some plots are prepared for rice cultivation and some plots are prepared for rotation crops, i.e. garlic and black gram, very often with zero tillage.

3.4.9 Socio-economic status of rice farmers

Due to problems of government policy about rice i.e. export/domestic pricing issue, sporadic export controls or erratic issuance (and revocation) of export quotas, the reliability of Myanmar as a rice supplier is affected leading to lower prices than other exporters. Hence, rice export is quite low and unstable for Myanmar.

Because of their low income, farmers use their own seed to grow rice and perform their cultivation and harvesting based on traditional and low cost agricultural practices rather than opting for new technologies i.e. machine, chemical fertilizers, pesticides and herbicides. However, crop yields have been increasing in Myanmar and are in the medium range when compared to other SEA countries.

3.4.10 Summary

Being an agro-based country, Myanmar's economy is highly depending on agricultural production. Among food crops in Myanmar, rice, oilseed crops and pulses play a dominant role. Myanmar has a sown acreage of more than 22 Million ha out of which more than 8.1 m ha (41% of total sown areas) are under paddy, the major food crop of the nation in 2009-10. Summer rice production was introduced in 1992 across the regions where the irrigation facilities are available. In most regions, farmers follow the rice – based cropping patterns, such as rice - pulses, rice – oil seed crops, and rice – vegetables. Most farmers are small land holders with low income relying therefore on traditional practices for rice cultivation and harvesting. Overall, the export of rice in Myanmar is quite unstable and in much lower amount as compared to neighboring countries.

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3.5 Thailand

Thailand is a country located in SEA covering a land area of 513,120 km2 (OAE, 2011). The country is bordered by Cambodia and Lao PDR on the east, Lao PDR and Myanmar in the north, Myanmar on the west and Malaysia and the Gulf of Thailand in the south. The country is divided into six regions, which are Central plain, South and east coast, Northeast plateau and North and West mountainous area. Thailand is located in the tropical zone, a hot and humid climatic zone. The climate is influenced by the seasonal monsoon and the local topography. Thailand's season is defined into summer (mid February to mid May), rainy season (mid May to mid October), and winter (mid October to mid February). Seasonal wind blows from northeast and southwest directions during winter and rainy season, respectively (Wikipedia, 2012). Rice is grown in every parts of Thailand, mainly found in northeast, north, and central region. Few paddy fields are located in south region.

3.5.1 Rice varieties

In Thailand, only *Oryza sativa* can be found. There are various varieties of rice in Thailand because new varieties are developed all the time. Main rice varieties recorded in national statistics are RD6, RD15, Khao Dawk Mali 105, Suphanburi 60, Suphanburi 90, Klongluang 1, Homsuphan, Patumthani, Suphanburi 1 (Office of Agricultural Economics). The selection of rice varieties to be planted depends mainly on geophysical and seasonal conditions as well as resistance to diseases/insects.

3.5.2 Rice ecosystems

In Thailand paddy fields cover a total area of 12,579,098 ha (24.52% of Thailand). Rice ecosystems are classified into lowland, upland, and deep water. Each type of rice ecosystem can resist to different level of water. Details for each ecosystem are as follows:

1) Upland rice can be planted in the area that is not flooded, just enough moisture to grow the plant. If this type of rice is grown in flooded area, lesser production will be achieved as compared to a dry area. This type of rice is generally found in high areas, i.e. upland, hillside and farm areas. This type of rice is not significant for the Thai economy as most of the production is directly consumed in the household and not sold or exported. The yield of this type of rice is low and milling quality is also low. Development for this rice is in progress to increase its yield and economic value.
2) Lowland rice is the rice that can be planted in both non-flooded area with high soil moisture content and flooded area with water level less than 1 m in depth. Plantation can be done by transplanting, broadcasting, and drilling. This rice type is planted in more than 80% of national rice cultivation area because of its high yield. Therefore, the lowland rice plays an important role for the Thai economy.
3) Floating rice or deep water rice is planted in deep water area during the cultivation season. The water level can be 4-5 m in depth. Most is planted by broadcasting and drilling. The flooding period should be after seedling because if the young rice is sunk for 7-10 days, it cannot survive. The suitable period of flooding is during the active vegetative phase, which is at the tillering stage, and booting stage when rice can stretch its stems to stay over the level of water (Palaruksa, 1980).

The season of rice planting is throughout the year. The period when most rice is planted is during June-August which corresponds to the wet season. The rice grown on that season is referred to as major rice, while it is referred to as second rice when grown during the dry season.

3.5.3 Land preparation

The most suitable method of land preparation depends on water, climate, geography, planting technique, crop ecosystem, and availability of equipments. There are two steps for land preparation, as follows:

Step 1 - Plowing: roughly in the first time and plow in regular furrows for the second time by machine or animal labor. Objective of roughly plow is to turn over, dry, and mash straw and weed into the soil. Plowing is usually performed using buffalo. Equipments for plowing can be rice tiller machine or 4 wheels tractor with disc tiller.
Step 2 - Harrowing: Harrowing is done to level the land, remove weeds and make soil cracking. Machines for harrowing are composed of a rotary harrow attached to a small size tractor.

The land preparation method depends on the geography of the area to be cultivated. The upland rice field is prepared by working animals or small machines because large machines cannot access high land. Cultivation of rice in rain-fed area is usually done once a year during the rainy season. As farmers have plenty of time to prepare the land, they can use small machines or working animals to prepare the land.

3.5.4 Planting methods

In Thailand, cultivation practices can be classified into 4 main methods: transplanting, broadcasting, drilling, and upland rice planting.

Transplanting or indirect seeding method: Seed transplanting in paddy fields is widely practiced for major rice planting in north-eastern and southern regions of Thailand. Rice seedlings are grown in nursery area, then they are pulled and transplanted into puddle and leveled fields manually or by machine.

Seed broadcasting or direct seeding method: Seed broadcasting is different from transplanting because rice seed is not grown in a nursery to be rice seedling before planting. Planting is done by direct seeding of dry seeds or pre-germinated seeds into prepared land. The advantages of this method are that it requires few labors and enable to avoid risks related to particular weather conditions in those areas. Seed broadcasting method can be divided into 4 sub-methods as follows:

- Dry seed broadcasting without harrowing: Dry seed is planted into prepared land before raining. When it is raining, the seed will be grown. There is no harrowing to cover the seeds after planting. This method is not popular. It can be found in every region of Thailand but the planting area represents only 0.31% of total planting area in the country (OAE, 2009).
- Dry seed broadcasting followed by harrowing: This method is similar to "Dry seed broadcasting without harrowing", but followed by harrowing to cover the seed with soil. The germination of seeds is faster than without harrowing. This method is usually done when raining is earlier than usual but there is no flooding.
- Pre-germinated seed broadcasting: The seed is pre-germinated before broadcasting in the flooded land because raining is earlier than usual. The pre-germinated method is done to prevent rotting of seeds as a result of being sunk in water for a long time in flooded areas.
- Pre-germinated broadcasting rice: After land preparation, water is drained into the field for 5-10 days to let weeds grow. Then, water level is increased to plough for weeds removal. This cycle can be repeated several times to remove weeds, but each cycle should be done after 5 days to increase efficiency. After finishing the cycles, land is flooded for 3 weeks to let aqua-weeds grow. Then, harrowing is done carefully to remove aqua-weeds out of the field. The water is then drained out before harrowing to level the field and plant seeds after 1 day. This planting method is the most popular in Thailand, i.e. 96.47% for second rice and 28.85% for major rice (OAE, 2009).
-

Seed drilling method: The seed drilling method is suitable for areas that are characterized by high variability in precipitation, i.e. early rain but low amount towards the end of April, drought period from June to July, second period of raining since mid August, and heavy rain/flooding in September. Rice cannot be planted by transplanting during drought or flooded period so seed drilling method is done on silt or sandy silt areas. Dry seeds are mixed with pesticides (carbaryl or herb) and planted in 2.5 cm (1 inch) depth and covered with soil. Another method is to plant seeds in rows of 5 cm depth and cover with soil. The advantages of planting in rows include avoidance of weeds growth between rows and low labor requirement. However, the row method requires more seeds than the pit method.

Upland rice planting method: Upland rice means species of rice planted in upland areas, which use natural rain for growing. After land preparation, the soil is left to rest for 7-10 days before applying fertilizer. Then fertilizers are applied and mixed with soil. In slope areas, the land should be leveled into steps (rice terrace) to prevent soil erosion. Upland rice planting method can be divided into 3 sub-methods as follows:

- Upland rice: Seed drilling method - Farmers use sharp sticks to make holes 3-5 cm in depth. Distance between each hole is 30 cm. Each hole uses 5-8 seeds. The seeds are covered by soil.
- Upland rice: Seeds in rows - Farmers make grooves using harrows or hoes. The distance between each groove is 30 cm. The seeds are covered by soil.
- Upland rice: Broadcasting - Broadcasting method is sowing seed in rows and shoveling soil to bury seeds (Chongkid, 2010).
-

Beyond these 4 traditional cultivation methods, new techniques are developed, e.g. the Parachute Rice Transplantation method. Management of rice cultivation is also developed e.g. the Rice Transplantation Technology and System of Rice Intensification (SRI). Details of these new techniques for rice cultivation and management are presented below.

Parachute rice transplantation technology: The parachute technique comes from China. Chinese farmers have been practicing parachute rice transplanting technology for many years in puddle and unpuddled soils. As part of the process to assess its potential for wider adoption, this cultivation method was tested in Thailand by the Patum Thani Rice Research Center, Rice Department of Thailand. The parachute can enhance efficiency for weed control, requires low amount of seeds, and increases production. Comparisons of costs and yields for different cultivation methods are presented in Table 23.

Parachute Rice Transplantation is a technique of tossing rice seedlings, uprooted from plastic trays containing soil balls, in a projectile manner into the field. In Thailand, there are two types of rice seedling techniques for parachute rice transplantation: dry (seedling in loamy and dry soil outside the paddy field) and wet (seedling in muddy soil in the paddy field). The seedlings used for transplantation are uprooted in such a way that sufficient soil adhere to the roots thereby dropping the seedlings upright. In order to ensure that a high percentage of seedlings is planted upright by the broadcasting method, flexible plastic trays are used for preparation of nurseries. Each plastic tray contains 434 - 561 plugs. Two to three healthy seeds are broadcasted in each plug of the tray and covered with a thin layer of soil. About 313 to 375 trays are sufficient to raise a nursery for one hectare. Light irrigation is applied frequently. The nursery thereby grown takes only 12-16 days to attain a height of about 8-13 cm and can be uprooted very simply (Nhuthong et al., 2010; and RWC, 2003).

Table 23 Comparison of cost and yield among different cultivation methods

No.	Cultivation		Broadcast	Transplant	Parachute
1	Land parathion	baht/rai	610	610	610
2	Seed	baht/rai	345	138	92
3	Seedling	baht/rai	-	100	100
4	Plantation	baht/rai	40	872	100
5	Fertilizer	baht/rai	948	948	948
6	Herbicide	baht/rai	200	-	-
7	Harvest	baht/rai	600	600	600
8	Total cost	baht/rai	2,743	3,308	2,490
9	Yield	kg/rai	775	875	880

(Rice Department of Thailand, 2008)

System of Rice Intensification (SRI): The SRI methodology was developed in Madagascar by Fr. Henri de Laulanié from France in the early 1980s. The purpose of the SRI is to help farmers improve their productivity without being dependent on external inputs i.e. less water, agrochemical inputs, seeds, and labors (SRI-Rice, 2010; Africare et al., 2010). The SRI is based upon a set of principles and practices for increasing the productivity of irrigated rice by changing the management of plants, soil, water and nutrients (SRI-Rice, 2010). The process of SRI is as follows:

- Seedlings get transplanted at a much younger age (8-12 days or 2 leaves presented),
- Only single seedlings, instead of a handful of seedlings get planted in each hill,
- Plants are spaced wider apart, and in a square pattern (25-40 cm),
- Intermittent water application to create wet and dry soil conditions, instead of continuous flood irrigation (dry during vegetative stage and flood during reproductive stage),
- Rotary weeding to control weeds and promote soil aeration, and
- Increased use of organic fertilizer to enhance soil fertility
-

Phrae Rice Seed Center planted rice by two methods (conventional and SRI method) to compare production of both methods. It was found that the production of SRI method was higher than conventional method for 12%. Moreover, water management had influence on yield of rice. The flooded paddy field through the cultivation period (conventional method) produced higher yield than the flooded paddy field only during reproductive stage (SRI method) (Phrae Rice Seed Center, NA).

Both new techniques of management (parachute and SRI) are based on transplanting, which is mainly found in the Northeastern part of Thailand.

3.5.5 Water management during growth

Major sources of water for rice cultivation in Thailand are direct rain and irrigation. For broadcasting method paddy field, water is drained into the field after rough plowing and before applying fertilizers, and water is drained out of the field before planting and before harvesting. For transplanting method, water is drained into the field after rough plowing, and water is drained out of the field before harvesting. The period of flooding after rough plowing is variable, between 7 days to 1 month, in order to ferment weeds/residues before draining out the water for harrowing/leveling the land (Sanchan et al., 2002). Suitable depth of water for the broadcasting method should not be over 5 cm from planting to tillering, and not over 10 cm after tillering. The suitable depth of water for the transplanting method should not exceed 20 cm (Rice Department, 2011).

3.5.6 Fertilization and liming

Fertilizer management in rice field can be classified into 2 categories: basal fertilizer and top-dressing fertilizer. Basal fertilizer is the amount of nutrient needed in the soil to sustain normal plant health. Applying basal fertilizer is done before plowing. Top-dressing fertilizer refers to the fertilizer that is applied to the surface of the soil to promote upward growth of rice. Basal fertilizer and top-dressing fertilizer for various agricultural practices are presented in Table 24.

Table 24 Fertilizer management

Cultivation method	Basal Fertilizer Type or N-P-K (kg/ha), timing of applying fertilizer after planting	Topdressing Fertilizer Type or N-P-K (kg/ha), timing of applying fertilizer after planting
Transplanting[1]	16-16-8 (125)	AS (187.5), 20 days
	CMP (630)	Urea (93.75), 64 days
Transplanting[2] Seedling Planting 1) Photoperiod-sensitive 2) Photoperiod-insensitive	 Manure/Compost (5000) 16-16-8 (100) 16-16-8 (156), -1-0 day or 15 days or AS (156) and KCl (30-60), -1-0 day or 15 days 16-16-8 (187.5), -1-0 day or 15 days or AS (187.5) and KCl (3-6), -1-0 day or 15 days	 16-16-8 (NA), 15 days Urea 46-0-0 (40), flowering or AS (21-0-0) (78.75), flowering Urea 46-0-0 (78), flowering or AS (21-0-0) (156.25), flowering
Broadcasting[3] Pre-germinated seed broadcasting	 -	 16-20-0 (137.5), 15 days Urea (18.75), 15 days Urea (39), 57 days

Note: CMP = chicken manure pellets, AS = ammonium sulfate, [1] Sanwangsi, 2005; [2] Rice Department, 2011; [3] Klaipongpan, 2004

To fertilize soil, organic amendment can also be applied before rough plowing. The type of organic amendment can be animal manure, compost 375 g dry/m^2 or dry leaves 156.25 g dry/m^2.

Lime is added into paddy fields to adjust the soil pH from acid to alkaline. A rusty red color soil is acidic in nature. The amount of lime generally applied is equivalent to 3 bags/rai. Each bag weighting 5kg, this translates into about 94 kg of lime applied per hectare of land (Rakbankerd, 2010a).

3.5.7 Use of pesticides and herbicides

Pesticides include insecticides and rodenticides. Pesticides in Thailand have more than 2,000 trademarks, which can be found in spray, can, bar, or powder. There are four major types of pesticide: organophosphates, carbamates, organochlorines, and pyrethroids. The organophosphates contain mainly phosphorus i.e. parathion (Folidol E-605), malathion. The carbamates can be dissolved in fat less than organophosphates and also less toxic. Examples of the carbamates frequently found are methomyl (Lannate), aldicarb (Temik), propoxur (Baygon), carbaryl (Sevin) and carbofuran (Furadan). The organochlorines are a very durable material that slowly decay and sustain in the environment for a long time; therefore, this group of insecticide is prohibited for agricultural purpose. Example of the organochlorines is DDT (dichlorodiphenyltrichloroethane), aldrin, dieldrin, heptachlor. The pyrethroids are harmful to insect but not toxic to animals and humans. However, it is expensive so it is applied by mixing with other substances to increase efficiency to kill insects but friendly to humans (Rueangyuttikan and Chokechamsai, NA). PExamples of pesticides used in Thailand's paddy fields are presented in Table 25 (BPRD, 2008).

Table 25 Pesticides

No.	Product name	Insects	Specification
1	Malathion Carbaryl	Thrips	83 % W/V EC Sevin 85% WP
2	Bensultap Carbosulfan Fipronil	Rice leaf roller Rice caseworm	Bancol 50% WP Pos 20% EC Ascend 5% SC
3	Buprofezin Buprofezin Buprofezin/Isoprocarb	Brown planthopper White backed planthopper	Applaud 25% WP Applaud 10% WP Apsin 5%/20% WP
	Etofenprox Etofenprox Etofenprox Carbosulfan Isoprocarb Finobucarb		Tribon 10%EC Tribon 5%EC Permit 5% EC Pos 20% EC Mipsin 50 WP BPMC 50 EC
	Dinotefuran Thiamethoxam		Stargle 10% WP Actara 25% WG
4	Chlorpyrifos Chlorpyrifos Carbosulfan	Rice stem borers	Lorsban 20% EC Lorsban 40% EC Pos 20% EC
5	Carbosulfan	Rice bug	Pos 20% EC
6	Carbosulfan	Rice black bug	Pos 20% EC
7	Imidacloprid Chlorpyrifos	Rice gall midge	Confidor 10% SL 40% EC

Weeds can be grouped by life cycle in to two categories: annual weeds; and biannual and perennial weeds. To protect or remove these weeds in the paddy field, there are many methods as followings:

1) Mechanical control consists of methods that kill or suppress weeds through physical disruption. Such methods include hand pulling, digging (hoeing), disking, tillage, and mowing (cutting). Success of various mechanical control methods is dependent on the life cycle of the target weed species.
2) Biological control is weed control through insect/plant interactions. Examples of biocontrol insects are beetle, borer, blast disease to remove khgrynu grass and kheddou grass; duck, fish to remove weeds; water fern to remove filamentous algae.
3) Chemical control can provide the most effective and time-efficient method of managing weeds by using herbicide.

Examples of the herbicides used in Thailand are shown in Table 26

Table 26 List of herbicides in Thailand

No.	Trade name	Common name	Specification
1	Fyratan 85, Aka-D 85	2, 4-D	85% SP
2	Essonud 85, Heddonal 95 SP	2, 4-D-sodium	85% SP, 95% SP
3	Chemo-D, Desweed-L Bio-D	2, 4-D-butyl	72% W/V EC 79.2% W/V EC
4	Wareherb 250	2, 4-D-polyethyleneglycol	60% W/V EC
5	Daraester, B-79	2, 4-D-isobutyl	79.2% W/V EC
6	Basta-X	Glufosinate-ammonium	15% W/V SL
7	Spark, Glyfosate 16%, Taker 16, backup 16	Glyfosate	16% W/V SL
8	Glyfosate 48, Sunup, Formula 48, Wrapup, Violet	Glyfosate-isopropylamine	48% W/V SL
9	Touchdown	Glyfosate-trimesium	48% W/V SL
10	Sotus 40, Farmer, Cannou	Quizalofop-P-tefuryl	4% W/V EC
11	Faset SC	Quinclorac	25% W/V SC
12	Gamit	Clomazone+propanyl	12+27 % W/V EC
13	Invest	Cyclosulfamuron	10% WP
14	Grandstand, Clincher	Cyhalofop-butyl	10 % W/V EC
15	Zenith, Dinyl	Diflufenican+propanyl	1.66+33.33 % W/V EC
16	Sattern-D	Thyobencarb+ 2, 4-D	5+2% G
17	Nagard Satternyl	Thyobencarb+propanyl	30+30 % W/V EC 40+20 % W/V EC
18	Macette 5 G Caddy, Austin 60 Nuta-D, Bustar 6.85 G	Butachlor	5% G 60 % W/V EC 3.75+3.1% G
19	Shutter Hibyl, Challenge, Chopan, Pepona, Chateau	Butachlor+Seffener	35+35 % W/V EC 27.5+27.5 % W/V EC
20	Nominy	Bispyribac-sodium	10 % W/V EC
21	Grammoxone, Noxone	Paraquat-dichloride	27.6 % W/V SL
22	Proud, Stomp	Pentamethyl	33 % W/V EC
23	Sofit 300EC	Pretilachlor	30 % W/V EC
24	Popa, Prenyl, Foranyll, Sunpa 36 EC, Sercopour 360 EC	Propanyl	36 % W/V EC
25	Nako	Oxadiazon+ 2, 4-D	20+40 % W/V EC
26	Serus	Pyrasosulfuran	10% WP
27	Negus, Ricestar Kendo, Fure, Wip 7.5	Phenoxaprop-p-ethyl	6.9 % W/V EC 7.5 % W/V EW
28	Tiller	Phenoxaprop-p-ethyl+ethoxesulfuran	6.9+8.9 % W/V SC
29	Lakrpro	Fentrazamide+propanyl	6.75+37.5% WP
30	Allye	Methylfuron-methyl	20% WG
31	Syndax Almix, Conto, Narika	Metsulfuron-methyl+chlorimuron-ethyl	1.75+8.25% WP 10+10% WP
32	Ronstar 25 EC	Oxadiazon	25 % W/V EC
33	Ronstar 2D	Oxadiazon+ 2, 4-D	8.3+16.6 % W/V EC
34	Tycoon, Ronstar PL	Oxadiazon+propanyl	10+30 % W/V EC
35	Raft 800, Raft 800 WG	Oxadiakyl	80% WG

No.	Trade name	Common name	Specification
36	Alnino, Arosin	Anilofos	30 % W/V EC
37	Gascoin	Anilofos+propanyl	18+36 % W/V EC
38	Sulrice, Sacoal, Gladium	Ethoxysulfuron	15% WG

Note: SP = water soluble powder, SL = Soluble concentrate, AS = aqueous solution, G granular, WG = water dispersable granule, WP = wettable powder, EC = emulsifiable concentrate, SC = suspension concentrate, EW = emulsion oil in water
(BPRD, 2008).

3.5.8 Harvesting methods

After flowering (30 days), seeds are ready to be harvested. Farmers can notice it as 80% of the seeds become yellow and the tips of the leaves are half dry. This period is called the maturation stage. The water is drained out of the field for 15 days before harvesting. Harvesting is the process of collecting the mature rice crop from the field. Paddy harvesting activities include cutting, stacking, handling, threshing, cleaning, and hauling. It is important to apply good harvesting methods to be able to 1) maximize grain yields, and 2) minimize grain damage and quality deterioration. Harvesting can be done manually using sickles and knives i.e. central, north, and northeast of Thailand; or mechanically with the use of strip harvester or combined harvester, especially in the central region of Thailand (Chongkid, 2010 and IRRI).

3.5.9 Management of rice residues

After harvesting, rice residues remain in field, which consist of rice straw and stubble. Rice straw contains the top portion of the rice stem with leaves, while the stubble is the bottom portion that is close to the ground.

Straw utilization: Rice straw can be utilized for many purposes such as: fuel, composer, mulching, animal feed, material for mushroom cultivation, paper tissue, cement filler, handicraft (Bridhikitti and Kanokkanjana, 2007; Thaitambon, 2002; Ruamduaychuaikun Chinat, 2009; Bectero, 2008; Rakbankerd, 2010b). However, obstacles of straw utilization are its collection and transportation. Straw is left in the field in the form of windrows after harvesting which are usually burnt because it is the most convenient and cheapest way to eliminate straw. The main reason for burning rice straw in Thailand is to prepare land for a new crop cycle, especially in irrigated areas in the central part of the country where rice can be cultivated for 2-3 crops/year. Burning of rice straw can be performed since late in the morning because straw is dry enough for ignition, but Thai farmers usually burn their fields in the afternoon. The paddy fields are burned over a short period of time, i.e. 1 hr, as the average area of a rice plantation does not usually exceed 2.5 ha.

Stubble utilization: Stubble is rarely moved out of the field but is usually incorporated or burnt in the field. The fraction of stubble burnt is less than 50% due to its high moisture content. Therefore, most stubble is plowed back into the soil.

Rice husk: Rice husk is the hard protecting cover of rice grains that remains after milling. Alternative uses of rice husks are as a source of energy for heat and/or electricity, and for cellulosic ethanol production (Prasara and Grant, 2008).

3.5.10 Rotation crops

Planting various types of rotation crops in paddy fields can help reducing weed problems and increase soil fertility when plowing them back into the soil (organic fertilizer) prior to the next crop plantation. Hence, the Department of Rice suggests to plant rotation crop. Most rotation crops being used inc;ude legumes i.e. Sanoe African (*Sesbania rostrata*), Por tueang (*Crotalaria juncea*), Thua Pra (*Canavalia ensiformis*), green gram, black gram, and soybean.

However, energy crops are retaining attention to be used as rotation crops. Energy crops are plants grown to produce biofuels, or combusted to generate electricity or heat. Energy crops are generally categorized as woody or herbaceous (grassy). With regards to ethanol production, the Biofuels Country Report for Thailand (2010) shows that sugarcane (molasses) and cassava (roots) are the top feedstocks used. In 2009, total ethanol production was 1.1 million liters per day, molasses contributing 60% to 70% of the overall production (USDA, 2010). However, the cultivation period for sugarcane and cassava is long, about 10 to 12 months. These energy crops are therefore not suitable as rotation crops for paddy fields during fallow periods. Short rotation crops are required and sweet sorghum and field corn are of interest due to their potential to grow anywhere in the SEA region, their low requirement in water and their ability to serve as feedstock for ethanol production. Further details about these 2 crops for Thailand are provided below.

Sweet sorghum: Sweet sorghum [*Sorghum bicolor* (L.) Moench] is an African native plant, similar to grain sorghum with sugar-rich stalks. Sweet sorghum is a good energy crop for rotation in paddy fields because it is a water-use efficient and non-food crop, has potential to be a feedstock for ethanol production (it is produced from the sweet juice available in the stalk of the crop plant), and can be harvested over a short period of time. Sweet sorghum is a highly competitive crop and can dominate over many weeds and other plants; however, several herbicides are available to compliment cultural and mechanical practices. In general, fertilizers inputs are 30-60 kg/ha of P, 60-120 kg/ha of K, 150 kg/ha of N (ICRISAT, 2007; and Bioenergy Wiki, 2010).

The sweet sorghum variety KKU 40 has been developed by the Khon Kaen University in Thailand. The cultivation period is 60-73 days. Average yields of fresh stalk are in the range 33.25-51.50 ton/ha, average sweetness is in the range of 18-21 degrees Brix, the height of the stem is in the range 169-330 cm, the size of the stem is between 1.07 to 1.83 cm, the yield of grain is around 544 to 1,638 kg/ha, and the average juice yield is in the range 5,231-18,300 L/ha. This variety is planned to be promoted as an energy crop so experiments have been conducted to identify suitable periods/seasons for growing sweet sorghum in Thailand.

It has been found that the plant yield is different when planted in different month. Planting in early February will yield fresh stalk approximately 5.0 to 5.3 tonnes/ha. For cultivation during March to early July, the yield is 6.19 to 8.24 tonnes/ha and production begins to decline when planting is made since mid-July onwards (from 3.61 to 6.22 tonnes/ha). Hence the optimum planting period for sweet sorghum in the upper part of North Eastern region of Thailand would be around February to mid-August. The yield in the early growing season (February) and late growing season (August) is lower than during the middle growing season (March-July) (Jaisil et al. 2007).

Corn: Corn is a raw material that can be used to produce ethanol. Ethanol can be made not only from the grain, but also from the leaves and stems. This fuel can replace gasoline up to 85%. However, it is still not clear whether the energy used for corn cultivation is higher or lower than the energy produced out of corn. In Thailand, the total harvested area of corn was 927.5 thousand ha in 2007 (OAE, 2008). Most corn residues are not utilized, but burned or left in the field after harvesting.

3.5.11 Soil organic carbon

Carbon in soil is stored mainly in form of soil organic carbon. The organic carbon enters the soil through the decomposition of plant and animal residues, root exudates, living and dead microorganisms, and other soil biota. Soil organic carbon is necessary to the soil because it can help maintaining soil fertility for sustainable crop production. The organic carbon is lost from soil to the atmosphere by gaseous emissions of carbon dioxide (CO_2) and methane (CH_4) which are major greenhouse gases. Appropriate land management can keep organic carbon longer in the soil.

The study of soil organic carbon in paddy fields in Thailand is needed because rice is the most important economic crop of country. At present, there are limited studies in this field of study. In Thailand, Saenjan et al. (2010) studied impact of soil tillage and rice straw addition on the density of organic carbon components in paddy soil. It was found that soil tillage affects the density of organic carbon components in paddy soil, but the addition of 4 tonnes of rice straw per rai (1 rai = 1,600 m^2) to paddy soil had no effect on the accumulation of organic carbon in soil for one growing season.
Monitoring of soil organic carbon in rain-fed rice field at the top soil layer 0-15 cm was performed by Cha-un and Towprayoon (2011) over 2 consecutive growing seasons. The SOC was found to have increased from 3.02±0.49 g/kg (SOC stock 7.87±1.33 Mg C/ha) for the first crop (grown during February-June) to 4.73±1.85 g/kg (SOC stock 11.81±4.17 Mg C/ha) for the second crop (grown during August-December).

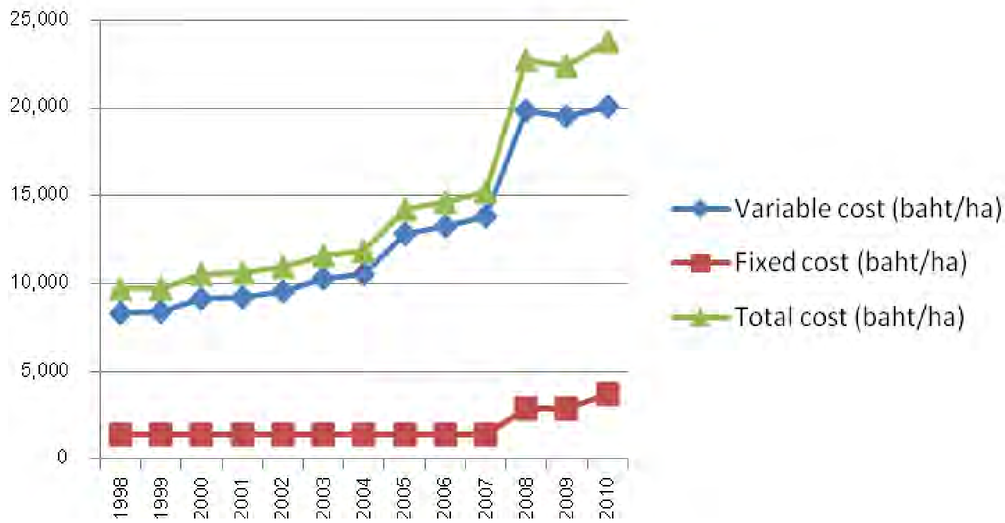
3.5.12 Socio-economic status of rice farmers

Investment for rice cultivation consists of fixed costs and variable costs as follows:

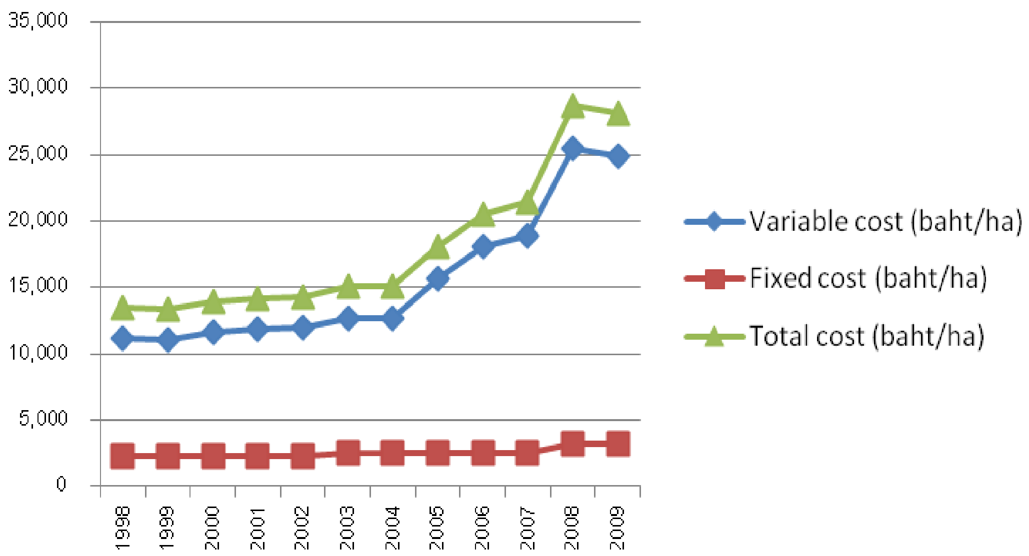
1. Fixed costs
- Land rental
- Depreciated replacement of agricultural equipments
- Interests of agricultural equipments investments

2. Variable costs
- Labor costs: land preparation, plantation, maintainance, and harvesting
- Material costs: seeds, fertilizers, herbicides, pesticides, gasoline, supplies, and fixing machines
- Interests of investments
- Others

Costs associated to major and second rice cultivation in Thailand are presented in Figure 23 over the period 1998-2010 (OAE, 2010)



a) Costs of major rice cultivation.



b) Costs of second rice cultivation.
Figure 23 Costs of major and second rice cultivation.

From Figure 23, it is observed that costs have been gradually increasing and more sharply since 2006. In 2010, the cost of rice cultivation in Thailand was 23,807 baht/ha, which fixed cost was 3,684 baht/ha and variable cost 20,123 baht/ha.

Income of farmers is calculated from national statistics based on the cost (Office of Agricultural Economics) and price of rice (the Department of Internal Trade). The income of farmers for major rice and second rice are presented in Table 27 and 28.

Table 27 Income of Thai farmers for major rice

	2005	2006	2007	2008	Sources
Cost (baht/ha)	14,251	14,652	15,188	22,702	OAE
Yield (tonnes/ha)	2.73	2.67	2.71	2.67	OAE
Price (baht/ha)	17,699	17,261	22,760	25,601	DIT
Income (baht/ha)	3,448	2,609	7,572	2,899	

Table 28 Income of Thai farmers for second rice

	2005	2006	2007	2008	Sources
Cost (baht/ha)	18,139	20,509	21,405	28,749	OAE
Yield (tonnes/ha)	4.22	4.28	4.24	4.29	OAE
Price (baht/ha)	27,578	26,492	51,552	41,499	DIT
Income (baht/ha)	9,439	5,983	30,147	12,750	

It is observed that for both major and second rice, incomes to farmers have been increasing over the period 2005-2008. During end of 2007 until April 2008, the price of rice increased sharply about 43%, due to several factors including, issues of rice production for important exporters (Vietnam and India), increased price of wheat leading to higher demand for rice, and issues of land use change from rice to corn for energy purposes in Australia. Following this short crisis, the price of rice decreased to reach back more regular levels (BOT, 2008).

3.5.13 Summary

Rice is the major economic crop of Thailand and is cultivated in every region of Thailand, especially in plain areas in the central and northeastern part of the country. Terrace rice is planted in mountainous areas in the north. Rice is cultivated by transplanting method in rainfed areas in the northern, northeastern, and southern part of the country; and broadcasting method in irrigated areas in the central region. The yield of rice in Thailand is among the lowest of SEA countries despite the introduction of modern technologies to prepare the land, grow rice and harvest it (second lowest after Cambodia). To reduce the emissions of greenhouse gases from current practices of rice cultivation, more strategic practices particularly focusing on water management and rotation with energy crops during fallow period are the subject of research investigations in Thailand. Although, there are many strategies from the Thai government to improve the welfare of rice farmers, their income still remains generally low as compared to the poverty line (1,600 Baht/person/month) (Wongsamutr, 2010).

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3.6 Vietnam

Vietnam covers a total land area of 331,210 km^2 and is surrounded by China to the north, Lao PDR to the upper west, Cambodia to the lower west, and coastal line in the east. Climate of Vietnam is tropical monsoon. The weather is divided into two main seasons: rainy season (from January to September) and dry season (from October to April). In addition, the weather can be subdivided into four seasons: spring (from February to April, average temperature 15-20°C), summer (from May to August, 32°C), fall/autumn (from September to November, 25°C), and winter (from December to February, 17.2°C or lower). In May to September, the country is dominated by south to southeasterly winds. In October to April, the north monsoon is dominant with northerly to northeasterly winds. There is a transition period between south and north monsoon when winds are light and variable. Vietnam has a single rainy season during the south monsoon (May to Sep) with annual rainfall exceeding 1,000 mm almost everywhere, and even higher in the hills facing the sea in the range of 2,000-2,500 mm. Rainfall is infrequent and light during off rainy season. For coastal areas and the parts of the central highlands facing northeast, maximum rainfall is in September to January during the south monsoon that the wind move from the South China Sea to the terrain. During the north monsoon, northern region has cloudy days with occasional light rain, while southern Vietnam tends to be dry and sunny. Temperatures are high all year round in southern and central Vietnam, but colder in northern Vietnam. Frost and some snow may occur on the highest mountains in the north for a few days annually. Vietnam is composed mostly of hills for 40% and dense tropical forests for 42 % of total land area.
The northern part of Vietnam consists mainly of highlands and the Red River Delta. The highest mountain is Phan Xi Păng, 3,143 m high located in Lào Cai province. The southern part of the country is divided into three main areas: coastal lowlands, mountains of the Annamite Range, and extensive forests. Nutrients of soil in the southern part of Vietnam are relatively poor. Regions of Vietnam are divided into Red River Delta, Northeast, Northwest, North Central Coast, Central Highlands, South Central Coast, Southeast, and Mekong River Delta. The main municipalities are located in Red River Delta (Hanoi and Hai Phong), South Central Coast (Da Nang), Southeast (Ho Chi Minh), and Mekong River Delta (Cần Tho). Although the Mekong Delta is a large plain area covering about 40,000 km^2, the population is lesser than in the Red River Delta which covers 15,000 km^2. The regions where rice cultivated are in the Northern Mountain, Red River Delta, Central Coast region, and Mekong Delta region (Wikipedia, 2012).

3.6.1 Rice varieties

The two main types of rice cultivated in Vietnam are sticky rice and ordinary rice. The sticky rice is used for special events and ceremonies such as Tet (Lunar New Year) and weddings (Mai Chau Trek, 2010).

The criteria considered for the development of rice seeds in Vietnam have been changing over the last 40 years. During 1960-1970, the criteria of rice improvement were selection of rice seeds based on outward aspects (physical) of rice plants. In the '80s, research of rice development aimed at producing good resistance to pestilent insect. In the '90s, development of rice concentrated on improving productivity and quality of rice seeds. Over the last ten years, research has been focusing on improving rice seed quality in combination with improved resistance.

Different rice varieties are found in different areas of Vietnam depending on local specific climate, soil, and traditions. In the north (Red River Delta, Mountainous & Northern Central) the following varieties are mainly used:

- Local varieties: Tam Xuan Đai, Tam Xoan Thai Binh, Tam Den Hai Phong, Tam bang Phu Tho, Du Huong, Nep cai Hoa vang, Tep lai, etc.
- Imported Chinese or originated Chinese varieties: Short Moc Tuyen, Short Bao Thai, M90, Bac Yu 64, Cross-Breeding 5, Nhi Yu 63, Khang Dan 18, Short Ay 32, etc.

- Originated IRRI' varieties: Selected or Cross-Breeded from: IR24, IR 17494, IR 1820, IR 36, IR 46, IR 2053-26-3-5-2, IR 2588, IR 19746-11-33, IR 8423-132-622

In the South (East-Southern, Mekong Delta, Central High Land) the following varieties can be found:

- Local varieties: Early Thom, Nang Thom Nha Be, Thom Binh Chanh, Nang thom Đuc Hoa, Nang thom cho Dao, Nang Huong, LC90-4, etc.
- Varieties originated from IRRI: Selected or Cross-Breeded from: IR 49517-23, IR 59606, IR 64, IR 68, IR 66, IR 66707, IR 56279, IR 32893, IR 48, IR 8423, IR 50401, IR 44592, IR 9729-6-7-3, IR 62032, etc.

In the Northern Mountainous region:

- "Milpa" cultivation: Depends on raining water, using dry varieties, without fertilizers & insecticides/Plant protection – Very Low productivity.
- Terraced fields: Depends on raining water, using dry varieties, without chemical fertilizers & insecticide/Plant protection, Very few compost - Very Low productivity.

3.6.2 Rice ecosystems

In Vietnam, paddy fields cover a total area of 33 million ha. Rice ecosystems in Vietnam can be classified into rainfed upland, rainfed lowland, irrigated lowland, and coastal rainfed areas. There is no deep water rice in the country. Vietnam is divided into six regions: 1) Red River Delta, 2) Northern Mountain, 3) Northern Central, 4) Central Highland, 5) South East, and 6) Mekong Delta, which are presented in Figure 24.

Figure 24 Regions of Vietnam.

Vietnam has two huge deltas, which are the Mekong in the south and Red River in the north. Rice ecosystem can be divided based on main rice cultivation in each region of the country as follows:

- The Northern Mountain (region 1): rainfed upland area in "Milpa" cultivation and terraced fields
- The Red River Delta (Region 2): irrigated lowland area
- The Central/Coastal region (Region 3): upland rainfed and coastal irrigated area
- The Mekong Delta region (Region 6): irrigated and rainfed lowland area

Calendar of rice cultivations in Vietnam is presented as following.

Table 29 Seasonal rice crop calendar in Vietnam

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10th month (main)												
- North												
- Central												
- South												
Winter-spring												
- North												
- Central												
- South												
Summar-fall												
- North												
- Central												
- South												

(mediumgrainrice.com, 2002)

Table 30 Seasonal rice crop calendar in Mekong Delta, Vietnam, 2004

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Upland crop* (Spring-Summer)												
1st rice crop (Summer-Autumn)					MV							
2nd rice crop (autumn-winter)												
>with Modern Varieties								MV				
>with Traditional varieties								TR				

Note:*Upland crops: maize (Zea mays L.), groundnut (Arachis hypogaea L.), casaba melon (Cucumis melo L.) and water melon (Citrullus vulgaris L.), MV – modern variety, TR-Traditional rice
(Nguyen, 2004)

Table 31 Seasonal rice crop calendar in Mekong Delta, Vietnam, 2013

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
3 rice												
Winter-Spring												
Spring-Summer												
Summer-Autumn												
2 rice												
Winter-Spring												
Summer												
Mungbean												

(Nguyen, 2013)

Seasonal rice crop in Vietnam consists of three main seasons: winter-spring crop, rainy season crop (Mua) or spring-summer, and summer-fall crop. Main season of rice cultivation in Vietnam is rainy season crop that cultivated in April to September/October in north region (The Red River Delta: RRD)

and in July/August to December in central coastal region (The Mekong River Delta Region: MRD). The winter-spring crop and summer-fall crop could be cultivated in irrigated area that covered 80% of rice field in RRD and 40% of rice field in MRD (Young et al. 2002).
From Table 25, the data was obtained from questionnaire. It was found that recent season of rice cultivation is shifted a few months earlier than previous when compare with Table 23 (2002) and Table 24 (2004).

3.6.3 Land preparation

Farmers prepare the land by emptying water from each field. Then plough deep manually and rake. Traditional tillage was partly replaced by new systems, dry tillage, wet tillage and mixed tillage (Mai Chau Trek, 2010 and Long et al., NA).

Dry tillage systems: all soil preparations are done when the fields are not inundated. In most cases, large (≥ 38kW) tractors with tillage implements perform the work, using a disc plough for primary tillage, followed by seedbed preparation with a disc harrow or a rotary tiller. Then the fields are inundated to create a mud layer for rice establishment.

Wet tillage systems: Systems which main tillage operations and seedbed preparations are done on inundated fields. In those cases, small (≤ 38kW) tractors (equipped with rotary tillers or rollers and puddle wheels) or animals (pulling a local mould board plough, comb harrow, wooden roller) are used.

Mixed tillage systems: the main tillage operations (mostly by large tractors) are done when the fields are not inundated, but seedbed preparations are done after the fields are inundated.
(Long et al. NA)

3.6.4 Planting methods

Rice is planted by both transplanting and broadcasting methods in Vietnam. Traditionally farmers used transplanting as the main planting method. More recently, with improvement of irrigation systems, new high yield varieties, with use of herbicides, insecticides, fertilizers and tractors have been introduced in Vietnam. Hence, the cultivation method changed from transplanting to broadcasting and from one crop to two or three crops per year (Young et al. 2002 and Long et al. NA).

3.6.5 Water management during growth

The water level in the paddy field depends on the type of rice. For example, water in rice-prawn farms is changed every day following the tidal regime and keeping water level in the field at a level of 20 to 30 cm (Duong, 2001). In the Red River Delta region, almost 90% of the growing time, the rice plants are in 10 to 15cm of water.
Some recent new practices have been applied to contribute mitigating climate change. During the period of growing seedling for rice transplanting: farmers keep rice in the field dry/damp over 2 periods:

- First period: during 7 to 10 days after 10 days from rice transplantation.
- Second period: during 7 to 10 days after 30 days from rice transplantation.

In the period of rice seedling reproducting growth: keeps rice filed in 4-5cm water in the period of time from 45 days after transpantation until 15-20 days before the harvest.

3.6.6 Fertilization and liming

The utilization of fertilizers in Vietnam can be classified into two groups: overuse and none. For overuse of chemical fertilizers, those are applied in lowland areas: Red River Delta (Region 2), both irrigated and rainfed areas in the Mekong Delta region (Region 6), and irrigated areas in the Central/Coastal region (Region 3) of Vietnam. In upland areas, rice is cultivated without chemical fertilizers. This concerns Northern Mountains (Region 1) and rainfed areas in the Central/Coastal region (Region 3). Production of rice depends on utilization of chemical fertilizers with high production for overuse of chemical fertilizers and low production for non-use of chemical fertilizers. In rice-prawn fields, before ploughing, 50 kg diammonium phosphate and 5 tonnes of manure/ha are applied. Top-dressing requires use of 50 kg urea/ha (Hung, 2001). Fertilizer formula for modern rice per hectare is 200 kg monosuperphosphate + 200 kg urea + 50 kg potash, or 100 kg 18-46-0 + 100 kg urea + 50 kg potash. Fertilizer formula for transplanted local rice per hectare is 200 kg monosuperphosphate + 100 kg urea + 50 kg potash, or 100 kg 18-46-0 + 50 kg urea + 50 kg potash (Duong, 2001).

In the Mekong Delta region, rice-prawn farming has become popular in freshwater areas. During land preparation, powdery lime is applied for 1tonne/ha to help get rid of wild fish and other carnivorous animals e.g. crabs, snakes, frogs, and so on.

3.6.7 Use of pesticides and herbicides

A summary of pesticides and herbicides usage is presented in Table 32.

Table 32 Use of pesticides and herbicides in each region of Vietnam

Region	Area	Use of pesticides/herbicides
Northern Mountains (region 1)	"Milpa" cultivation	Without insecticides/Plant protection
	Terraced fields	
Red River Delta (region 2)	Irrigated fields	Overuse of Pesticides
Northern Central (region 3)	Mountainous areas	Without insecticides/Plant protection
	In coastal plain areas	Overuse of Pesticides
Mekong Delta region (region 6)	Irrigated fields	Overuse of Pesticides
	Rainfed fields	Overuse of Pesticides

3.6.8 Harvesting methods

Rice harvesting technology is comprised of many steps, including: reaping, gathering, threshing, separation and cleaning. In the Mekong Delta, all these steps take place in the field; in other areas, after being reaped, rice is transferred, threshed and separated in the yard (Viet, 2006). The reaping process can be done both manually and mechanically.

Manual harvesting is done by using sickles or small knives or by stripping the panicles. The harvest is stored on-farm in traditional granaries. Farmers harvest the rice crop by cutting the straw at knee height then threshing the grain. The straw is then spread on the rice stubble in the field, dried, and burnt. Burning rice straw in the zero-tillage system apparently is advantageous because it expels rats from the fields (this is a common problem in the zero-tillage system) and reduces disease pressure in the intensified cropping system. In addition, burning straw prevents ratoon crops and weeds and, because the turnaround time is short, no weed control is required at sowing. In addition, the contact of the sown seeds with the soil surface may be improved after burning because the crop residues that might prevent contact between seeds and soil are removed. In addition, straw burning may improve the crop establishment in wet seeding because rice-crop establishment may be inhibited by the products of anaerobic decomposition of rice straw (Yamauchi et al. 1995).

Mechanized harvesting is done by using reaper or combine harvester (reaping and threshing) as detailed below:

Reaper: During 1990-1994, VIAEP carried out the research, design and manufacture of the GRH-1.2 reaper with vertical upper delivery device (base on the model AR 120 of KUBOTA-Japan). The reaper was divided into two parts: reaping–conveying part (reaping head) and driving, mobile part (motive power). Several mechanical companies (Nam Hong, Thai Binh, FUTU) designed and manufactured vertical conveyor reapers with cutting width of 0.9m and 1.2m. Since 1995, many private mechanical companies (Mekong Delta) have brought on to the market vertical conveyor reapers with the same features: cutting width 1.5m, upper delivery device in the form of flat belt with lug plates, 7-8 hp diesel engine. In dry fields with straight, suitable height of rice stalks the reaper can reach high output 2.5 –3.0 ha/day. Difficulties in applying reaper are based on field conditions and the requirement for many labors to gather and transfer the rice grains. The combine harvester was developed to resolve this issue enabling both harvesting and threshing to be performed at the same time.

Combine harvester: during 1992-1996, VIAEP and Dong Thap company produced self-propelled combine harvesters GLH –0.2. Main features are cutting width 1.5m, axial threshing part with mix - teeth drum, 24HP diesel engine, moving system by rubber track, laying conversion enabling working in the swampy field with less than 15 cm depth, time spent 0.16 ha/h, grain loss less than 2% and the rate of clean grain >96%. However, the machine was not durable with minor faults in operation and was not mass-produced because of lack of technology and equipment. During 2001 –2005, the national research project: Research, design and production of harvesters of main crops, suitable with production conditions, enabled to produce the combine harvester GLH –0.3 A. Main features are 35 hp, cutting width 2 m, rubber track-laying conversion with greater dimensions, average output 0.25ha/h, clean grain >97%, grain loss <2%. A three-wheel combine harvester GDLH –1.2 is produced by the Nam Hong Mechanical Firm and the Tractor and Agricultural Machines Company based on the same principle as that of the GLH –0.2 and GLH –0.3A. Main features are 12 –16 hp diesel engine, cutting width 1.2m. Main drawbacks include low cleanliness of grains, high loss (> 4%), threshing cylinder clogged when cutting lower and able to work only on hard ground. Combine harvesters were also manufactured by farmers and private companies. These combine harvesters were therefore cheap, working effectively in dry fields with straight rice stalks, and with an output of 0.15 ha/h. Two main weak points are dependence on working conditions and low durability of the moving chain harvester. Differences with GLH –0.2, GLH –0.3 are reaping and transferring part of the vertical conveyor reaper leaving out reel and gathering screw, decreasing size and weight; transferring part to drum with 2 paddled chains, old gearbox of a Japanese two-wheel tractor and a home-made chain moving system.

3.6.9 Management of rice residues

Residues from rice cultivation in Vietnam consist of rice husk, bran and rice straw. Rice husk is utilized as fuel, paving material for raising chicken/poultry, energy for burning bricks or pottery and porcelain. Bran is used for raising animal/pigs, chickens, ducks and so on. Rice straw is used in Northern and Central parts of the country as a source of fuel, feed for cattle or is burnt in the field. In some areas, rice straw is used for production of bio-fertilizers. In the Mekong Delta, rice straw is used as feed for cattle and is normally buried in the field to prepare the land for the next cultivation.

3.6.10 Rotation crops

The dry season lasts from November to May (winter and spring). This season is fallow period that the land is empty so farmers can cultivate alternative crops in their farm.

Farmers in Bình Thuận province grow green pea, peanut, black sesame, sweet potato, and creamy beans, because these plants are drought resistant. High-yield beans, also called creamy beans, green

peas, red beans, and black beans are planted after harvesting rice. But the most suitable is the high-yield creamy bean. As for turn-around time, peanuts take from 100-115 days, creamy beans and green peas take about 60-65 days to harvest. These plants need neither fertilizer nor irrigation (SOS Global warming, 2011).
Farmers in rainfed coastal areas of Tra Vinh Province, Mekong Delta, Vietnam were introduced to plant upland crops i.e. maize, groundnut, casaba melon, and water melon during spring (January to April) to increase farm productivity through crop diversification and to improve the household income of resource-poor farmers. (De et al. 2004).

Rotation crops and number of rice cultivation are summarized in Table 33.

Table 33 Summary of rice and rotation crops in Vietnam

Region	Rice crop management	Area coverage
Northern Mountains (region 1)	2 rice crops	50%
	1 rice crop 1subsidiary/vegetable crop	20%
	1 rice crop (Terraced field & "Milpa cultivation")	30%
Red River Delta (region 2)	2 rice crops	50%
	2 rice crops + 1 subsidiary/vegetable crop	40%
	1 rice crop + 1-2 subsidiary/vegetable crops	10%
Northern Central (region 3)	2 rice crops	50%
	1 rice crop + 1 subsidiary/vegetable crops	30%
	1 rice crop	20%
Central Highlands (Region 4)	2 rice crops	30%
	1 rice crop + 1 subsidiary/vegetable crop	30%
	1 rice crop	40%
East-Southern region (region 5)	2 rice crops	60%
	2 rice crops + 1 subsidiary/vegetable crop	30%
	1 rice crop + 1 subsidiary/vegetable crop	10%
Mekong Delta region (region 6)	In Alluvial soil & freshwater: 2-3 rice crops 2 rice crops + 1 subsidiary/vegetable crop 2 rice crops + fish/shrimp integration	40-45%
	In raining water with salty contamination: 2 rice crops 1 rice crops + fish/shrimp integration 1 rice crop	55-60%

3.6.11 Socio-economic status of rice farmers

The Annual income of farmers has been estimated as shown in Table 34. This estimation is based on the situation without diseases, natural disasters, and other unusual cases.

Table 34 Income of farmers in Vietnam

Regions	Area of rice cultivated in a year (m^2/capita)	Average rice yield (tonnes/ ha)	Annual rice productivity (tonnes/ capita)	Average price or rice (USD/tonne)	Total annual income (USD/capita)
1, 2, 3, 4	400	5.29	0.212	1,000	212 $
5, 6	1,000	5.29	0.529	1,000	529 $

Note: regions: 1) Red River Delta, 2) Northern Mountain, 3) Northern Central, 4) Central Highland, 5) East Southern, and 6) Mekong Delta
(Thanh, 2011)

The income of farmers in South East and Mekong Delta is around 529 USD per person over a year, which is higher than the per capital annual income of farmers in other regions i.e. 212 USD. However, the income of farmers is still lower than the average salary of a Vietnamese person which on a GDP per capita basis stands at 1,224 USD (World Bank, 2010).

3.6.12 Summary

In Vietnam, rice is planted both by transplanting and broadcasting techniques. Transplanting has been practiced for a long time, while broadcasting is a new method used essentially in modern farms. Paddy fields are located in the northern and southern part of Vietnam, and rarely found in the central region. Due to the hilly nature of the country, rice is planted in high areas following both the traditional method called "Milpa" and new method called "terraced field." Some paddy fields are located in the Red River Delta and Mekong Delta region. The low land areas can be accessed by machines so new technologies and also chemicals are used in such areas. There is a great variety of rice cultivated in Vietnam as the seeds are imported from China and developed by IRRI. Most rotation crops are vegetable crops; however, half the paddy fields in Vietnam do not plant rotation crops and continue planting rice twice a year. Income of farmers in the northern region is lower than in the southern part due to smaller cultivation area and lower rice yields. But all in all the income of farmers are still much below the average of a Vietnamese person when compared on a per capita GDP basis.

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CHAPTER 4 CONCLUSION

The report provides information on the state of the art of rice cultivation in SEA Countries with a focus on Cambodia, Indonesia, Lao PDR, Myanmar, Thailand and Vietnam. The report provides Statistics of rice cultivation. This information reveals that harvested area, yield, and production of rice for most SEA countries have been steadily increasing over the past few decades. Total production of rice in SEA (Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand, and Vietnam) was 190.40 million tonnes in 2008. Although Indonesia produces the highest amount of rice in SEA (60.25 million tonnes) and is the third-largest producer of rice in the world, it is also the major importer of rice in the region. That is because rice is the staple food for the majority of the 210 million people living in Indonesia. In SEA, Thailand and Vietnam are the major exporters of rice worldwide.

From the country reports on rice cultivation practices detailed in this report, it is observed that climate plays an important role for rice cultivation. Climate in the region is influenced by seasonal monsoon events and classified into wet and dry season. The wet season of rice cultivation spans over the period May to December while the dry season of rice cultivation is found during January to April. Wet season rice is cultivated in both non-irrigated and irrigated areas, and dry season rice is mainly cultivated in irrigated areas. Cultivation practices of rice in SEA do not differ much. Rice cultivation starts with land preparation, planting, water management during growth, farm management of young plants using fertilizers/ lime/ pesticides/ herbicides, and harvesting. However, the production of rice depends on the cultivation practices followed in a particular area starting with land preparation and up to harvesting. Following rice harvesting, a fallow period usually follows during the dry season in rainfed areas. However, farmers can grow alternate plants during this period if there is enough water to cultivate. In this regard, strategic practices of rice cultivation in rotation with energy could be similarly implemented in several countries in SEA.

Appendix 2
Questionnaire of rice cultivation practices in South East Asia

For Interviewer
Date of Interview:________________
Interviewer's name:____
Latitude:_______________________ Longitude:______________________

A. General Information			
A1	Farmer name:	A2	❒Female ❒Male
A3	Age:	A4	Telephone no.:
A5	Email:	A6	Address of the paddy field:

B. Rice Cultivation Practice			
B1	**Detail of paddy field**		
1.1	Paddy field is located in: (please select) ❒Non-irrigated area ❒Irrigated area	1.2	Soil type in the paddy field ❒ Clay ❒ Loam ❒ Sand ❒ Others (please specify)___________
1.3	Planted area (ha):	1.4	Harvested area (ha):
1.5	Planted area is divided into how many crop plot(s):	1.6	Estimated plot size (ha):
1.7	Are there trees present around crop plot? (on crop boundary) ❒ No ❒ Yes (if yes please answer 1.8)		

1.8 Trees on crop plot boundary

Type	Species/type	Number (trees)	Age of tree (years)
1			
2			
3			

B2. Land preparation

2.1	Duration of land preparation____day(s)	2.2	Number of working hour: ______hrs/d
2.3	Number of plowing__________time (s)	2.4	Number of labor _________person (s)
2.5	Method of land preparation ❒ Animal: Number of animal_______ type of animal__________ age of animal__________years ❒ Machine	2.6	Cost of land preparation ________ (please specify unit/ha)

B3. Detail of rice

3.1 Rice variety

Number of rice cultivation rotation ____________________time(s)/year or crop(s)/year

Cycle	Rice variety	Type of rice (by Photoperiodism)	Type of rice (by Geography)	Cost of seed (specify unit)	Seed (kg/ha)	Growing period (days)
1						
2						
3						
4						
	Please specify name variety (official or local name)	Please specify P = photosensitive N = Non-photosensitive	Please specify U = upland rice L = lowland rice F = floating rice O = Other (please specify)	Price of seed, unit can be USD/kg	Production for planting 1 ha	Number of day since planting until harvesting

Note: Please write down selected alphabet; see description at the bottom of Table

3.2 Seeding

3.2.1	Method of seeding ❒ Transplanting ❒ Pre-germinated broadcasting ❒ Dry-seeded broadcasting ❒ Parachute ❒ Other (please specify):__________	3.2.2 3.2.3 3.2.4	Time spent of seeding (days):______ Number of working hour (hr/d):_____ Number of labor _________persons Cost of seeding ________________ (please specify unit/ha)

B4. Water management

4.1	Water source (Major source) ❒ direct rain ❒ irrigated system ❒ man made pond ❒ ground water ❒ natural canal/river ❒ other (please specify)____________	4.2	Water source (Alternative source) ❒ direct rain ❒ irrigated system ❒ man made pond ❒ ground water ❒ natural canal/river ❒ other (please specify)____________

4.3 Number of water flooded _________time (s)

Water drainage into the field	Timing of drainage into the field (DAP)	Depth of water (cm)	Duration of flooding (days)	Water drain out (DAP)	Purpose of draining water out
1st					
2nd					
3rd					
4th					

Note: DAP = days after planting

4.4	Do you use pump to drain water? ❒ No ❒ Yes (please answer 4.5)	4.5	4.5.1 Pump type:__________________ 4.5.2 Trademark:__________________ 4.5.3 Model:_____________________ 4.5.4 Power (watt):________________ 4.5.5 Price:______________________ 4.5.6 Fuel type:__________________ 4.5.7 Fuel consumption (L/ha):_____ 4.5.8 Cost of fuel per ha:__________ 4.5.9 Operating period (hr):________ 4.5.10 Pumping rate (L/min):

B5. Chemical Fertilizer

5.1	Do you apply fertilizer in the paddy field? ❒ No ❒ Yes	5.2	Frequency of applying fertilizer in planting per one cycle of rice (times):
5.3	Do you apply fertilizer in the same way/amount/type in all crop plot? ❒ Yes ❒ No (Please specify in space)	5.4	Do you apply fertilizer in the same way/amount/type in all crop rotation? ❒ Yes ❒ No (Please specify in space)

____

____

5.5 Fertilizer Application

No	Type of fertilizer	Trade-mark/ common name	N:P:K	Price of fertilizer	Timing of application (DAP)	Applied amount (kg/ha)	Purpose of applying fertilizer	Labor (persons)	Labor cost of applying fertilizer
1			__:__:__						
2			__:__:__						
3			__:__:__						
4			__:__:__						
				Please specify unit: ________					Please specify unit: _______

Note: DAP = Day after planting

B6. Organic amendment/ Organic fertilizer

6.1	Do you apply organic amendment/ organic fertilizer in the paddy field? ❒ No ❒ Yes	6.2	Frequency of organic amendment/ organic fertilizer for one cycle of rice (times):
6.3	Do you apply organic amendment/ organic fertilizer in the same way/amount/type in all <u>crop plots</u>? ❒ Yes ❒ No (Please specify the difference in space below)	6.4	Do you apply organic amendment/ organic fertilizer in the same way/amount/type in all <u>crop rotation</u>? ❒ Yes ❒ No (Please specify the difference in space below)

____

6.5 Organic amendment/ organic fertilizer application

No.	Type	Price of organic material	Timing (DAP)	Applied amount (kg/ha)	Purpose of organic amendment	Labor (persons)	Labor cost
1							
2							
3							
4							
	S = straw, M = manure, C = compost, G = green manure, EM = effective microorganism O = other please specify	Please specify unit (i.e. USD/kg): ________					Please specify unit: _______

Note: DAP = day after planting

B7. Liming

7.1	Is lime applied? ❒ No ❒ Yes	7.2	Amount of lime (kg/ha):
7.3	Cost of lime (please specify unit i.e. USD/kg):	7.4	Labor cost for liming (please specify unit):

B8. Pesticide

8.1	Do you apply pesticide in the paddy field? ❒ No ❒ Yes	8.2	Frequency of applying pesticide in planting per one cycle of rice (times):
8.3	Do you apply pesticide in the same way/amount/type in all crop plots? ❒ Yes ❒ No (Please specify the difference in space below)	8.4	Do you apply pesticide in the same way/amount/type in all crop rotation? ❒ Yes ❒ No (Please specify the difference in space below)

____

____

8.5 Pesticide application

No.	Type	Price of pesticide	Timing of applica-tion (DAP)	Dilution	Applied amount	Purpose of applicatio n	Labor (persons)	Labor cost
1								
2								
3								
4								
		Please specify unit (i.e. USD/kg): _______		Please specify unit (i.e. g/20L): _______	Please specify unit i.e. L/ha, kg/ha: _______			Please specify unit: _______

B9. Herbicide

9.1	Do you apply herbicide in the paddy field? ❒ No ❒ Yes	9.2	Frequency of applying herbicide in planting per one cycle of rice (times):
9.3	Do you apply herbicide in the same way/amount/type in all crop plots? ❒ Yes ❒ No (Please specify the difference in space below)	9.4	Do you apply herbicide in the same way/amount/type in all crop rotation? ❒ Yes ❒ No (Please specify the difference in space below)

____

____

9.5 Herbicide application

No.	Type	Price of herbicide	Timing (DAP)	Dilution	Applied amount	Purpose	Labor (persons)	Labor cost
1								
2								
3								
4								
		Please specify unit (i.e. USD/kg): _______		Please specify unit (i.e. g/20L): _______	Please specify unit: _______			Please specify unit: _______

Note: DAP = day after planting

B10. Harvesting

10.1	Harvesting method ❒ Manual ❒ Machine	10.2	Plant height at harvest (cm):
10.3	Stubble height after harvest (cm):	10.4	Fallow period of after harvesting until cultivating new rice (days):

(Please see 10.4 and 11 in next page)

B12. Management of rice residues

12.1	Fate of rice residues after harvesting ❒ Moved out ❍All ❍>50% ❍ <50% ❍None ❒ Burned: ❍All ❍>50% ❍ <50% ❍None ❒ Left in the field (not burning) ❍All ❍>50% ❍ <50% ❍None	12.2	Fraction of rice residue utilized ❒ Straw ❍All ❍>50% ❍ <50% ❍None ❒ Stubble ❍All ❍>50% ❍ <50% ❍None
12.3	Rice straw utilization (Please specify % of utilization) ❒ Animal food _______% ❒ Mulching _______% ❒ Soil amendment _______% ❒ Mushroom cultivation _______% ❒ Other (please specify):	12.4	Rice stubble utilization (Please specify % of utilization) ❒ Animal food _______% ❒ Mulching _______% ❒ Soil amendment _______% ❒ Mushroom cultivation _______% ❒ Other (please specify):
12.5	Reason of burning rice residues ❒ Land preparation ❒ Pest removal ❒ Weed removal ❒ Other (please specify):	12.6	Fraction of rice residues burned ❒ Straw ❍All ❍>50% ❍ <50% ❍None ❒ Stubble ❍All ❍>50% ❍ <50% ❍None
12.7	What time do you burn the paddy field? ❒ morning (6:01-12:00) ❒ afternoon (12:01-18:00) ❒ night (18:01-6:00)	12.8	How long do you burn the paddy field? ❒ < 1 hour ❒ 1-2 hours ❒ 1 day ❒ Other (please specify)

10.5 Production (Grain yield)

Month of plantation	Rice cultivation no. (in 1 year)	Rice variety	Yield (ton/ha)	% moisture	Total Production (ton)	Amount sold (ton)	Price (specify unit)	Quantity for consumption (ton)	Quantity saved seed (ton)	Other uses (specify) (ton)
	1									
	2									
	3									
	4									

B11. Information on Machine Utilization

Cultivation practice	Type of machine	Maker	Model	Price of machine	Operating period (hr/d; no. of day)	Fuel type	Fuel use (L/ha)	Age of machine (years)	Life time (years)	Ownership
Land preparation										
Seeding										
Water management										
Fertilizer										
Pesticide/ Herbicide										
Harvesting										
Milling										
Straw baler										

A. Rotation Crop			
C1.	Detail of Rotation Crop		
1.1	Do you plant rotation crop? ❒ Yes ❒ No (Finish questionnaire)	1.2	How many times per year? ______________________
1.3	Timing of rotation crop plantation (please specify month or season): _____________	1.4	Do you plant the same rotation crop type every year? ❒ Yes ❒ No

1.5 Type of crop rotation

	Crop type	Crop variety	Cost of seed (please specify unit)	Crop duration (days)	Purpose of cultivation
1					
2					
3					
	i.e. corn, sugarcane, etc.				S = soil improvement I = income generation O = other please specify

C2. Land preparation of crop rotation

2.1	Duration of land preparation____day(s)	2.2	Number of working hour:_______hrs/d
2.3	Number of plowing__________time (s)	2.4	Number of labor _________person (s)
2.5	Cost of land preparation ________ (please specify unit/ha)	2.6	Method of land preparation ❒ Animal: Number of animal_______ type of animal__________ age of animal__________years ❒ Machine

C3. Plantation

3.1	Method of plantation ❒ Manual ❒ Machine	3.2 3.3 3.4 3.5	Time spent of plantation (days):______ Number of working hour (hr/d):_____ Number of labor _________persons Cost of plantation _______________ (please specify unit/ha)

C4. Water management

4.1	Water source (Major source) ❒ direct rain ❒ irrigated system ❒ man made pond ❒ ground water ❒ natural canal/river ❒ other (please specify)___________	4.2	Water source (Alternative source) ❒ direct rain ❒ irrigated system ❒ man made pond ❒ ground water ❒ natural canal/river ❒ other (please specify)___________
4.3	Do you use pump to drain water? ❒ No	4.4	4.4.1 Pump type: 4.4.2 Trademark:

	❒ Yes (please answer 4.5)		4.4.3 Model: 4.4.4 Power (watt): 4.4.5 Price: 4.4.6 Fuel type: 4.4.7 Fuel consumption (L/ha): 4.4.8 Cost of fuel per ha: 4.4.9 Operating period (hr): 4.4.10 Pumping rate (L/min):

C5. Fertilizer

5.1	Do you apply fertilizer in the rotation crop? ❒ No ❒ Yes	5.2	Frequency of applying fertilizer in planting per one cycle of rotation crop (times):
5.3	Do you apply fertilizer in the same way/amount/type in <u>all crop plot</u>? ❒ Yes ❒ No (Please specify the difference in space below)	5.4	Do you apply fertilizer in the same way/amount/type in all <u>rotation crops</u>? ❒ Yes ❒ No (Please specify the difference in space below)

____

____

5.5 Chemical fertilizer application to rotation crop

No.	Type	Trade-name common name of fertilizer	N:P:K	Price of fertilizer	Timing of application (DAP)	Applied amount (kg/ha)	Purpose of applying fertilizer	Labor (persons)	Labor cost of applying fertilizer
1			__:__:__						
2			__:__:__						
				Please specify unit: ________					Please specify unit: ________

Note: DAP = day after planting

C6. Organic amendment

6.1	Do you apply organic amendment to the rotation crop? ❒ No ❒ Yes	6.2	Frequency of organic amendment for one cycle of rotation crop (times):
6.3	Do you apply organic amendment in the same way/amount/type in all <u>crop plots</u>? ❒ Yes ❒ No (Please specifyin space below)	6.4	Do you apply organic amendment in the same way/amount/type in all <u>crop rotations</u>? ❒ Yes ❒ No (Please specify in space below)

____

____

6.5 Organic Fertilizer

No.	Type	Price of organic materials	Timing (DAP)	Applied amount (kg/ha)	Purpose of organic amendment	Labor (persons)	Labor cost
1							
2							
	S = straw, M = manure, C = compost, G = green manure, EM = effective microorganism O = other (please specify)	Please specify unit (i.e. USD/kg): __________					Please specify unit: ______

C7. Liming

7.1	Is lime applied? ❐ No ❐ Yes	7.2	Amount of lime (kg/ha):
7.3	Cost of lime (please specify unit i.e. USD/kg):	7.4	Labor cost for liming (please specify unit):

C8. Pesticide

8.1	Do you apply pesticide to the rotation crop? ❐ No ❐ Yes	8.2	Frequency of applying pesticide for one rotation crop (times):
8.3	Do you apply pesticide in the same way/amount/type in all crop plots? ❐ Yes ❐ No (Please specify the difference in space below)	8.4	Do you apply pesticide in the same way/amount/type in all crop rotations? ❐ Yes ❐ No (Please specify the difference in space)

8.5 Pesticide application to rotation crop

No.	Type	Price of pesti-cide	Timing (DAP)	Dilution	Applied amount (L/ha)	Purpose of application	Labor (persons)	Labor cost
1								
2								
		Please specify unit (i.e. USD/kg) : _____		Please specify unit (i.e. g/20L)	Diluted pesticide			Please specify unit: _______

Note: DAP = day after planting

C9. Herbicide

9.1	Do you apply herbicide to the rotation crop? ❒ No ❒ Yes	9.2	Frequency of applying herbicide in planting per one cycle of rotation crop (times):
9.3	Do you apply herbicide in the same way/amount/type in all crop plots? ❒ Yes ❒ No (Please specify the difference in space below)	9.4	Do you apply herbicide in the same way/amount/type in all crop rotations? ❒ Yes ❒ No (Please specify the difference in space below)

____

____

9.5 Herbicide application to the rotation crop

No.	Type	Price of herbicide	Timing of application (DAP)	Applied amount (kg/ha)	Purpose	Labor (persons)	Labor cost
1							
2							
		Please specify unit: __________					Please specify unit: _______

Note: DAP = day after planting

C10. Harvesting of rotation crop

10.1	Harvesting method ❒ Manual ❒ Machine	10.2	Plant height at harvest (cm):
10.3	Production utilization ❒ Energy use Type of energy_______________❒ Other use		

(Please see 10.4 and 11 in next page)

C12. Management of rotation crop residues

12.1	Rotation crop residues after harvesting ❒ Moved out ❍All ❍>50% ❍ <50% ❍None ❒ Burn: ❍All ❍>50% ❍ <50% ❍None ❒ Leave in the field (not burning) ❍All ❍>50% ❍ <50% ❍None	12.2	Fraction of rotation crop residues utilization ❍All ❍>50% ❍ <50% ❍None Which part? ___________________ Utilization of residues by ___________
12.3	Reason of burning crop residues ❒ Land preparation ❒ Pest removal ❒ Weed removal ❒ Other (please specify):	12.4	Fraction of rotation crop residues burned ❍All ❍>50% ❍ <50% ❍None
12.5	What time do you burn the field? ❒ morning (6:01-12:00) ❒ afternoon (12:01-18:00) ❒ night (18:01-6:00)	12.6	How long do you burn the field? ❒ < 1 hour ❒ 1-2 hours ❒ 1 day ❒ Other (please specify)

10.4 Production

Month of plantation	Crop rotation no. (in 1 year)	Crop variety	Yield (ton/ha)	% moisture (optional)	Total Production (ton)	Amount sold (ton)	Price (specify unit)	Quantity for consumption (ton)	Quantity saved seed (ton)	Other uses (specify) (ton)
	1									
	2									

C11. Information on Machine Utilization

Cultivation practice	Type of machine	Maker	Model	Price of machine	Operating period (hr/d; no. of day)	Fuel type	Fuel use (L/ha)	Age of the machine (years)	Life time (years)	Ownership
Land preparation										
Seeding										
Water management										
Fertilizer										
Pesticide										
Herbicide										
Harvesting										

Appendix 3

Expert meeting on “State-of-the-art of rice cultivation practices in South East Asia”

Expert Meeting on
"State-of-the-Art of Rice Cultivation Practices in South **East Asia"**

Under APN-ARCP funded Project on:
Rice Cultivation for Sustainable Low Carbon Society Development in South-East Asia

2-3 June 2011
The Joint Graduate School of Energy and Environment at
King Mongkut's University of Technology Thonburi, Bangkok, Thailand

Organized by
The Joint Graduate School of Energy and Environment (JGSEE)

Purpose of the meeting

The objective of this expert meeting is to share information with stakeholders from SEA including: Cambodia, Indonesia, Lao PDR, Myanmar, Thailand and Vietnam, on current practices of rice cultivation in the region, including state of the art of rice cultivation practices and ways towards more sustainable cultivation practices including reduced GHG emissions, crop rotation, and enhanced livelihood for farmers.

Date and venue

The event will take place during 2 - 3 June 2011 at The Joint Graduate School of Energy and Environment at King Mongkut's University of Technology Thonburi in Bangkok, Thailand

Participants

Researchers, scientists, government officers, from the agricultural and environmental sector

Registration

Free of change with limited number of participants under first come first served basis

Language

The workshop will be held in English

Programme of the Expert Meeting

Thursday 2 June:

8.30 – 9.00	Registration	
9.00 – 9.10	Opening address	Assoc Prof Dr Sirintornthep Towprayoon JGSEE, Thailand
9.10 – 9.20	Introduction to APN project	Assoc Prof Dr Sirintornthep Towprayoon JGSEE, Thailand
9.20 – 9.50	Sustainability of biomass-based energy: Challenges ahead	Dr Sebastien Bonnet JGSEE, Thailand
9.50 – 10.20	Coffee Break	
10.20 – 11.00	Rice cultivation in Japan and GHG emissions	Dr Shigeto Sudo NIES, Japan
11.00 – 12.00	Overview of rice production in SEA	Assoc Prof Dr Savitri Garivait JGSEE, Thailand
12.00 – 13.00	Lunch Break	
13.00 – 15.00	Country report session	All experts from SEA
13.00 – 13.20	Rice cultivation practices in Cambodia	Dr Seng Vang CARDI, Cambodia
13.20 – 13.40	Rice cultivation practices in Indonesia	Dr Iman Rusmana Bogor University, Indonesia
13.40 – 14.00	Rice cultivation practices in Lao PDR	Mr Immala Inthaboualy Climate Change Office, Department of Environment, Lao PDR
14.00 – 14.20	Rice cultivation practices in Myanmar	Dr Khin Swe Yezin Agricultural University, Myanmar
14.20 – 14.40	Rice cultivation practices in Vietnam	Mr Pham Van Thanh CCRD, Vietnam
14.40 – 15.00	Rice cultivation practices in Thailand	Assoc Prof Dr Amnat Chidthaisong JGSEE,Thailand
15.00 – 15.30	Coffee Break	
15.30 – 16.30	Group discussions	All experts
16.30 – 16.40	Wrap Up Session	

Friday 3 June:

8.30 – 9.00	Registration	
9.00 – 9.40	Mitigation and adaptation options	Assoc Prof Dr Sirintornthep Towprayoon JGSEE, Thailand
9.40 – 10.00	Coffee Break	
10.00 – 11.00	Implications of rice cultivation practices on GHG emissions	Dr Shigeto Sudo NIES, Japan
11:00 – 12:00	Implications of rice cultivation practices on soil carbon stock	Assoc Prof Dr Amnat Chidthaisong JGSEE, Thailand
12.00 – 13.00	Lunch Break	
13.00 – 14.20	Group discussions on potential mitigation options	All experts
14.20 – 14.50	Coffee Break	
14.50 – 16.00	Group discussions on adaptation options and suggestions for sustainable rice cultivation in SEA	All experts
16.00 – 16.10	Closing of the Expert Meeting	

Newsletter article

The Joint Graduate School of Energy and Environment (JGSEE), Center of Excellence on Energy Technology and Environment (CEE) at King Mongkut's University of Technology Thonburi, organized the expert meeting on "State-of-the-Art of Rice Cultivation Practices in South-East Asia" under APN-ARCP funded project on Rice Cultivation for Sustainable Low Carbon Society Development in South-East Asia, during 2-3 June 2011 in Bangkok.

The objective of this expert meeting was to share information with stakeholders from SEA on current practices of rice cultivation in the region, including state-of-the-art of rice cultivation practices and ways towards more sustainable cultivation practices including reduced GHG emissions, crop rotation, and enhanced livelihood for farmers.

Experts from South-East Asian countries including Cambodia, Indonesia, Japan, Myanmar, Vietnam and Thailand, contributed to the event and had a chance to share their country report on rice cultivation practices, as well as possible options for mitigation and adaptation to climate change. The knowledge gathered from this expert meeting will be integrated into a report providing information on the state-of-the-art of rice cultivation practices and potential of rotation with energy crops in SEA countries. This will also serve as a basis for the next activities of the project which ultimately aim at identifying sustainable cultivation practices options enabling to contribute to climate change mitigation.

List of participants

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Presentation materials

JGSEE CEE-PERDO

Introduction to the project

Strategic Rice Cultivation for Sustainable Low Carbon Society Development in South East Asia

ARCP2010-17NMY-Towprayoon

Expert meeting on "State of the Art of Rice Cultivation Practices in South-East Asia" 2-3 June 2011 Bangkok Thailand

JGSEE CEE-PERDO

ARCP: Annual Regional Call for Research Proposal Programme

- Two years project
- Contributing parties
  - Thailand   Lead PI   JGSEE-CEE, KMUTT
  - Indonesia   Co PI   Bogor University
  - Japan   Co PI   NIAES

JGSEE CEE-PERDO

Food and Fuel Competition

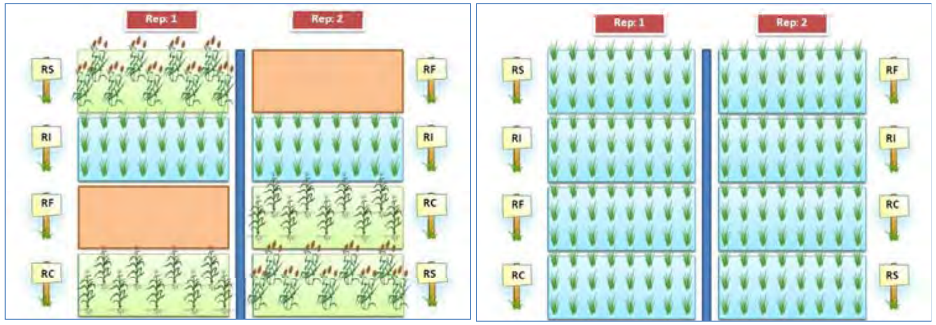
- Global rice plantation area covers 12.5% of the total crop plantation area.
- The production of rice amounts 659 millions tones annually, and is consumed by 281 billion people worldwide, corresponding to an impact of 164 billion US dollars per year on the world economy.
- South East Asia (SEA) is the major rice plantation area, which cover 30.0% percent of the world plantation.
- Maximizing rice yield in this region is essential to increase global food stock.
- Climate and energy crisis strongly influence the regional rice production.
- Temporary or permanently conversion of rice plantation area into oil palm and other energy crop cultivation have been observed in Thailand and Indonesia.

JGSEE CEE-PERDO

Strategic Rice Cultivation for Sustainable Low Carbon Society Development in South East Asia

- What is 'strategic rice cultivation'
  - enabling to solve both climate and energy security issues by rotating rice with energy crops in order to fully utilize the rice plantation fallow period to optimize rice and energy feedstock.
  - Proposed cultivation practice aims at reducing GHG emissions while increasing potential long-term soil carbon stock by optimizing land use change and cultivation practice

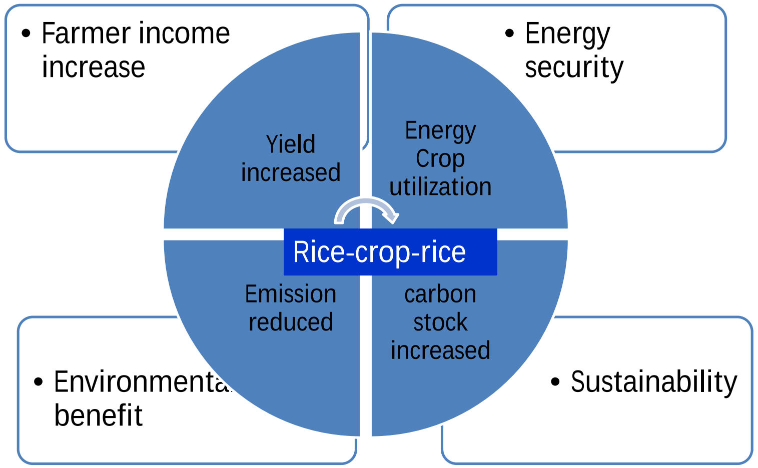
Strategic rice cultivation



Strategic Rice Cultivation for Sustainable Low Carbon Society Development in South East Asia

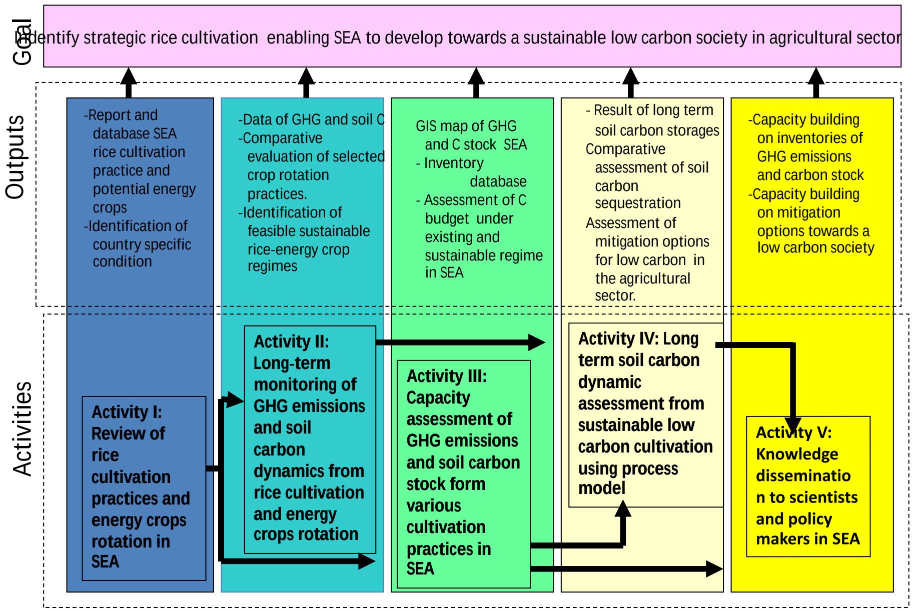
- Why 'Sustainable low carbon society'
  - Sustainable development will be considered in terms of enhancing economic and social benefits while developing a low carbon society to bring down the net GHG emissions.
  - Strategic rice cultivation practice enabling SEA to develop towards a sustainable low carbon society while enhancing the adaptive capacity in the agriculture sector.

Sustainable low carbon society

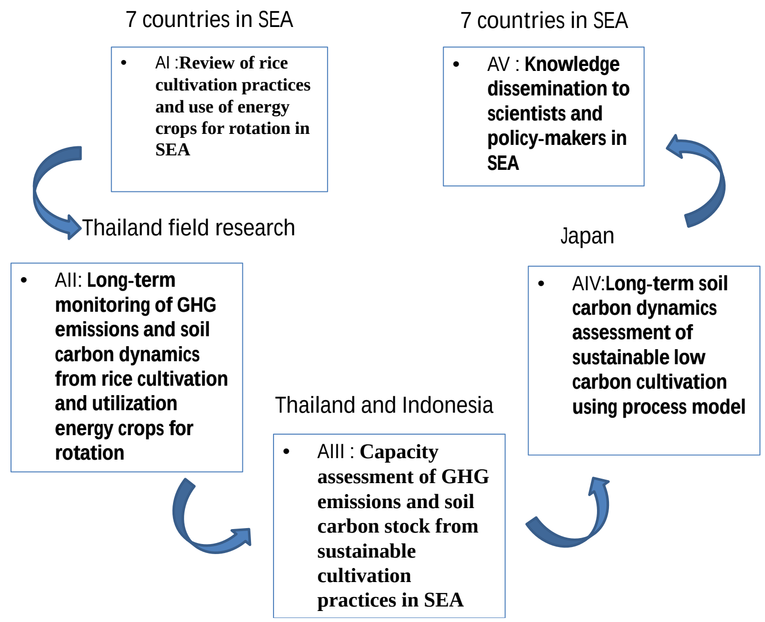


Objectives

- To develop sustainable low carbon agriculture in SEA through improved cultivation practices of rice and energy crops (crop rotation),
- To develop long-term field studies to measure, monitor and evaluate the impacts of various cultivation practices on climate change and identify potential adaptive measures and mitigation options,
- To enhance regional capacity of scientists and policy makers in SEA to contribute to sustainable low carbon development of their society.



JGSEE CEE-PERDO



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Activity I

- **Review of rice cultivation practices and use of energy crops for rotation in SEA**
- Information on current rice cultivation practices in SEA including land management will be reviewed and assessed to evaluate the state-of-the-art of the regional traditional practices and potential for introducing selected energy crops to be cultivated in rotation with rice.
- Selected SEA experts on agriculture sector will be invited to join the expert meeting co-organized by Thailand to help assess and confirm the review study.
-

- ***Deliverables***:
- Report on the state-of-the-art of rice cultivation practice and use of energy crops as the potential rotation crops for SEA countries.
- Database of rice cultivation practice of each country in SEA
- Identification of country specific rice cultivation practices and potentials for energy crop cultivation in SEA countries
- Background data for preparation of Activity II and III

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Activity II

- **Long-term monitoring of GHG emissions and soil carbon dynamics from rice cultivation and utilization energy crops for rotation**
- Assess the GHG emissions and soil carbon dynamics from studied rice-energy crop rotation cultivation system.
- Selected energy crops will be cultivated in rice field experiment plots during fallow period at KMUTT - Ratchaburi campus in Thailand..
- Continuous monitoring on trace gas emissions, soil carbon stock, biological and physical changes of above-ground and below-ground biomes will be examined

- ***Deliverables***:
- Data of long-term monitoring of GHG emissions and soil carbon dynamics from specific rice-energy crops cultivation practices.
- Comparative evaluation of selected crop rotation practices in term of carbon cycle, economic and social benefits, barriers, best practice issues, etc.
- Identification of feasible sustainable rice-energy crop cultivation practices under well-defined conditions.

Activity III

- **Capacity assessment of GHG emissions and soil carbon stock from sustainable cultivation practices in SEA**
- Assessing the capacity of C budget in terms of emission and soil carbon stock in rice fields in SEA.
- GIS database of GHG emissions and mitigation options obtained from activity I and II will be prepared to serve as input to a GHG emission inventory software program, i.e. ALU software.
- GIS maps of emissions resulted from existing and sustainable cultivation practices will be developed.

- *Deliverables*:
- GIS maps of GHG emissions from rice fields vs. cultivation practices in SEA.
- GIS map of carbon stock of SEA rice fields.
- Database of GHG emissions inventory using ALU software.
- Assessment of C budget of rice cultivation system under existing and sustainable practices in SEA.

Activity IV:

- **Long-term soil carbon dynamics assessment of sustainable low carbon cultivation using process model**
- The assessment of long-term soil carbon storage and sequestration of the feasible rice-energy crop system will be conducted using monitoring and modeling data.
- Relevant data generated from activity II will be used as input into existing process modeling tools, i.e. DNDC, for analyzing the time-series change in carbon storage vs. the corresponding GHGs emissions.

- *Deliverables*:
- Informative data on long-term soil carbon storage vs. selected rotation crops and cultivation practices.
- Comparative assessment of soil carbon sequestration under selected rice-energy crops rotation regime.
- Assessment of appropriate cultivation practices as mitigation options for development of low carbon emission in agriculture sector.

Activity V:

- **Knowledge dissemination to scientists and policy-makers in SEA**
- Build capacity of the scientists and policy-makers in SEA in terms of understanding the strategic approach of sustainable rice cultivation management that would lead to lower GHG emissions while increasing energy crop production.
- The project closing workshop will be conducted in Thailand with invited participants from selected SEA countries.

- ***Deliverables***:
- Capacity building of scientists on inventories of GHG emissions and carbon stock as well as process modeling tools
- Capacity building of scientists and policy-makers on mitigation options in the agricultural sector for a low carbon society.

Activity I

- **Expert Meeting on "State of the Art of Rice Cultivation Practices in South-East Asia"**
- **Objective**

The objective of this expert meeting is to share information with stakeholders from SEA including: Cambodia, Indonesia, Lao PDR, Myanmar, Thailand and Vietnam, on current practices of rice cultivation in the region, including state of the art of rice cultivation practices and ways towards more sustainable cultivation practices including reduced GHG emissions, crop rotation, and enhanced livelihood for farmers

Activity I

- Mechanisms:
  - Special lecture
  - Country report
  - Discussion and brainstorm
- Expected output
  - Understanding rice cultivation practice in SEA
  - Potential to implement strategic rice cultivation in rice field of SEA

Thank you

Sustainability of biomass based energy: Challenges ahead

Dr Sebastien Bonnet and Prof Shabbir H Gheewala
The Joint Graduate School of Energy and Environment

APN Expert Meeting on "State-of-the-art of rice cultivation practices in SEA"

2-3 June 2011

Bangkok, Thailand

Joint Graduate School of Energy and Environment

www.jgsee.kmutt.ac.th

- Center of Excellence in Energy Technology and Environment established in 1998
- Research-based and Professional-oriented graduate programs in Energy and Environmental Technology & Management
- Consortium of 5 universities:
  - ❖ King Mongkut's University of Technology Thonburi
  - ❖King Mongkut's Institute of Technology North Bangkok
  - ❖Chiang Mai University
  - ❖Sirindhorn International Institute of Technology at Thammasart University
  - ❖Prince of Songkhla University

Strategic Environmental Assessment

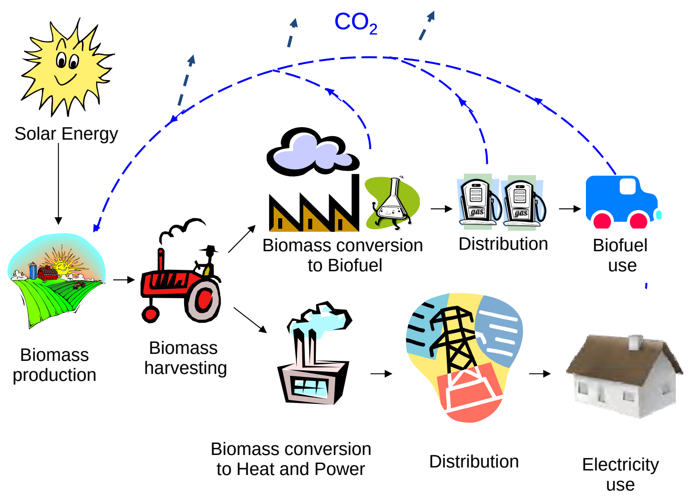
- *Vision*
  - To provide R&D support to energy and environmental decision-making bodies in Thailand with a view to moving towards the goal of sustainable development in the area of energy conversion, use and conservation
- *Objectives and Scope*
  - Environmental assessment of energy systems by LCA
  - Energy & Environment policy-support tools

Focus Areas of SEA

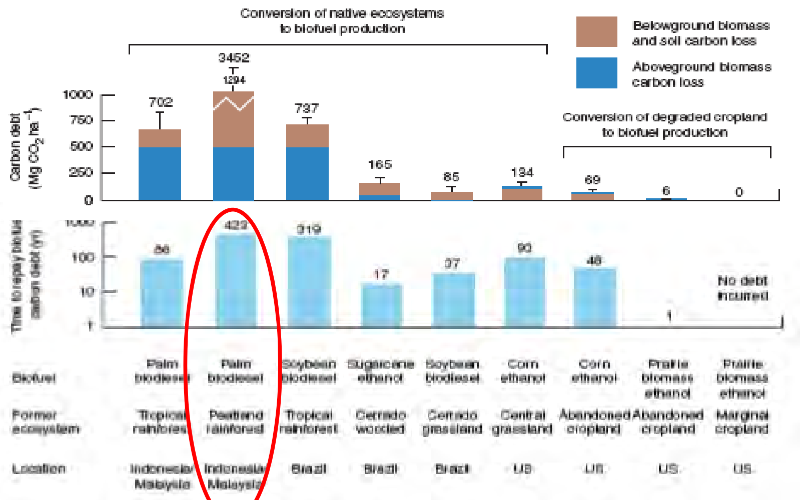
- *Focus Area 1:* Environmental assessment of energy systems
  - Power production units
    - Conventional (fossil-based)
    - Renewable – biomass, mini-hydro, solar, wind
  - Transportation
    - Fuels – biofuels, hydrogen
    - Vehicle technologies – electric cars, hybrid cars
  - Built environment
    - Ecodesign of buildings

- *Focus Area 2:* Energy & Environment policy-support tools
  - Ecolabelling
  - Sustainable development indicators

Strategic Environmental Assessment



Bioenergy: a path toward mitigation of GHG emissions?



Source: Fargione et al., Science 319, 1235 (2008)

System boundaries of biofuels

- Only use phase – carbon neutral
- From the cultivation to end use – carbon benefits achievable
- Expand the boundary further to include land use effects – carbon benefits questionable
- Ripple effects throughout the whole world
  - How does reduced soybean production in the US affect biofuel prices (and probably impacts too) in Thailand?
  - What if a biofuel is produced at sites that have been converted a few years ago?
  - What if biofuel production results in displaced food production at another location where forests are cleared?
  - Should these be part of the "environmental baggage" of the biofuel?

Food versus fuel

- Increasing food prices affecting the world's poorest – too simplistic
- Socio-economics are complicated
- Increased price of agricultural products actually also benefit farmers
- Positive effect on the rural economy and employment generation
- Need for indicators to capture all these issues = Sustainability assessment

Biodiversity

- Monoculture (diversity of species)
- How do we characterize this?
- Biomass planted on degraded land - not usable for cultivation of food crops – land zoning
  - "restore soil organic matter and nutrient content, stabilize erosion and improve moisture conditions"
  - "using surplus agricultural land for biofuel production is more advantageous for greenhouse gas reduction than afforestation"
- Utilization of marginal land

Land and water use

- Improvement of plantation yields
- Maximisation of biomass based by-products utilisation
- Crop rotation during fallow period and no tillage practices
- Assessment of water stress areas and climatic conditions
- Water consumption must be strictly adapted to regional resources (availability), and the needs of other users taken into account
- Harmful contamination of surface and ground water must be minimized

Competitive production of bioenergy

- "Best" production of biodiesel, bioethanol or another energy feedstock?
  - What are the criteria for judging what's *BEST* ?
    - C-reduction
    - Reduction of oil imports?
    - Socio-economics?
    - A combination of the above?

Some existing certification schemes

- Energy
  - Roundtable on Sustainable Palm Oil (RSPO)
  - Roundtable on Responsible Soy (RTRS)
  - Green Gold Label (GGL)
- Forestry
  - Forest Stewardship Council (FSC)
  - Program for Endorsement of Forest Certification (PEFC)
  - Malaysian Timber Certification Council (MTCC)

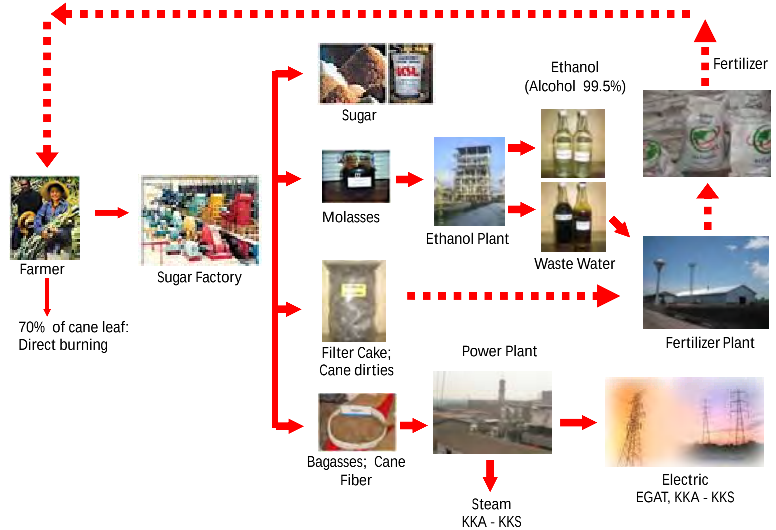
Some existing certification schemes

- Agriculture
  - International Federation of Organic Agriculture Movements (IFOAM)
  - Sustainable Agriculture Network (SAN)
  - Bioland (German organic farmers' association)
  - BIO (Organic Farming – EC control system)
  - GLOBALG.A.P.
  - CCCC (Common Code for the Coffee Community)

Biorefinery

- ***Biorefinery complex*** *- facilities integrating processes for the conversion of biomass and equipments for the production of fuels, chemicals and energy from biomass resources*
- ***By-product utilisation*** *– waste biomass can be utilized for various purposes including for feed production, energy conversion, soil conditioner application etc.*
- ***Energy recycling*** *– a fraction of process heat and steam can be trapped and converted in the form of useful energy such as power to supply processing units within the biorefinery*

Example of a biorefinery in Thailand



Environmental performance in terms of GWP

	Ethanol (kg CO_2e)				Gasoline (kg CO_2e)
	Base Scenario	Scenario 1		Scenario 2	
		0%	35%		
Production	13.50	5.91	8.38	11.20	5.04
Use	-	-	-	-	21.66
Total	13.50	5.91	8.38	11.20	26.70

Note: Results based on reference flow of 14.95L ethanol which is equivalent to 9.89L gasoline
Scenario 1: Percentage of cane trash burning (base case is assumed as 70%)
Scenario 2: Utilization of excess steam

- Benefits of sugarcane biorefinery:
- A reduction of GWP by 50% for ethanol as compared to gasoline (Base scenario)
- A further reduction by 70% and up to 80% when cane trash burning is reduced or avoided (Scenario 1)
- A potential additional 10% GHG savings from utilisation of unused steam (Scenario 2)

Gheewala, S.H., Bonnet, S., Prueksakorn, K. and Nilsalab, P. (2011) Sustainability assessment of a biorefinery complex in Thailand, Sustainability, 3, 518-530

Socio-economic implications

- Farmers – sugarcane plantation
  - Belong to lower income class of society
  - Benefit form steady income due to contract farming with sugar mill
  - Salaries to farm laborers is the Largest fraction of total value added (TVA)
- Employees – biorefinery complex
  - Higher income than average at provincial level
  - Better living conditions due to employment at biorefinery complex
  - After profits, salaries is the second largest fraction of TVA

THANK YOU

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Rice cultivation in Japan and GHG emissions

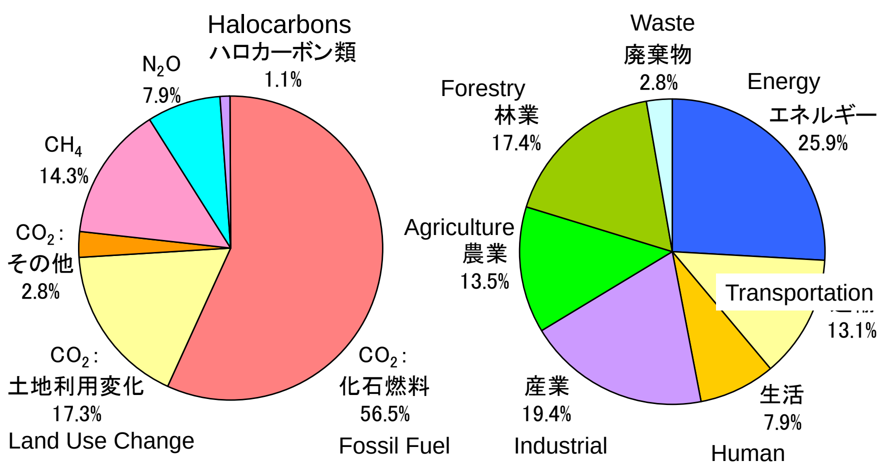
Dr Shigeto Sudo
(APN Project Investigator)
Scientist, NIAES, Japan

APN Expert Meeting on "State-of-the-art of rice cultivation practices in SEA"
2-3 June 2011
Bangkok, Thailand

Rice cultivation in Japan and GHG emissions

- Trends in greenhouse gas emissions from the Agriculture sector
- Rice cultivation in Japan
- Agricultural Field (1961 – 2009) in Japan
- Rice harvest yield 2010 in Japan
- CH4 emission from rice cultivation in Japan
- Typical case of water management for rice cultivation in Japan --- intermittent drainage
- Estimations of soil carbon accumulation and applications of organic manures (OM) in rice paddy
- Numerical model (DNDC-rice) fitting on CH4 emission from Japanese rice paddy field
- Residue management in paddy field

World GHG Inventory



IPCC 2004 AR4

Trends in greenhouse gas emissions from the Agriculture sector

Table 2-11 Trends in greenhouse gas emissions from the Agriculture sector

[Thousand tonnes CO_2 eq.]

Category	1990	1995	2000	2005	2007	2008	2009
4A. Enteric Fermentation(CH_4)	7,677	7,606	7,370	7,002	6,974	6,914	6,849
4B. Manure Management	8,627	8,045	7,563	7,253	7,150	7,083	7,061
CH_4	3,094	2,893	2,678	2,503	2,376	2,321	2,300
N_2O	5,533	5,152	4,885	4,749	4,773	4,762	4,761
4C. Rice Cultivation(CH_4)	6,960	7,083	5,920	5,739	5,652	5,599	5,567
4D. Agricultural Soils (N_2O)	7,898	7,210	6,703	6,468	6,267	6,077	5,842
4F. Field Burning of Agricultural Res	133	126	103	87	85	85	83
CH_4	101	94	77	65	65	64	63
N_2O	33	32	25	21	21	21	20
Total	31,295	30,070	27,658	26,549	26,128	25,757	25,402

Agricultural Field 2009 in Japan

According to the Food and Agriculture Organization (FAO) for the year 2007, global rice plantation area covers <u>12.5% of total crop plantation area</u>. (Preface of this meeting program)

Categories	Sub categories	ha	ha	ha	%	%
Total area of agricultural field in				4,609,000		
Rice paddy			2,506,000			54%
Upland			2,103,000			46%
	crop & vegi field	1,169,000			25%	
	grassland, grazing	618800			13%	
	orchard	314700			7%	

Statistics from MAFF(Ministry of Agriculture, Forestery and Fishery, Japan)

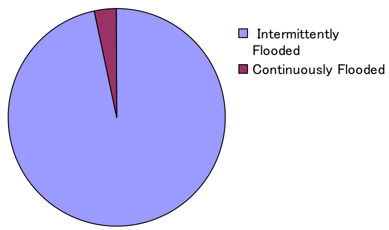
Agricultural Field (1961 – 2009) in Japan

		1961	1971	1981	1991	2001	2009
Categories	Sub categories	ha	ha	ha	ha	ha	ha
Total area of agricultural field in Japan		6,085,000	5,741,000	5,442,000	5,205,000	4,609,000	4,609,000
Rice paddy		3,388,000	3,364,000	3,031,000	2,825,000	2,506,000	2,506,000
Upland		2,697,000	2,377,000	2,411,000	2,380,000	2,103,000	2,103,000
	crop & vegi field	2,165,000	1,409,000	1,241,000	1,266,000	1,169,000	1,169,000
	grassland, grazing	81,000	352,000	589,000	649,000	619,000	618,800
	orchard	451,000	616,000	581,000	464,000	315,000	314,700
Land area of Japan(ha)	37,600,000						
ratio of agricultural field		16.2%	15.3%	14.5%	13.8%	12.3%	12.3%
ratio of rice cultivation		9.01%	8.95%	8.06%	7.51%	6.66%	6.66%

Rice harvest yield 2010 in Japan
unit: brown rice yield (kg/10a)

CH4 emission from rice cultivation in Japan

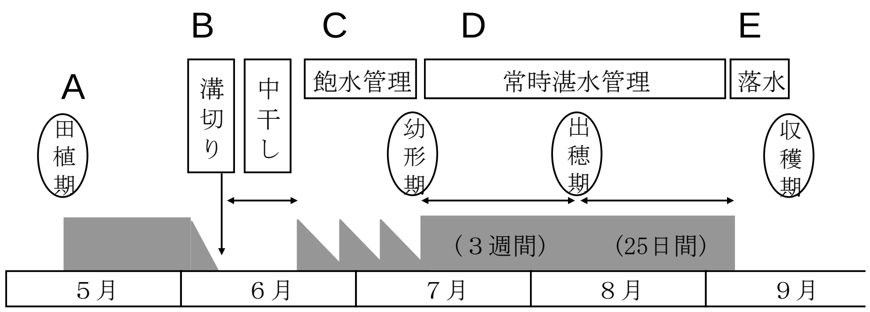
CH4 emissions from rice cultivation	year						
Gas Item	Unit	1990	1995	2000	2005	2007	2008	2009
4.C.1.- Intermittently Flooded	Gg-CH4	319.9	325.5	272.1	263.8	259.8	257.3	255.8
4.C.1.- Continuously Flooded	Gg-CH4	11.6	11.8	9.8	9.5	9.4	9.3	9.2
Total CH4 from rice cultivation	Gg-CH4	331.5	337.3	281.9	273.3	269.2	266.6	265
Total CH4 from rice cultivation	Gg-CO2eq	6961.5	7083.3	5919.9	5739.3	5653.2	5598.6	5565



Emission factor of CH4 was not changed while cultivation area was decreasing…..

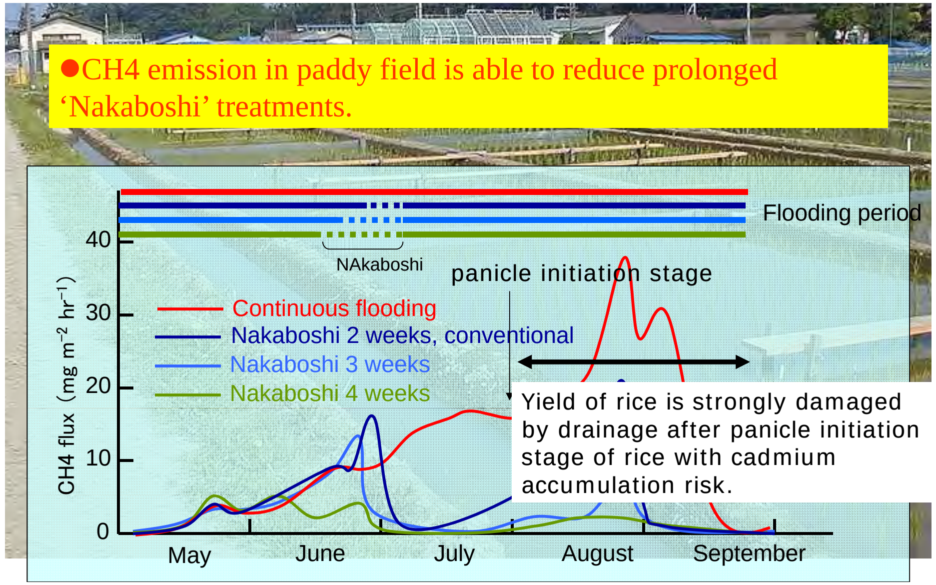
98% of rice cultivation was managed by intermittently flooded condition in Japan.

Typical case of water management for rice cultivation in Japan

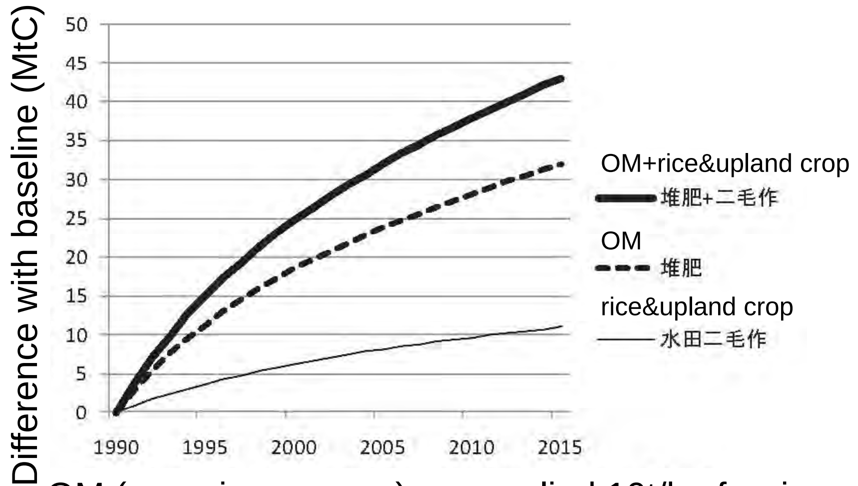


A. Transplanting
B. Mid-season drainage
C. Saturated water management
D. Flooded
E. Drainage

Reduction of CH4 emission by prolonged Nakaboshi (mid-season-drainage period; Fukushima Prefectural Agricultural Center in 2004.



Estimations of soil carbon accumulation and applications of organic manures (OM) in rice paddy, Japan compared with baseline of non-application of OM and single rice.



OM (organic manures) are applied 10t/ha for rice paddy and 15t/ha for upland crop

Numerical model (DNDC-rice) fitting on CH4 emission from Japanese rice paddy field (Dr. T. Fumoto, NIAES).

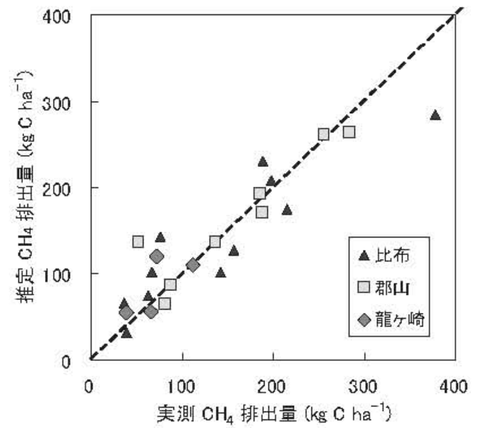


図７　DNDC-Rice モデルの検証結果．３地点において，それぞれ年次，水管理または有機物投入量を変えて測定した水稲栽培期間 CH_4 発生量を推定した．

Estimation methods for CH4 and N2O emissions from field burning of agricultural residues

CH_4 emission associated with field burning of agricultural residues(kg-CH_4)
= CH_4 emission factor (kg-CH_4-C/kgC) × Total carbon released(kg-C) × 16/12

N_2O emission associated with field burning of agricultural residues(kg-N_2O)
= N_2O emission factor (kg-N_2O-N/kgN) × total nitrogen released(kg-N) × 44/28

●***Emission Factors***

The default values shown in the Revised 1996 IPCC Guidelines and the *GPG* (2000) were used.

Table 6-56 Emission factors for CH_4 and N_2O emissions associated with field burning of rice, wheat, barley, rye, and oats residues

	Value	Unit
CH_4	0.005	[kg-CH_4/kg-C]
N_2O	0.007	[kg-N_2O/kg-N]

Source: Revised IPCC Guidelines Vol.2 Table 4-16 (Reference 3)

Rice straw residue management

Total carbon/total nitrogen released by field burning of agricultural residues(kgC, kgN) (Rice)
= Amount of burning rice straw and rice chaff [t] × proportion of dry matter in residue [t-dm/t] × Oxidation rate × Carbon/nitrogen content of residues [t-C/t-dm, t-N/t-dm] × 10^3

Table 6-57 Amount of burning rice straw and rice chaff on crop field

Item	Unit	1990	1995	2000	2005	2008	2009	2010
Rice straw	t	438,197	536,908	429,091	276,619	203,588	203,588	203,588
Rice chaff	t	581,302	528,290	291,260	260,289	249,870	249,870	249,870
Total	t	1,019,499	1,065,198	720,350	536,908	453,458	453,458	453,458

Reference: Survey by MAFF

Proportions of residue to crop yield, dry matter in residue, carbon content, proportion burned in field and oxidation rate.

Crop	Residue/ Crop product ratio	Dry matter fraction in residue [a)]	Carbon content	Nitrogen content	Proportion burned in field	Oxidation rate
Rice	---	0.85 [a]	0.4144 [a]	0.00688 [i]	---	0.90 [b]
Wheat (grain)	1.39 [i]	0.85 [a]	0.4853 [a]	0.00368 [i]	0.135 [b]	
Barley (grain)	1.39 [i]	0.85 [a]	0.4567 [a]	0.00368 [i]	0.135 [b]	
Wheat/barley (green crop)	---	0.17 [c]	0.48 [d,g]	0.017 [h,g]	0.135 [b]	
Rye	2.84 [e]	0.90 [c]	0.4710 [f]	0.0048 [f]	0.135 [b]	
Oats	2.23 [e]	0.92 [c]	0.4710 [f]	0.007 [f]	0.135 [b]	
Rye (green crop)	---	0.17 [c]	0.4710 [f]	0.0116 [h]	0.135 [b]	
Oats (green crop)	---	0.17 [c]	0.4710 [f]	0.0169 [h]	0.135 [b]	

a: *GPG (2000)*, p. 4.58, Table 4.16 (Reference 4)

b: Survey by MAFF

c: Determined based on the percentage of dry matter in green crop wheat indicated in the *Standard Table of Feed Composition in Japan* (National Agriculture Research Organization, pub. by Japan Livestock Association)

d: Determined based on the values shown in the *GPG (2000)* for wheat (grain) and barley (grain) by apportioning for yields

e: Determined based on the results of crop tests for rye and oats in Japan

f: Used the average of the values shown for "wheat" and "barley" in the *Good Practice Guidance (2000)*.

g: Values change over the years

h: Owa, *New Trends in Technology for Efficient Use of Nutrients – Nutritional Balance of Crops in Japan* (1996) (Reference 33)

i: Matsumoto N., Development of Estimation Method and Evaluation of Nitrogen Flow in Regional Areas (2000) (Reference 55)

CH4 and N2O emissions from field burning of agriculture

residues.

Table 6-55 CH_4 and N_2O emissions from field burning of agriculture residues

Gas	Item		Unit	1990	1995	2000	2005	2007	2008	2009
CH_4	4.F.1. Cereals	Wheat	Gg-CH_4	0.42	0.23	0.30	0.40	0.41	0.38	0.33
		Barley	Gg-CH_4	0.15	0.10	0.09	0.08	0.09	0.09	0.08
		Maize	Gg-CH_4	1.89	1.66	1.48	1.32	1.34	1.37	1.38
		Oats	Gg-CH_4	0.02	0.02	0.04	0.04	0.04	0.04	0.04
		Rye	Gg-CH_4	0.002	0.002	0.002	0.002	0.002	0.002	0.002
		Rice	Gg-CH_4	2.06	2.27	1.53	1.06	0.98	0.96	0.96
	4.F.2. Pulses	Peas	Gg-CH_4	0.008	0.006	0.005	0.004	0.004	0.004	0.004
		Soybeans	Gg-CH_4	0.08	0.04	0.08	0.07	0.08	0.08	0.08
		Adzuki beans	Gg-CH_4	0.02	0.02	0.02	0.02	0.01	0.01	0.01
		Kidney beans	Gg-CH_4	0.005	0.005	0.003	0.003	0.003	0.003	0.003
		Peanuts	Gg-CH_4	0.008	0.007	0.006	0.005	0.004	0.004	0.004
	4.F.3. Tubers and Roots	Potatoes	Gg-CH_4	0.03	0.03	0.02	0.02	0.02	0.02	0.02
		Sugarbeat	Gg-CH_4	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	4.F.4. Sugarcane		Gg-CH_4	0.06	0.04	0.04	0.03	0.04	0.04	0.04
	Total		Gg-CH_4	4.8	4.5	3.7	3.1	3.1	3.1	3.0
			Gg-CO_2eq	101	94	77	65	65	64	63
N_2O	4.F.1. Cereals	Wheat	Gg-N_2O	0.006	0.003	0.005	0.006	0.006	0.006	0.005
		Barley	Gg-N_2O	0.002	0.002	0.001	0.001	0.001	0.001	0.001
		Maize	Gg-N_2O	0.03	0.02	0.02	0.02	0.02	0.02	0.02
		Oats	Gg-N_2O	0.001	0.001	0.002	0.002	0.002	0.002	0.002
		Rye	Gg-N_2O	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
		Rice	Gg-N_2O	0.056	0.062	0.042	0.029	0.027	0.026	0.026
	4.F.2. Pulses	Peas	Gg-N_2O	0.0003	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002
		Soybeans	Gg-N_2O	0.003	0.002	0.003	0.003	0.004	0.004	0.004
		Adzuki beans	Gg-N_2O	0.001	0.001	0.001	0.001	0.001	0.001	0.001
		Kidney beans	Gg-N_2O	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001
		Peanuts	Gg-N_2O	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001
	4.F.3. Tubers and Roots	Potatoes	Gg-N_2O	0.003	0.002	0.002	0.002	0.002	0.002	0.002
		Sugarbeat	Gg-N_2O	0.004	0.003	0.004	0.004	0.004	0.004	0.003
	4.F.4. Sugarcane		Gg-N_2O	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Total		Gg-N_2O	0.11	0.10	0.08	0.07	0.07	0.07	0.06
			Gg-CO_2eq	33	32	25	21	21	21	20
Total of all gases			Gg-CO_2eq	133	126	103	87	85	85	83

Overview of rice production in SEA

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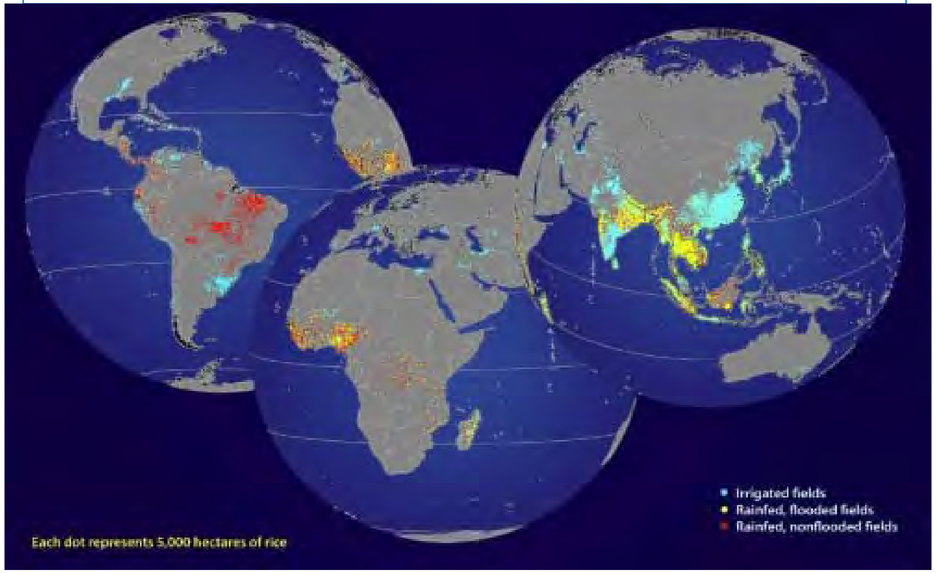
Expert Meeting
2-3 June 2011
Bangkok, Thailand

Overview on Global Situation



Overview on Global Situation

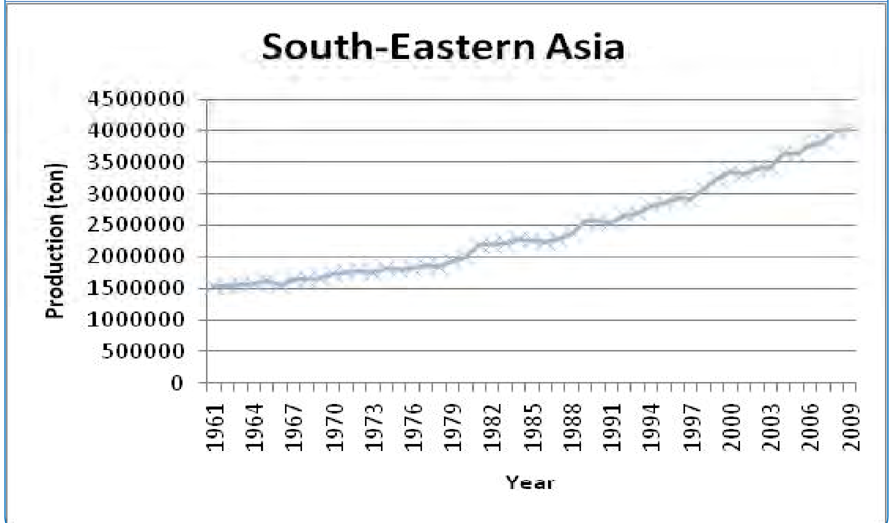
- Rice is grown in more than **100 countries**
- The global rice **area harvested** at present represents more than **150 million hectares**, but the amount of **land used** for rice is less, in the order of about **125 million hectares**, because in some fields farmers plant two, or even three, rice crops each year, producing nearly **630 Mt of rough (unmilled) rice**

➡ **95 kilograms for each person on Earth**

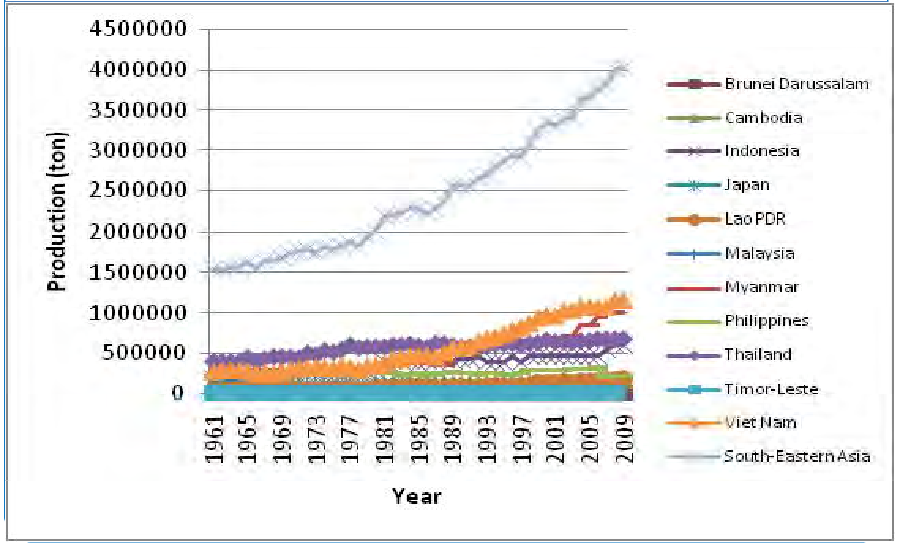
Overview on Global Situation

- Almost half the global rice area is in India and China and **89% is in Asia**
- **Africa** and **the Americas** each have a little more than **5%**
- The eight countries with the most rice area are all in South and Southeast Asia, including India, China, Indonesia, Bangladesh, Thailand, Vietnam, Myanmar, and the Philippines ➔ **80% of the global rice area**

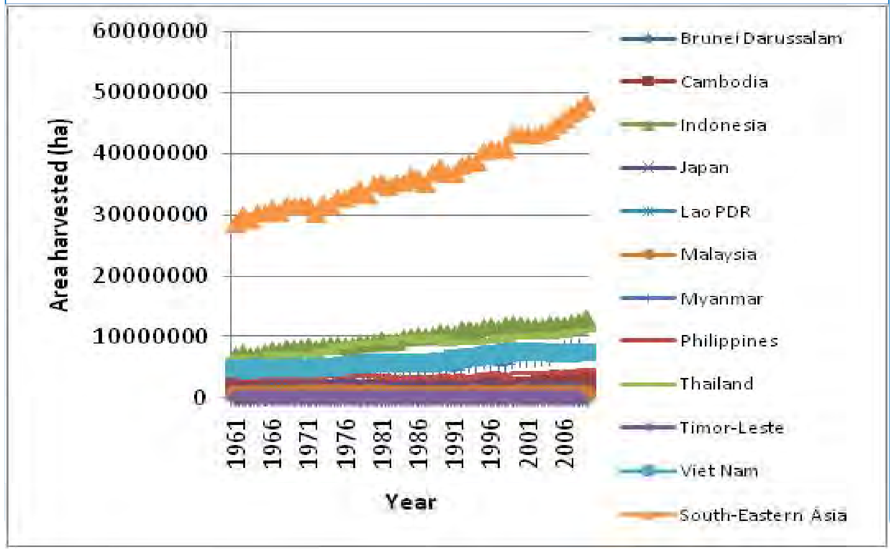
Overview on SEA Situation - Production



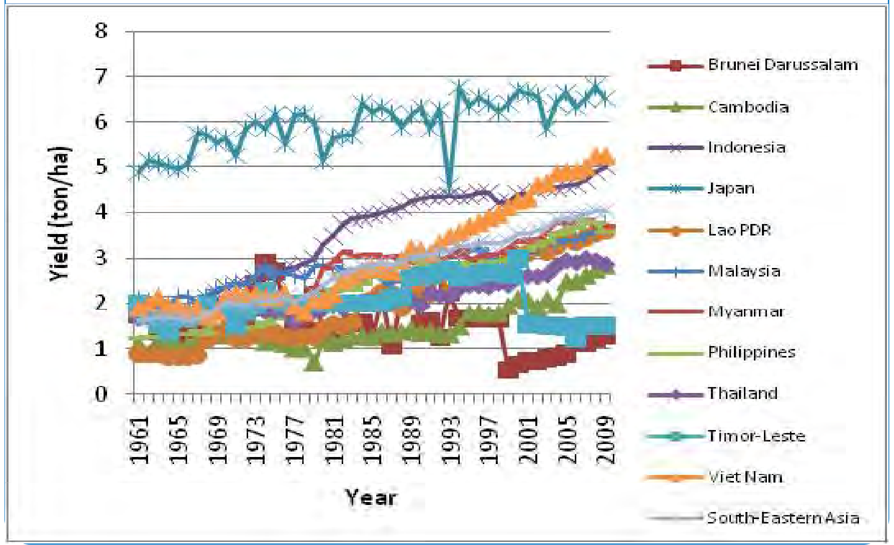
Overview on SEA Situation - Production



Overview on SEA Situation – Harvested Area



Overview on SEA Situation – Yield



Rice Production and Processing

- Rice can be grown in a wide range of locations and climates. In particular, rice is most closely associated with South, Southeast, and East Asia, where 90% of the world's rice is produced (about 640 million tons)
- It is grown in the wettest areas in the planet to the driest deserts
- It is cultivated in relatively warm places to areas of considerable cold

Rice Production and Processing

- Rice is produced at sea level on coastal plains and in areas near river deltas to the heights of the Himalayas
- There are primarily four ecosystems where rice is grown: irrigated, rainfed lowland, upland, and flood-prone. Each of these environments has its own ideal growing conditions, as well as limiting factors

Rice Production and Processing

- The **irrigated** rice environment accounts for about half of the harvested rice area and contributes 75% of global rice production
- Because water is available for most part of the year, farmers can grow rice all year long
- Worldwide, about 80 million hectares of rice are grown under irrigated areas

Rice Production and Processing

- High-yielding areas of irrigated rice can be found in China, Egypt, Japan, Indonesia, Vietnam, the Republic of Korea, and the Senegal River Valley in Africa
- The main factors that limit the yield in such areas include poor management of production inputs, losses from weeds, pests, and diseases, inadequate land formation, levelling, and irrigation water, and inadequate drainage that may lead to a build up of salinity and alkalinity

Rice Production and Processing

- **Rainfed lowland** rice is grown in bunded fields that are flooded with rainwater for at least part of the cropping season. Bunds are mounds or embankments made of earth designed to contain water in the field
- This environment is characterized by a lack of water control, with floods and drought being potential problems

Rice Production and Processing

- About 60 million hectares of rainfed lowlands supply about 20% of the world's rice production. Adverse climate, poor soils, and a lack of suitable modern technologies keep farmers from being able to increase productivity
- Majority of lands in this ecosystem face different risks as compared to irrigated environments, and as such require different rice varieties and management strategies

Rice Production and Processing

- **Upland** rice is grown in Asia, Africa, and Latin America
- About 14 million hectares of land is dedicated to upland rice, accounting 4% of global rice production
- This rice environment can be found in low-lying valley bottoms to undulating and steep sloping lands with high runoff and lateral water movement

Rice Production and Processing

- In many places, including Indonesia, the Philippines, Southwest China, and Brazil, upland rice may be intercropped with maize
- Also, some upland rice fields are frequently bunded in areas with scarce water. Upland rice is grown under dryland conditions in mixed farming systems without irrigation and without puddling
- Although factors that limit yield in upland areas are numerous, the most severe biological constraint are weeds, followed by blast disease and brown spot

Rice Production and Processing

- The **flood-prone** ecosystem (this includes deepwater and floating rice environments) incorporates special rice varieties that are well-suited to flooded environments
- These rice plants must be adapted to conditions such as deepwater, flash floods that may last longer than 10 days, salinity in low-lying coastal areas, and problems soils, such as acid-sulfate and sodic soils
- Around 11 million hectares of rice lands worldwide are affected by one or more of these conditions.

Rice Production and Processing

- In these environments, rice yields are low and extremely variable because of problem soils and unpredictable combinations of drought and flood
- Deepwater rice and floating rice are mainly grown on the floodplains and deltas of rivers such as Bangladesh, the Irrawaddy of Myanmar, the Mekong of Vietnam and Cambodia, the Chao Phraya of Thailand, and the Niger of West Africa
- Flooding occurs in the later stages of plant growth and can last for several months

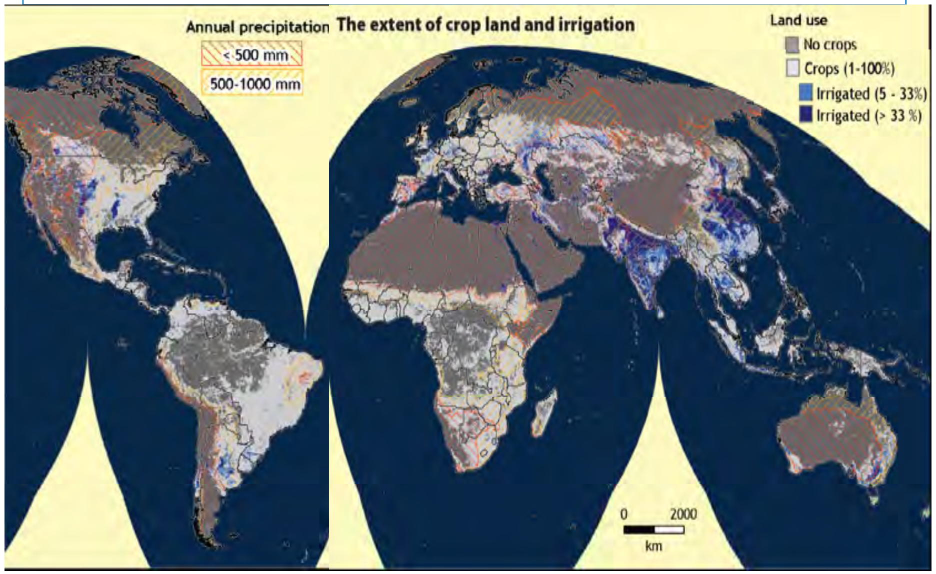
Rice Production Agro-ecosystem Distribution

- Rice production **agro-ecosystems** are often classified according to the **dominant water regime**, e.g. irrigated or rainfed, and for being flooded or not flooded
- **Irrigated rice**, typically grown on **bunded fields** that retain water to assure **flooded conditions**, makes up about **44% of the global rice area = Dominant system at high latitudes** (both north and south), but also in southern India and on the Indonesian island of Java.

Rice Production Agro-ecosystem Distribution

- **Flooded rice** is the most productive rice ecosystem, producing **about 75% of the global output**
- **Rainfed rice** fields are also flooded for at least part of the growing season, commonly known as "rainfed lowlands," comprises about **45% of the global rice area** (particularly important in eastern India and Southeast Asia)
- Remaining **11% of the world's rice area = "upland" ecosystem**, comprising fields that are **neither flooded nor irrigated** ➔ Although it has declined considerably in Thailand and China, but is still important

Irrigation



Irrigation

- **Water availability** is a fundamental requirement for crop growth
- In many places, **rainfall** is scant or erratic and this can diminish crop yield and strongly affect the livelihoods of farming households
- There are striking regional differences in the use of irrigation ➔ **India and China** each have about **20%** of the world's irrigated lands, and about **68%** of the world's irrigated area is in **Asia,** and that about **half** of this land is used for rice

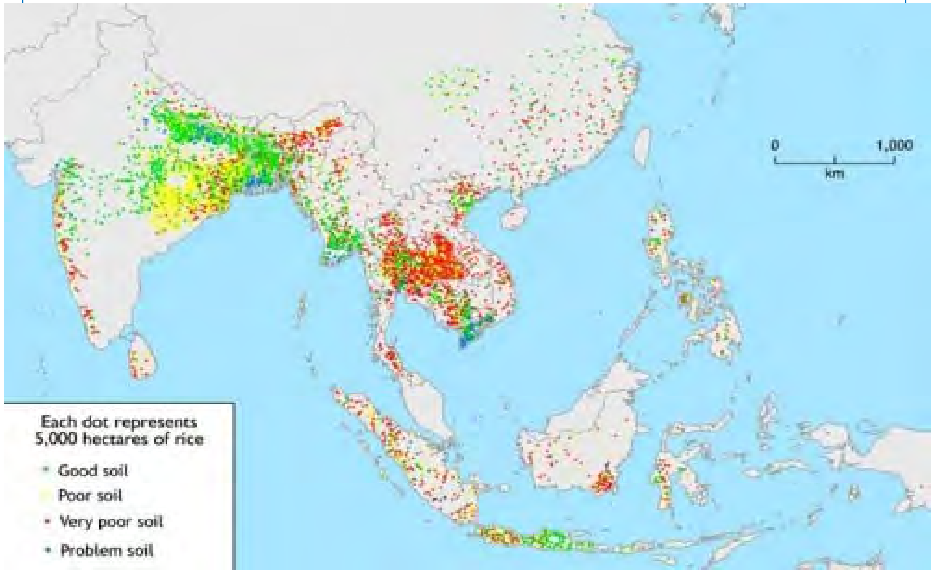
Irrigation

- Currently about **300 million hectares** of irrigated land worldwide = **double the area in 1960**
- About **80 million hectares** (27%) of this irrigated land is used for **rice production** ➔ it uses some **39% of the world's irrigation water**
- About **28% of Asia's crop land is irrigated**, versus **9% for the rest of the world**
- Only **5%** of the crop land in Africa is irrigated, and unlike in Asia, there is **very little irrigation** in zones with **500 to 1,000 mm annual rainfall**

Irrigation

- Only **30%** of the world's irrigated area is in areas with **less than 500 mm** of rain per year
- Another **30%** is in areas with between **500 and 1,000 mm** per year
- The **majority** of irrigated rice land in Asia receives **more than 750 mm of rain per year** ➔ **Irrigation** provides **additional water** during the **rainy season,** and **opportunity for dry-season crops**

Soil Quality in Rainfed Lowland Rice



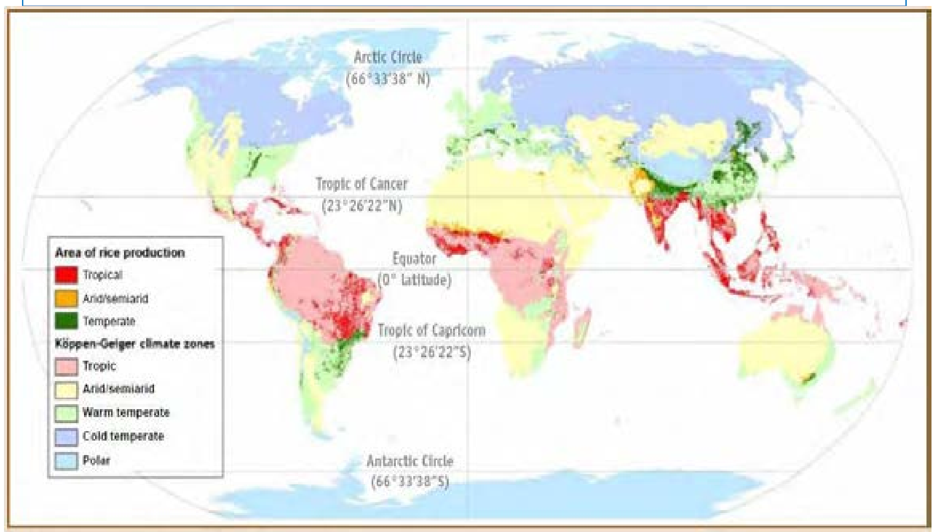
Soil Quality in Rainfed Lowland Rice

- **Rainfed** lowland rice agro-ecosystems are characterized by fields that are **flooded** for at least part of the growing season, but that are **not irrigated**
- **Asia** has about **46 million hectares** of **rainfed lowland rice = 30% of the global rice area**
- Rice production in these ecosystems is often hampered by drought, submergence, and problem

Soil Quality in Rainfed Lowland Rice

- **Recent technological advances**, such as the development of **stress tolerant** rice **varieties** and **improved crop-management** options, can help **boost yields** substantially
- However, such **benefits** depend strongly on the **quality** and **availability of natural resources**, particularly **soil and water**.

Climate Distribution and Rice Cultivation



Map 1. Rice-growing areas in the tropical and temperate zones.

Climate Distribution and Rice Cultivation

- The temperate regions of the world lie between the Arctic Circle and Tropic of Cancer, and the Antarctic Circle and Tropic of Capricorn
- Diverse **climates** are found within these regions depending on latitude, **prevailing winds, mountain ranges, and oceanic influences**
- **Areas of rice cultivation** are clearly split between the **tropical and temperate areas** of the world, although some cultivation is also seen in semiarid zones

Climate Distribution and Rice Cultivation

- **Drops in temperature during the key stages of rice's growth can damage production output**
- For example, during the seedling stage, temperatures below 10–15 °C inhibit the establishment of seedlings and cause seedlings to rot; during the reproductive stage, temperatures below 18–19 °C can cause sterility
- **Cold-tolerant varieties** are keenly sought after in temperate areas to **boost yields** and, in some cases, to allow farmers in the region to grow a **second crop**

Climate Distribution and Rice Cultivation

- Cold-tolerant varieties are required not only in areas of high latitude, but also in the **subtropics** and **tropical** areas have zones of **high altitude** where rice cultivation also needs to endure cold temperatures

Map 2. High-altitude areas in the tropics.

Climate Distribution and Rice Cultivation

- The highland plateau has high potential for rice production but its temperate climate means that cold tolerant varieties are required before this area can be considered for widespread rice cultivation

Flood and Drought

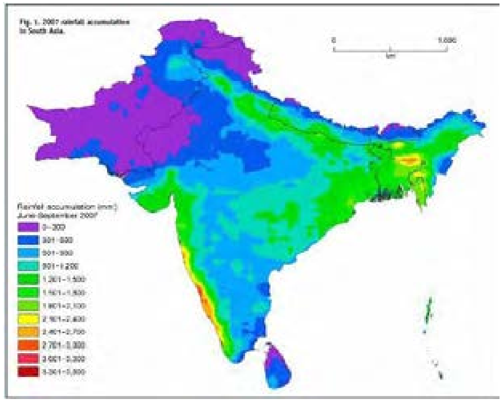
- Water is essential in rice farming and its control in rice fields helps farmers attain high yield
- Drought leaves them with little water, while storms ravage their crops
- During the monsoon season, South Asia regularly experiences widespread floods
- In 2007, ADB reported that floods damaged 13.3 million hectares of crop area in Bihar, India, and 130,000 hectares of arable land in Nepal, and took away 25% of the potential wet-season crop area in Bangladesh

Flood and Drought

- NASA (USA) in collaboration with JAXA (Japan) launched on 27 November 1997 the Tropical Rainfall Measuring Mission (TRMM) satellite that gives researchers and scientists access to near-real-time rainfall information on a global scale
- TRMM products are available in image and ASCII formats
- It can be downloaded for free from NASA's Web site using TOVAS
- The satellite observations are complemented by ground radar and rain-gauge measurements to validate the satellite rain estimation techniques

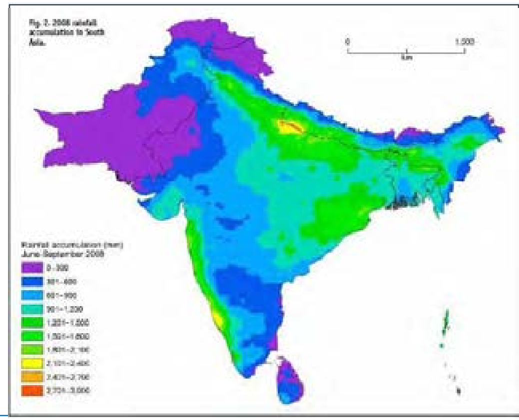
Flood and Drought

- TRMM accumulated rainfall (mm) images were captured during the monsoon season (June-September) in South Asia



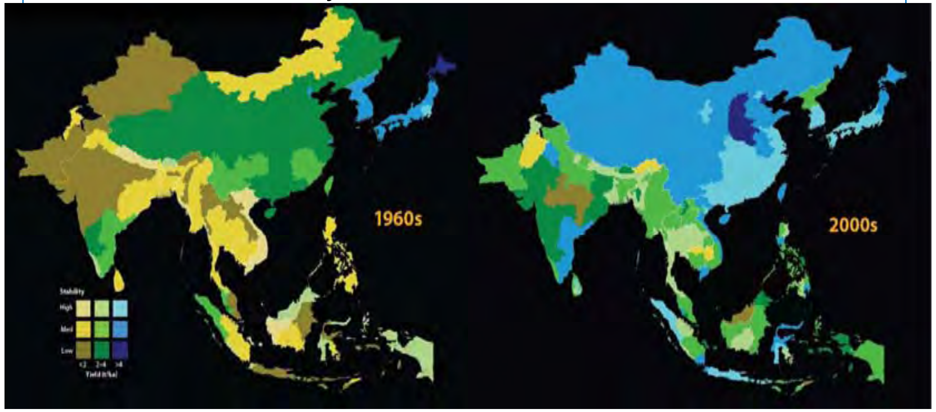
Flood... And So Drought

- In 2008, an excessive amount of accumulated rainfall was recorded in the northern part of India



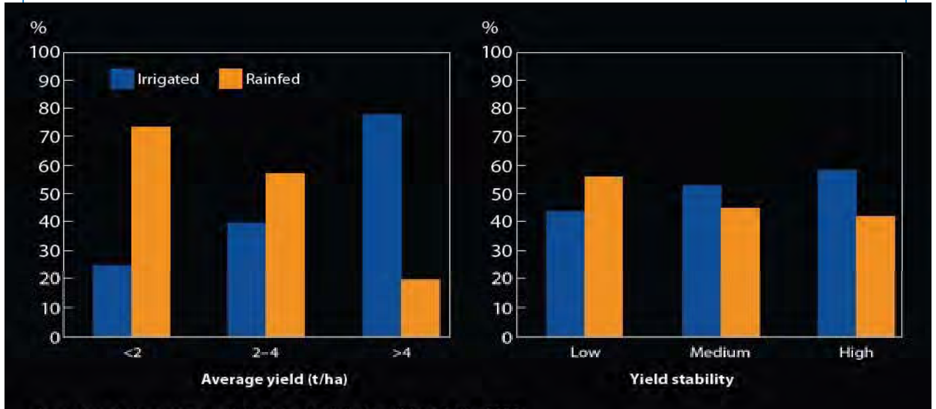
Rice yield trends in Asia over the past 50 years

- For the past 50 years, rice yield in Asia has generally increased from year to year
- However, when we look at stability, the numbers reflect variations in annual yield



Rice yield trends in Asia over the past 50 years

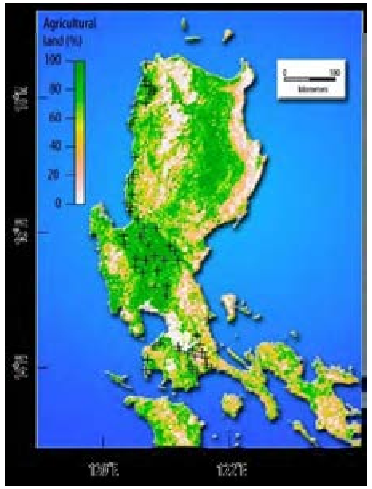
- Cultivation under rainfed vs. irrigated conditions



Percentage of rice area under irrigated and rainfed conditions in the 2000s.

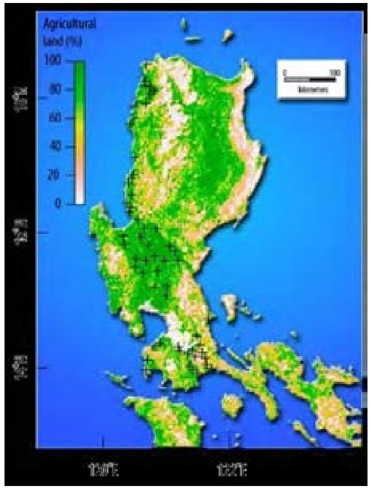
Ecosystem services for biological control in tropical rice

- **Rice is produced in landscapes that range from extreme monocultures to highly diverse areas**
- **Tropical rice fields often have a great diversity of naturally occurring arthropod groups that function as predators and parasitoids**
- **At least 200 species of parasitoids and 150 species of predators live in this environment**
- **Their diversity and abundance are the key indicators of the degree of biological control services present in an ecosystem, such as resisting pest invasion and regulating pests**



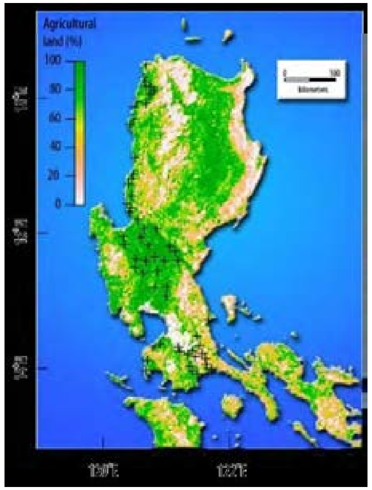
Ecosystem services for biological control in tropical rice

- **Since rice is grown in seasons, and so does not provide a permanent habitat for pests, most of them come and infest fields when rice is planted**
- **They multiply their population rather quickly. Their natural enemies, however, tend to prevent their exponential growth**
- **When rice is harvested, these natural enemies take refuge in other habitats surrounding the rice fields**
- **But, as soon as a new crop is established, they too swarm the fields again**
- **Generalist predators, however, such as spiders and crickets, are less mobile**



Ecosystem services for biological control in tropical rice

- **Based on the above-mentioned, factors such as landscape structure, habitat diversity, cropping patterns, and farmers' crop management practices can greatly affect these groups and the services they provide**
- **These relationships are often scarcely studied and quantified.**



Rice Cultivation

Rice production can generally be divided into the following stages:

- Seed selection
- Land preparation
- Crop establishment
- Water management
- Nutrient management
- Pest management
- Harvesting
- Postharvest

GHG Emissions and Cultivation Practices

- Estimation of the Emission

EQUATION 5.1
CH_4 EMISSIONS FROM RICE CULTIVATION

$$CH_{4\ Rice} = \sum_{i,j,k} (EF_{i,j,k} \bullet t_{i,j,k} \bullet A_{i,j,k} \bullet 10^{-6})$$

Where:

$CH_{4\ Rice}$ = annual methane emissions from rice cultivation, Gg CH_4 yr^{-1}

EF_{ijk} = a daily emission factor for *i*, *j*, and *k* conditions, kg CH_4 ha^{-1} day^{-1}

t_{ijk} = cultivation period of rice for *i*, *j*, and *k* conditions, day

A_{ijk} = annual harvested area of rice for *i*, *j*, and *k* conditions, ha yr^{-1}

i, *j*, and *k* = represent different ecosystems, water regimes, type and amount of organic amendments, and other conditions under which CH_4 emissions from rice may vary

GHG Emissions and Cultivation Practices

- Estimation of the Emission

EQUATION 5.2
ADJUSTED DAILY EMISSION FACTOR

$$EF_i = EF_c \bullet SF_w \bullet SF_p \bullet SF_o \bullet SF_{s,r}$$

Where:

EF_i = adjusted daily emission factor for a particular harvested area

EF_c = baseline emission factor for continuously flooded fields without organic amendments

SF_w = scaling factor to account for the differences in water regime during the cultivation period (from Table 5.12)

SF_p = scaling factor to account for the differences in water regime in the pre-season before the cultivation period (from Table 5.13)

SF_o = scaling factor should vary for both type and amount of organic amendment applied (from Equation 5.3 and Table 5.14)

$SF_{s,r}$ = scaling factor for soil type, rice cultivar, etc., if available

GHG Emissions from Rice Cultivation

Country	$MtCO_2e$ 1990	1995	2000	2005	2010	2015	2020	New Projections 2025	2030
Albania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Algeria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Argentina	0.3	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.1
Armenia									
Australia	0.5	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Austria									
Azerbaijan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bangladesh	16.1	15.4	16.5	18.3	20.0	21.7	23.4	25.1	26.8
Belarus									
Belgium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bolivia	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Brazil	5.0	6.0	5.1	5.4	5.7	5.9	6.2	6.5	6.7
Bulgaria	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cambodia	3.1	3.2	3.3	3.7	4.2	4.7	5.1	5.5	6.0
Canada									
Chile	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
China	237.3	220.2	215.9	223.9	231.1	237.5	242.1	248.7	255.2
Colombia	3.5	3.0	3.3	3.6	3.8	4.1	4.3	4.6	4.8
Croatia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Czech Republic									
Democratic Republic of Congo (Kinshasa)	2.5	3.0	2.3	2.6	3.0	3.5	3.9	4.4	4.8
Denmark	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ecuador	2.2	3.2	3.1	3.4	3.6	3.8	4.0	4.2	4.5
Egypt	4.0	5.4	6.0	6.7	7.4	8.0	8.6	9.3	9.9
Estonia									
Ethiopia									
Finland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
France	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Georgia									
Germany									
Greece	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Hungary	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Iceland									
India	85.7	85.9	89.5	96.5	103.3	109.7	115.5	120.9	126.3
Indonesia	41.2	47.9	48.3	51.4	54.4	57.1	59.5	62.4	65.2
Iran	2.2	2.4	2.6	2.6	2.7	2.8	2.8	2.9	3.0
Iraq	0.5	1.0	0.8	0.9	1.0	1.1	1.2	1.4	1.5
Ireland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Israel									
Italy	1.5	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Japan	7.1	7.2	6.0	6.2	6.4	6.6	6.8	7.0	7.1
Jordan									

GHG Emissions from Rice Cultivation

Country	$MtCO_2e$ 1990	1995	2000	2005	2010	2015	2020	New Projections 2025	2030
Kazakhstan	1.2	1.4	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Kuwait									
Kyrgyzstan	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Laos	3.3	2.8	3.5	3.9	4.3	4.8	5.2	5.7	6.2
Latvia									
Liechtenstein									
Lithuania									
Luxembourg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Macedonia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mexico	0.4	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.5
Moldova									
Mongolia									
Myanmar	27.9	35.3	35.2	37.5	39.5	41.2	42.8	45.0	47.1
Nepal	5.9	6.4	6.9	7.4	7.9	8.1	8.3	8.7	9.1
Netherlands									
New Zealand									
Nigeria	15.3	22.8	26.2	29.7	33.3	36.9	40.4	44.3	48.3
North Korea	3.0	2.7	2.5	2.6	2.6	2.6	2.7	2.8	2.8
Norway									
Pakistan	4.6	4.7	5.0	5.6	6.4	7.2	8.0	8.7	9.5
Peru	1.1	1.2	1.7	1.8	2.0	2.1	2.2	2.4	2.5
Philippines	12.6	14.3	15.3	16.8	18.2	19.5	20.8	22.1	23.5
Poland									
Portugal	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Romania	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Russian Federation	2.4	1.4	1.5	1.4	1.4	1.3	1.3	1.2	1.2
Saudi Arabia									
Senegal	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3
Singapore									
Slovak Republic									
Slovenia									
South Africa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South Korea	8.6	7.3	7.2	7.4	7.6	7.6	7.7	7.8	7.9
Spain	0.2	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Sweden									
Switzerland									
Tajikistan	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Thailand	42.8	44.3	45.3	45.7	46.2	46.6	47.1	47.8	48.4
Turkey	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5
Turkmenistan	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Uganda	0.5	0.7	0.9	1.1	1.3	1.5	1.8	2.0	2.2
Ukraine	0.4	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
United Arab Emirates									
United Kingdom									
United States	7.1	7.6	7.5	7.6	6.8	6.9	6.9	6.8	6.7

GHG Emissions from Rice Cultivation

Country	$MtCO_2e$ 1990	1995	2000	2005	2010	2015	2020	New Projections 2025	2030
Uruguay	1.5	2.7	3.4	3.6	3.7	3.8	3.9	4.0	4.1
Uzbekistan	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Venezuela	0.5	0.7	0.6	0.7	0.7	0.8	0.8	0.9	1.0
Viet Nam	29.2	32.8	37.1	39.6	42.3	44.9	47.5	50.5	53.5
Rest of Africa	7.3	11.7	13.8	15.9	18.2	20.8	23.6	26.1	28.7
Rest of Latin America	2.3	2.4	2.6	2.8	2.9	3.1	3.2	3.4	3.5
Rest of Middle East	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rest of Non-EU Eastern Europe									
Rest of OECD90 & EU									
Rest of SE Asia	8.5	8.2	8.0	8.9	9.7	10.4	11.1	11.9	12.7
Global	**601**	**621**	**634**	**672**	**708**	**744**	**776**	**812**	**848**
E. Europe	3	2	2	2	2	2	2	2	2
W. Europe	2	2	2	2	2	2	2	2	2
CWANA	8	11	11	12	13	14	15	15	16
SSE Asia	530	531	539	569	597	624	647	674	700
L. America	17	21	21	23	24	25	26	28	29
SS Africa	26	38	43	49	56	63	70	77	84
Other developed	15	15	14	15	14	14	14	14	15
World Totals	**601**	**621**	**634**	**672**	**708**	**744**	**776**	**812**	**848**

GHG Emissions and Cultivation Practices

- Climate Change = Change in Temperature and Precipitation ➔ Farmers will need to adapt
- Rice Production System = Source of greenhouse gases and a Potential Sink for atmospheric carbon ➔ Rice cultivation=Mitigation

Further Steps…

- In this WS, we will discuss on the followings
  - National cultivation practice
  - Observed impacts of climate change
  - Potential mitigation options
  - Possible adaptation

Country report on rice cultivation practice: Cambodia

Dr Seng Vang, CARDI

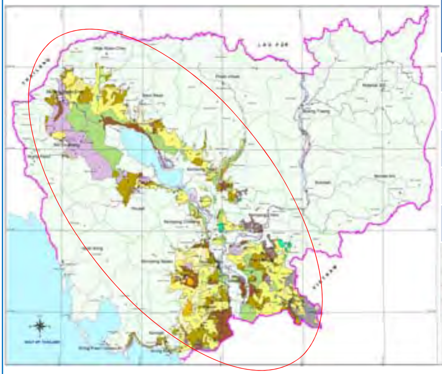
Expert Meeting
2-3 June 2011
Bangkok, Thailand

Outline

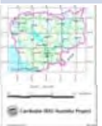
- General Information
- Rice Variety
- Ecosystem
- Rice cultivation practice
- Management of Rice Residues
- Rotation Crops
- Soil Organic Carbon
- Socio-economic Status of Rice Farmer

General Information

Current status of rice production in Cambodia



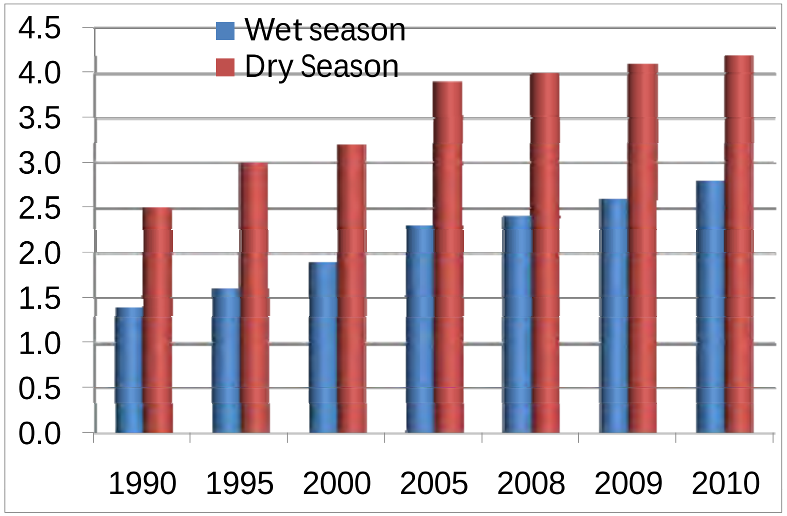
	2010	Relative to 2009 (%)
Cultivated area (mil ha)	2.80	↑2.82
Harvested area (mil ha)	2.78	↑3.84
Average yield (t/ha)	2.97	↑4.74
Total production (mil t)	8.25	↑8.75
Paddy surplus (mil t)	3.93	↑12



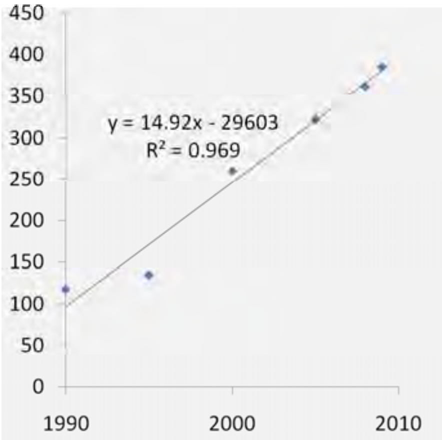
Data source: MAFF (2011)

Map of the main rice-growing areas in Cambodia

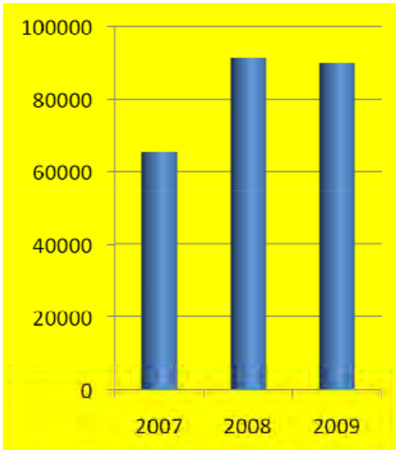
Average rice yield (t/ha) in wet season and dry season



Trends of cultivated area for dry season (‘000 ha) and early wet season (ha) rice

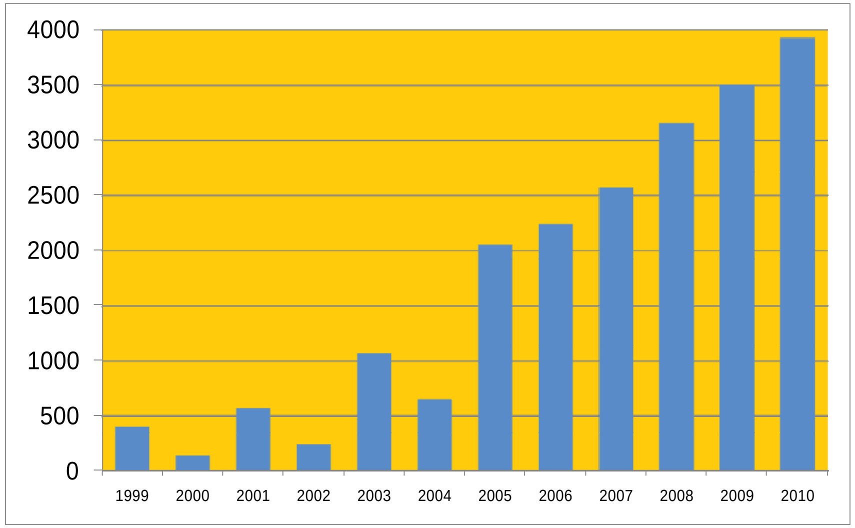


Dry season rice

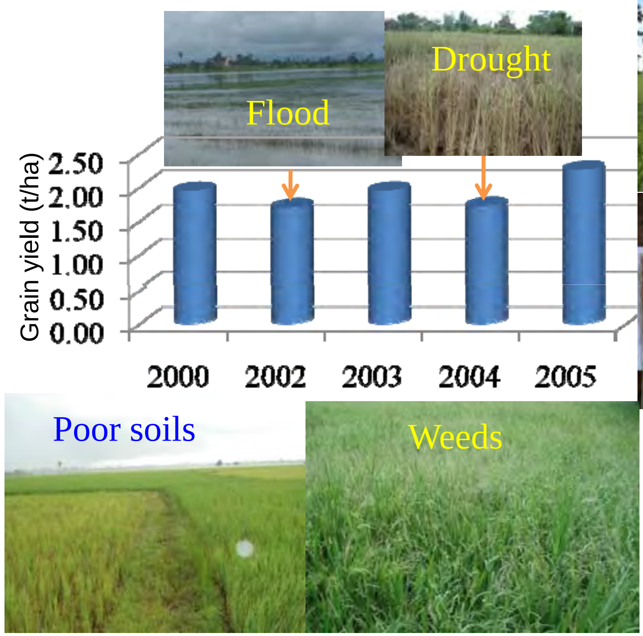


Early wet season rice

Surplus of paddy rice: 1999-2010 (‘000 t)



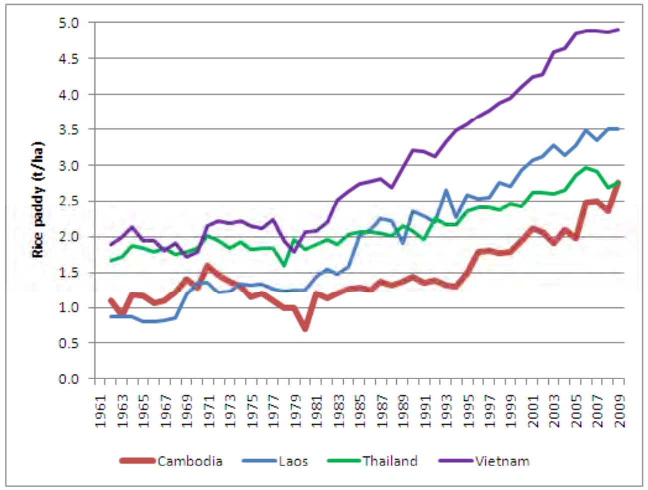
Why variable productions?



Rats, birds, BPH, leaf caterpillars, stem borers

Bacterial leaf blight and streak, brown spot

Cambodia’s rice yield compared to neighbouring countries



Rice Variety

9

Crop Variety Released: Rice=38 varieties

Rainfed lowland and Irrigated	:	33
Early duration	:	9
Medium duration insensitive	:	5
Medium duration sensitive	:	6
Medium duration aromatic	:	5
Long duration sensitive	:	8
Upland	:	2
Deepwater	:	3

Rice varieties tolerant to environmental stresses

Tolerant to 10-12 days submergence:
CAR9, Phka Romduol and Phka Romdeng

Tolerant to 7-10 days submergence:
CAR6, Phka Romchek and Phka Romeat

Tolerant to moderate drought:
CAR3 and CAR4

Moderate resistant to BPH:
IRKesar, Kru, Chul'sa and CAR12

Resistance to stripe stem borer:
Kru, IR72, Sen Pidao and IR66

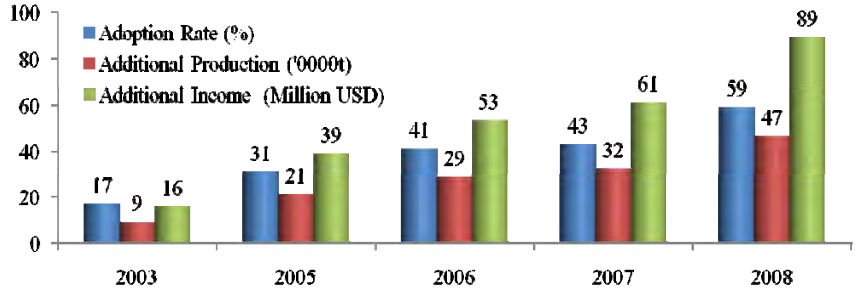
Ten Rice Varieties Promoted by the RGC from 2011

Early maturity
1. Sen Pidao
2. Chul'sa
3. IR66

Intermediate maturity
1. Phka Rumdoul
2. Phka Romeat
3. Phka Romdeng
4. Phka Chan Sen Sar

Late maturity
1. Riang Chey
2. CAR4
3. CAR6

Impact of Rice Variety Improvement



Rice Genebank at CARDI

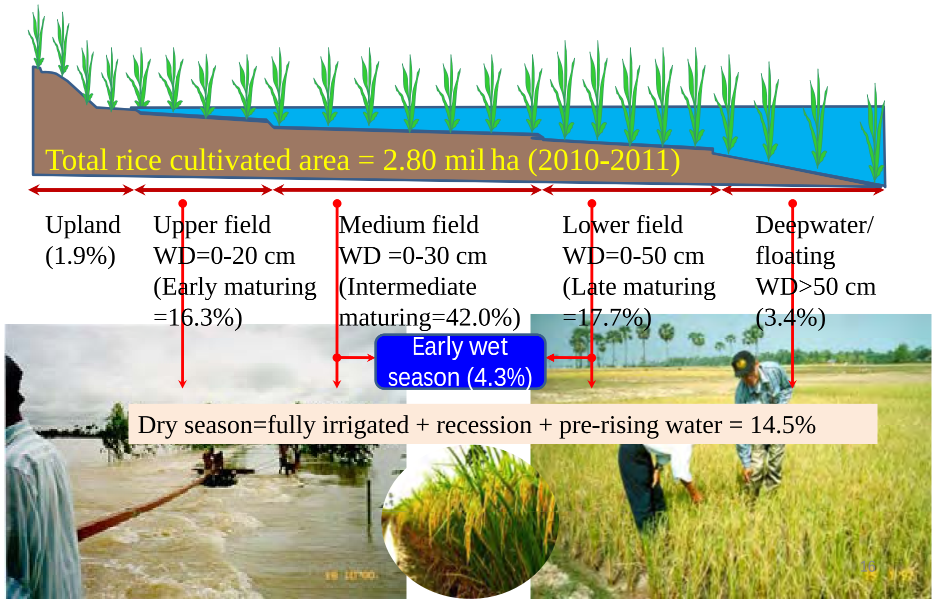
Accession: 2557
(in 3 catalogues)

Rainfed Lowland : 88.0%
Irrigated : 0.2%
Deepwater/Floating: 1.2%
Upland : 10.6%
Mild Aromatic : 10.0%
Strong Aromatic : 0.2%
Glutinous : 8.4%
Insensitive : 7.0%
Mild sensitive : 4.5%
Moderate sensitive: 30.7%
Strong sensitive : 60.1%

Ecosystems

Rainfed Lowland: 80.2%
Upland: 1.9%
Deepwater/Floating: 3.4%
Dry Season: 14.5%
(Data as of 2010)

Rice Ecosystems and Proportion in 2010-2011



Relative occurrence (as percentage of total area) of the main rainfed lowland rice sub-ecosystems in Cambodia compared to neighbouring countries

Country	Shallow (0–25 cm) and prone to:				Medium To Deep	Total Area
	No water stress	Drought	Drought + submerg.	Submerg-ence	(25–50 cm)	('000 ha)
Laos	33	33	33	0	0	277
Cambodia	**10**	**29**	**57**	**0**	**5**	**747**
Thailand	9	52	24	12	3	6,039
Total	20	36	15	16	13	35,907

Source: Bell and Seng (2001)

Rice Cultivation Practices

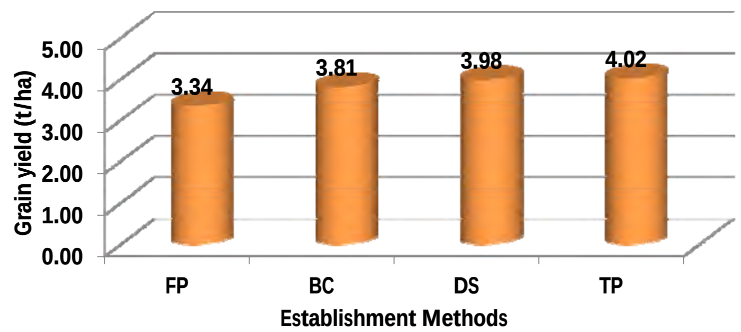
Ecosystem	Establishment practice	Notes
Rainfed lowlands	Transplanting with 2-3 seedlings/hill, 25-30 days olds , random spacing 20x20 cm. Some areas broadcast at very high rate 100-150 kg/ha. Land preparation: plowed twice, followed by harrow, generally by animals.	Tendency toward changes to more mechanization (land preparation, and harvesting). Unleveled fields are common.
Dry season/ Irrigated	Mostly broadcasting with very high seeding rate 200-250 kg/ha. Some farmers practice SRI technique in a small field (1 seedling/ hill, 10 days old, wider hill spacing).	More mechanization, Unleveled fields are less common.
Uplands	Direct seeding	Shifting toward field crops.
Deepwater	Broadcasting	Shifting toward recession rice.

Recommended rate of nutrients for rainfed lowland rice based on soil types

Soil types	Recommended rate of nutrients (kg/ha)		
	N	P	K
Prey Khmer (Psamments)	**28**	**4**	**33**
Prateah Lang (Plinthustalfs)	**50**	**10**	**25**
Bakan (Alfisol/Ultisol)	**75**	**13**	**25**
Koktrap (Kandic Plinthaquult)	**73**	**15**	**25**
Toul Samroung (Vertisol/Alfisol)	**98**	**15**	**0**
Krakor (Entisol/Inceptisol)	**120**	**11**	**0**

Source: Seng et al. (2001)

Grain yield of rice, cv. Sen Pidoa grown by various methods. Plotted values are mean of 2 sites x 3 replicates.



FP: farmer practice (BC 60 kg/ha, no weeding)
BC: broadcasting (60 kg/ha)
DS: drum seeder (60 kg/ha)
TP: transplanting (2-3 seedlings/hill, 20 days, 20x20cm)

Response of rice, cv. Phka Rumduol to NPK addition. Data are mean of 3 years x 4 replicates (CARDI 113 Project).

N timing	Total NPK (kg/ha)	Grain yield (kg/ha)	GY Increase compared to control (%)	Profit (USD/ha)
Control	0	2126	0	547
3 splits (BS, TL, PI)	183	3657	72	809
Briquette (BS)	196	3475	63	776
Delayed (15, 30, 70 ATP)	183	3365	58	735
Delayed (30, 70 ATP)	184	3523	66	778
LCC	331	3999	88	826
lsd (5%)		*268***		

Drought escape approach

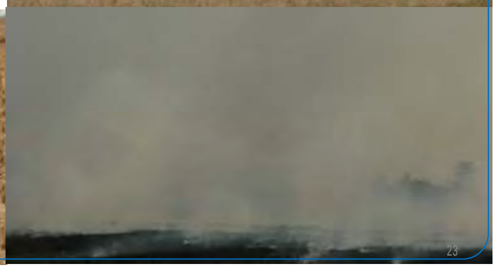
Sowing	Sowing Period	Farmer's variety	Released variety
Delay sowing	Late July-Early Aug	2.37 t/ha	3.62 t/ha
Delay in flowering		7-14 days	

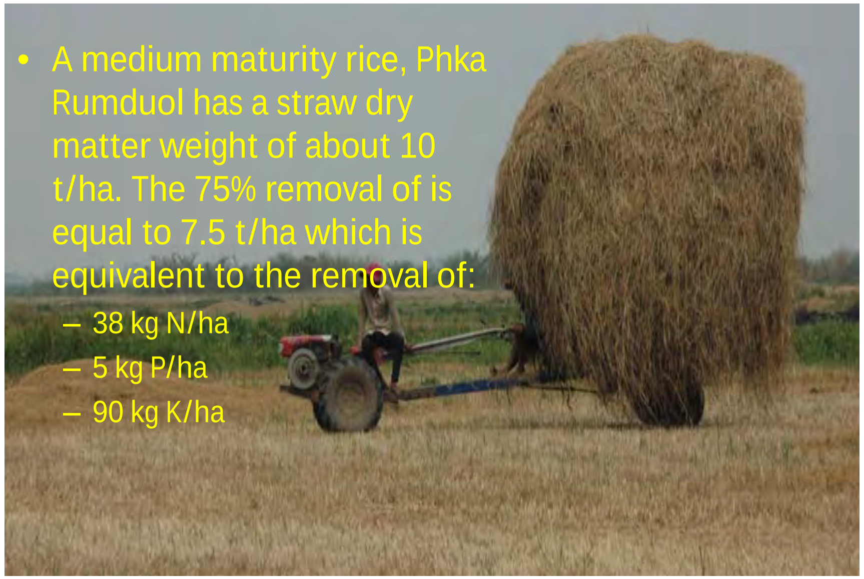
		Farmer's variety	Released var., CAR3
Mild drought tolerant	3rd week of June		
Grain yield (t/ha)		2.00	3.31
Additional gross margin		US$ 225/ha	

Management of Rice Residues

Common practices include:

- Straw removal for animal feed (60-75% of the above-ground biomass removed).
- Straw burned (Commonly in intensive dry season rice cropping).





- A medium maturity rice, Phka Rumduol has a straw dry matter weight of about 10 t/ha. The 75% removal of is equal to 7.5 t/ha which is equivalent to the removal of:
  - 38 kg N/ha
  - 5 kg P/ha
  - 90 kg K/ha

Rotation Crops

- Post-rice legumes (Mungbean, peanut)
- Rice-maize system
- Rice-water melon

Four mungbean varieties have been released:
1. **CARDI Chey**
2. **CMB01**
3. **CMB02**
4. **CMB03**


The effect of furrow irrigation frequency on grain yield and water use efficiency (WUE) of mungbean and peanut grown after WS rice (ACIAR-07 Project)

Irrigation Frequencies	Water use (mm)	Grain yield (kg/ha)	WUE (kg/ha/mm)
Mungbean			
Every 3 days	250	985	3.94
Every 6 days	216	1044	4.84
Every 9 days	177	686	3.87
Mean	*216*	*899*	*4.16*
lsd (5%)	**	168**	0.75*
Peanut			
Every 3 days	285	720	2.52
Every 6 days	244	812	3.33
Every 9 days	211	649	3.08
Mean	*249*	*749*	*3.01*
lsd (5%)	**	114*	0.48**

Soil Organic Carbon

Properties of major rice soils in the lowlands

Soil Groups (Local name)	Landscape	Area	Sand	Silt	Clay	pH	Organic C	Total N	Olsen P	Exchangeable Cations (cmol/kg)			
		(%)	(%)			(1:1 H_2O)	(g/kg)	(g/kg)	(mg/kg)	K	Na	Ca	CEC
Prateah Lang	Old colluvial/ alluvial	28	50	37	13	4.0	**2.9**	0.3	0.4	0.08	0.55	1.20	3.71
Krakor and Kbal Po	Active floodplain	28	18	34	48	5.9	**9.1**	1.0	4.6	0.24	0.62	6.68	15.1
Bakan	Old colluvial/ alluvial	13	35	49	16	5.8	**6.6**	0.6	1.0	0.09	0.51	1.75	4.84
Prey Khmer	Old colluvial/ alluvial	11	73	22	5	5.6	**4.7**	0.5	1.3	0.04	0.05	0.61	1.45
Toul Samroung	Old colluvial/ alluvial	10	28	29	42	5.5	**8.8**	0.9	3.1	0.17	0.29	7.10	16.0
Koktrap	Old colluvial/ alluvial	5	36	41	23	4.0	**10.9**	1.1	2.6	0.10	0.25	1.13	8.09

Classification of N, P, and organic C of soil samples in the Cambodian Soil Database developed by CARDI

Soil properties	Classifications#				
	VL	L	M	H	VH
Total N (%)	<0.05	0.05-.15	0.15-0.25	0.25-.50	>0.50
% of soils in class	63	34	3		
Olsen P (mg/kg)		0-7	7-15	>15	
% of soils in class		88	5	7	
Org C (%)	**<0.06**	**0.06-1.00**	**1.00-1.80**	**1.80-3.00**	**>3.00**
% of soils in class	**1**	**86**	**11**	**2**	

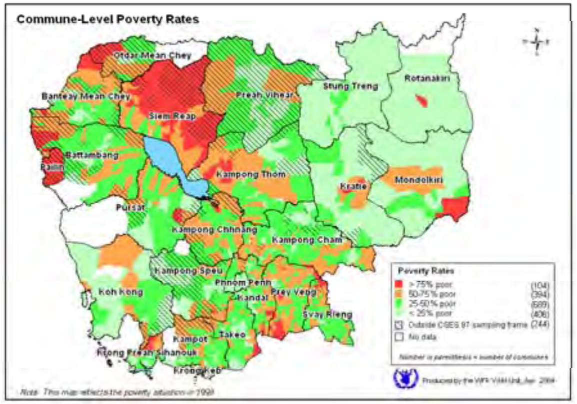
VL-very low, L – low, M – medium, H – high, VH – very high

Fertilizer effect on soil organic C and other soil qualities

Time	SNMS	pH (1:5, Soil:H_2O)	Organic C (%)	Total N (%)	Olsen P (mg/kg)	Exch. K (cmol+/kg)
Before experiment	O	5.03	0.30	0.03	1.74	0.06
	I	5.08	0.31	0.03	1.47	0.10
	OI	5.00	0.25	0.03	1.34	0.16
After 6 crops	O	5.42	0.34	0.04	1.34	0.14
	I	5.72	0.37	0.03	1.48	0.17
	OI	5.67	0.34	0.03	5.39	0.19
Changes	O	0.39	0.04	0.01	-0.40	0.08
	I	0.64	0.06	0.00	0.00	0.06
	OI	0.67	0.09	0.00	4.05	0.03
Interpretation		*Strongly to moderately acidic*	*Extremely low*	*Very low*	*Very low*	*Low to very low*

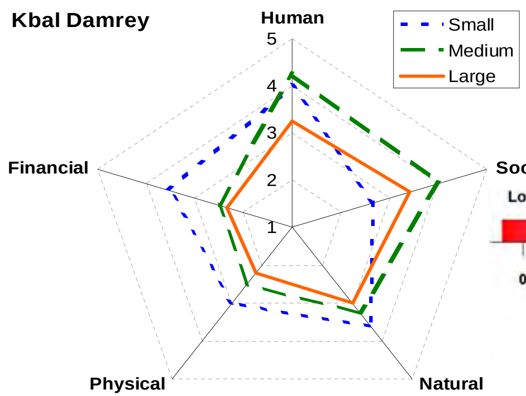
After 6 crops, soil organic C increased by 0.04-0.09%, but levels remained relatively
Seng et al. (2010).

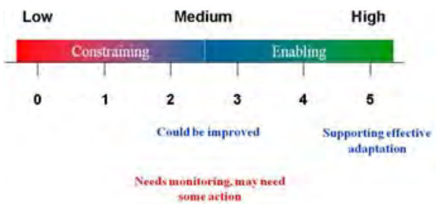
Socio-economic Status of Rice Farmer



Tendency toward shifting from subsistence-oriented to commercial oriented production with improved enabling environments:
-rice export policy,
-contract farming,
-rice mills (large scale),
-seed suppliers, and
-marketing and market information access.

Self assessment of capital assets using **SRL** framework for 3 farmer groups in Svay Rieng province (ACIAR LWR-19)





Opportunities to increase rice yields

- Science-based 'cropcheck' extension programs
- Focus on increasing water-use efficiency
- Breeding for drought tolerance/quick maturity
- Crop and whole-farm diversification
- Direct seeding crops before/after rice
- Adoption of land-leveling
- Supplementary irrigation
- Better management of livestock

Thank you,...

CEE-PERDO Center for Energy Technology and Environment · APN · JGSEE The Joint Graduate School of Energy and Environment

Country report on rice cultivation practice: **Indonesia**

Iman Rusmana
Bogor Agricultural University

Expert Meeting
2-3 June 2011
Bangkok, Thailand

INDONESIA

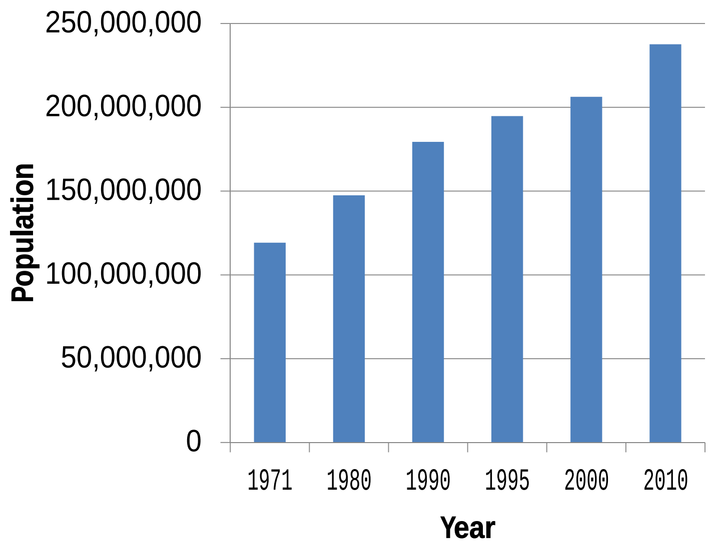
Population : 230 mill, 4th in the world
17.300 islands

Java : 60 % of population,
60 % of food production
13 % of land

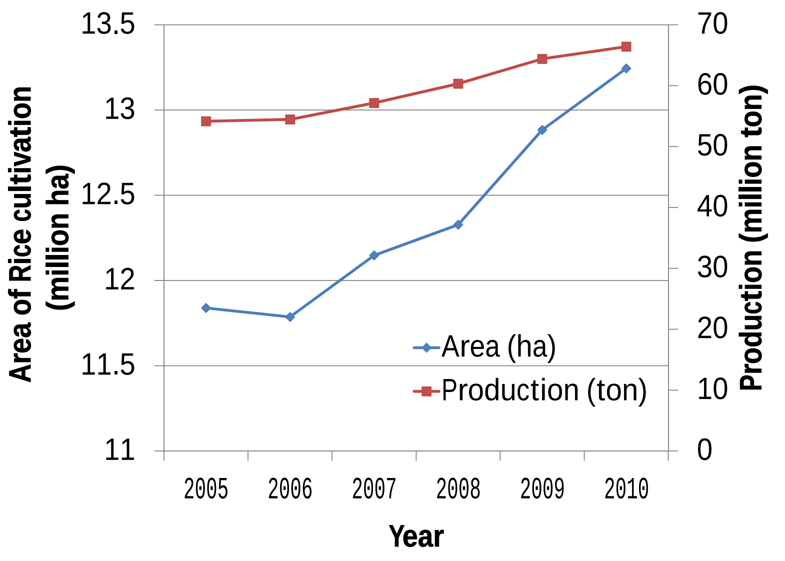
General Information

Figure of Indonesia

- Population : 230 million
- Pop growth rate : 1.35%/year
- Total land area : 190 million ha
- Agriculture sector in Indonesia
  - Provides job opportunities to 20 million households
  - Contributes 66% to GDP
  - Rice productivity : 5.01 ton/ha
  - Rice consumption : 137 kg/cap/year



Area of Rice Cultivation and Production in 2005-2010



Rice Variety

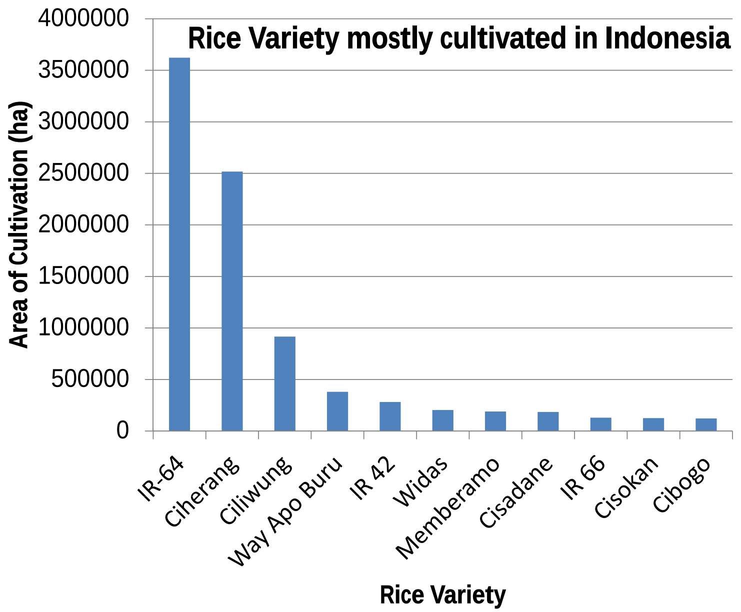
Form 1943 up to 2007:

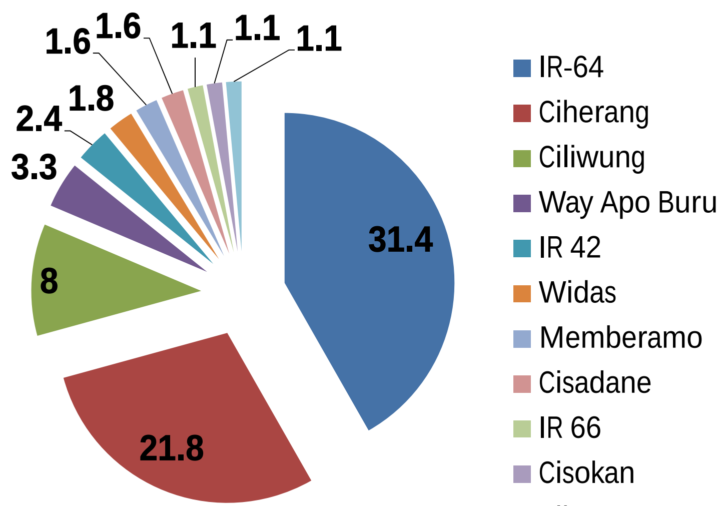
→ 190 rice varieties of wetland were released

→ 30 rice varieties of dryland were released

Mostly cultivated:

IR-64	**Ciherang**	**Ciliwung**
Way Apo Buru	IR 42	Widas
Memberamo	Cisadane	IR 66
Cisokan	Cibogo	



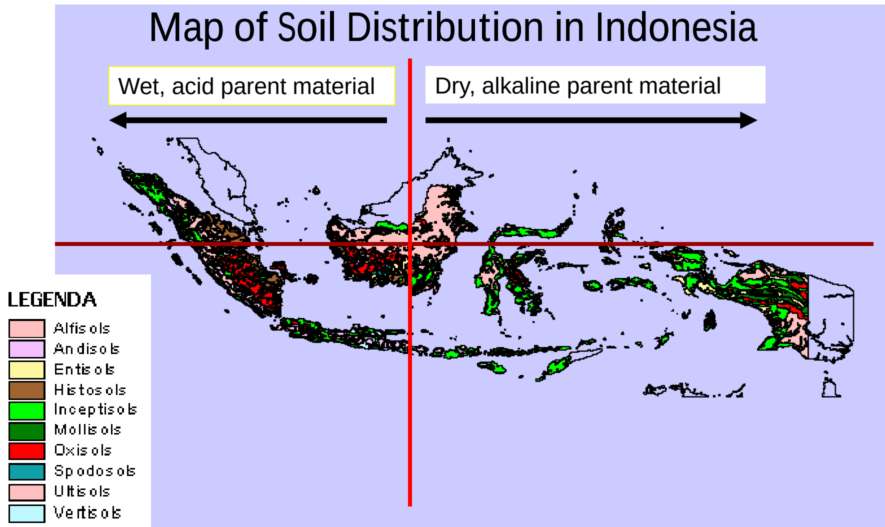


Percentage of Rice Variety Cultivated in Indonesia

Methane emission and rice productivity of several rice varieties

Ekosistem/varietas	Emisi CH_4 (kg/ha)	Hasil (t/ha)
Lahan sawah irigasi dan sawah tadah hujan[1]		
Dodokan	74	3,3
Tukad Balian	115	5,1
Maros	117	4,3
Cisantana	124	5,4
Muncul	127	4,6
Way Apoburu	154	7,4
Memberamo	173	7,4
Ciherang	175	5,8
IR64	176	6,7
Tukad Unda	185	5,3
Batang Anai*	196	4,5
Cisadane	218	6,4
IR36	112	4,9
Lahan sawah pasang surut[2]		
Martapura	171	5,99
Sei Lalan	153	6,75
Indragiri	141	6,03
Punggur	105	5,65

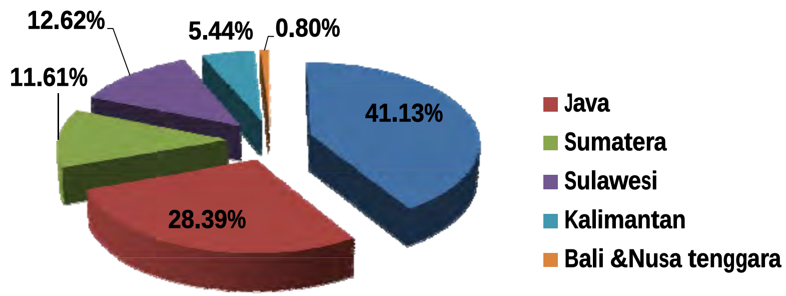
Rice Cultivation Practices



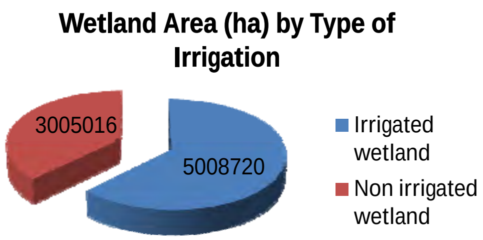
Distribution of rice soils in Indonesia

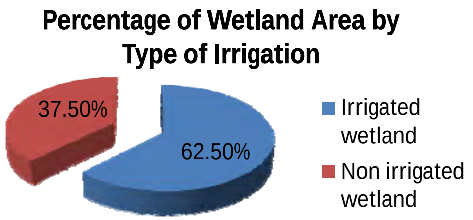
No.	Ecosystem / rice soil types	distribution
A	Lowland	55%
	Aquept, Aquent (Alluvial and Gley soil)	
B	Highland	17%
	Udept (Latosols and Regosols)	
C	Complex (Combination between A and B)	
1	Vertisols (Grumusols) (Sub ordo Aquert, udert, and ustert)	7%
2	Ultisols and Oxisols (Red yellowish podsolic)	6%
	(Sub ordo: Aquult and Paleudult, Aquox and Kandiudox)	
3	Alfisols (Red yellowish Mediteranean)	4%
	Sub ordo udand, ustand, and aquand	
4	Newly opened rice field: Ultisols (red yellowish podsolic)	10%
5	Newlye opened rice field: Oxisols	1%
	(Latosol, lateritic)	
	Total	100%

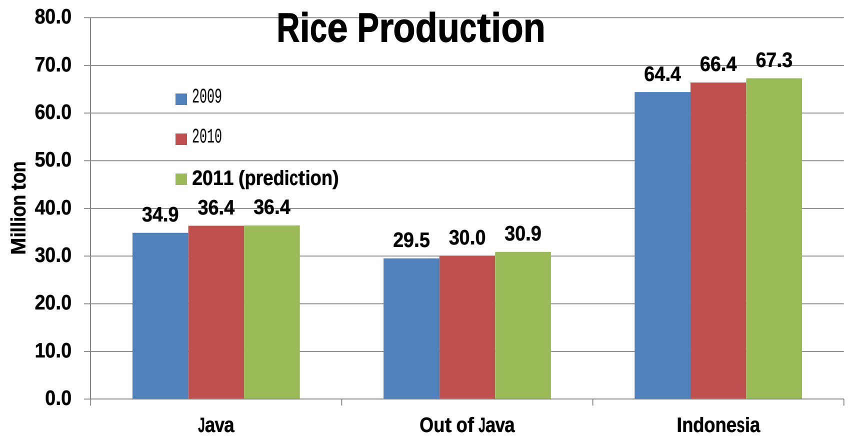
Wetland Distribution by Island



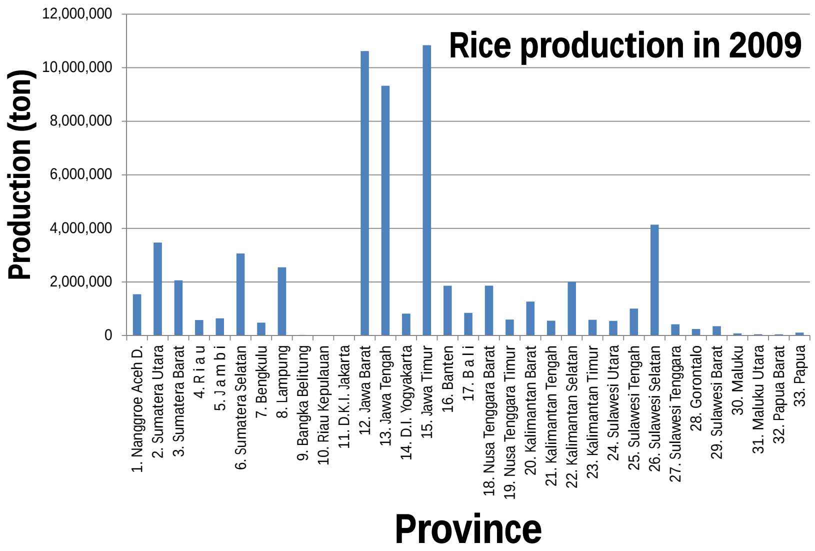
Total area of wetland in Indonesia in 2008 was 8.01 million hectare

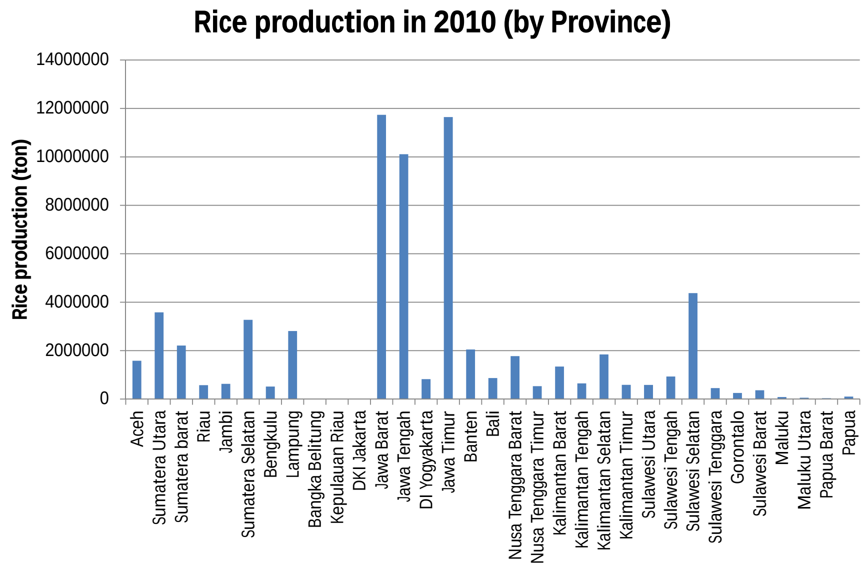


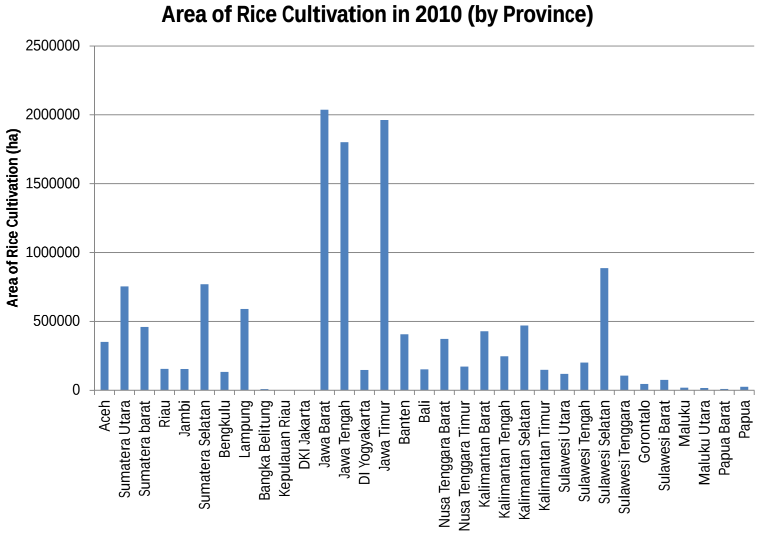




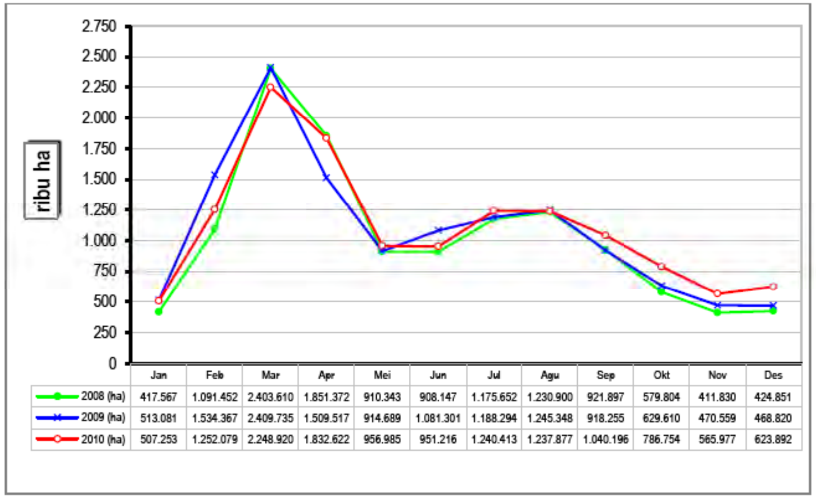
Berita Resmi Statistik No. 18/03/Th. XIV, 1 Maret 2011







Profile of harvest in 2008-2010



	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Agu	Sep	Okt	Nov	Des
2008 (ha)	417.567	1.091.452	2.403.610	1.851.372	910.343	908.147	1.175.652	1.230.900	921.897	579.804	411.830	424.851
2009 (ha)	513.081	1.534.367	2.409.735	1.509.517	914.689	1.081.301	1.188.294	1.245.348	918.255	629.610	470.559	468.820
2010 (ha)	507.253	1.252.079	2.248.920	1.832.622	956.985	951.216	1.240.413	1.237.877	1.040.196	786.754	565.977	623.892

Rice Cultivation Practices

Wetland:

→Flooded wetland is still the dominant of rice production in Indonesia

→SRI (System of Rice Intensification):

→The Agriculture ministry of Indonesia plans to increase the use of the SRI:

- 2011 : 100.000 ha
- 2012 : 200.000 ha
- 2015 : 1,5 million ha

Study of SRI in Indonesia

NATIONAL AVE. 4.8 T/HA

YIELD INCREASES

LOCATION	CONVEN-TIONAL	S.R.I	Reference
	(TONS/HA)		
CENTRAL LOMBOK	-	11.2	Sato (2007)
SUMBAWA	-	14.3	Sato (2007)
GARUT	-	13.5	Sato (2007)
SUKABUMI	-	12.6	Sato (2007)
SUKABUMI, NOSC	**5.38**	**6.85**	Ardi and Iswandi (2008)
S.E.T.C. PANDAAN EAST JAVA	5.5	10.5	Herodian *et al*, (2008)
BOGOR, WEST JAVA	5.0	7.5	Sugiyanta (2008)
PADANG, W. SUMATRA	-	9.67-11.0	Musliar (2007-2008)

S.R.I RICE CULTIVATION AT THREE LOCATIONS IN WEST JAVA

YIELD COMPONENTS

NO. OF TILLERS/HILL

RICE CULTIVATION	TANJUNG SARI	SUKABUMI	DEPOK
CONVENTIONAL	30.30 a	30.30a	17.3a
INORGANIC S.R.I	41.15b	41.15b	26.45c
ORGANIC S.R.I	29.60a	29.60a	20.95b
MIXED	39.40b	39.40b	18.7ab

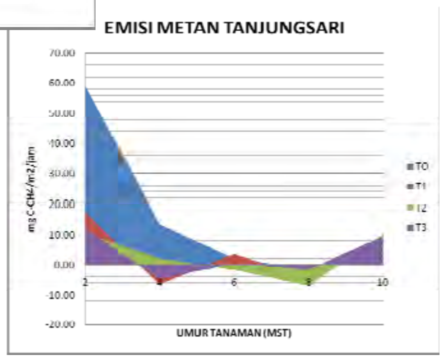
YIELD (TON/HA)

RICE CULTIVATION	TANJUNG SARI	SUKABUMI	DEPOK
CONVENTIONAL	3.59	4.58	
INORGANIC S.R.I	4.35	5.32	
ORGANIC S.R.I	3.55	4.72	
MIXED	3. 96	4.97	

Correlation between SRI and Methane emission

METHANE EMISSION FROM SUKARAJA (SUKABUMI) (Iswandi *et al*. 2009)

TREATMENTS	2 WAT	4 WAT	6 WAT	8 WAT	10 WAT	AVERAGE
	mg C-CH4 m-2 h-1					
T0 =CONVENTIONAL	2021.2	9939.3	-1.95	-5.48	2.49	2391.1
T1=IN-ORGANIC S.RI.I	0.00	0.00	1.00	-3.77	-1.05	-0.76
T2=IN-ORGANIC S.RI.I	0.00	-279.4	5.07	-1.98	0.43	-55.2
T3= MIXED	0.00	1517.3	3.50	1.25	5.82	305.6



S.R.I. REDUCED CH_4 EMISSION FROM RICE FIELD SIGNIFICANTLY

N2O EMISSION SUKABUMI

TREATMENTS	6 WAT	8 WAT	10 WAT
	µg N-N20/m2/h		
T0= CONVENTIONAL	-173.35	158.78	36.06
T1= IN-ORGANIC S.R.I.	4128.40	489.75	42.32
T2 = ORGANIC S.R.I.	-359.20	35.74	-100.84
T3= MIXED	230.13	165.11	10.24

N20 EMISSION AT TANJUNGSARI

TREATMENTS	6 WAT	8 WAT
	µg N-N20/m2/h	
T0=CONVENTIONAL	63.88	423.91
T1=IN-ORGANIC S.R.I.	97.14	1247.84
T2=ORGANIC S.R.I	-509.96	-769.28
T3=MIXED	64.59	359.11

ORGANIC FERTILIZER REDUCED N20 EMISSION

Total microbes and number of beneficial soil microbes under conventional and S.R.I. rice cultivation methods at Tanjung Sari and Bogor (Iswandi *et al.* 2009)

Treatments	Total Microbes* ($x10^5$)	*Azotobacter** ($x10^3$)	*Azospirillum** ($x10^3$)	PSM* ($x10^4$)
Conventional (T0)	2.3a	1.9a	0.9a	3.3a
Inorganic S.R.I (T1)	2.7a	2.2a	1.7ab	4.0a
Organic S.R.I (T2)	3.8b	3.7b	2.8bc	5.9b
Inorganic S.R.I + BF (T3)	4.8c	4..4b	3.3c	6.4b

*CFU/g soil PSM = Phosphate Solubilizing Microbes

N2 fixation and CH4 oxidation activities of methanotrophic bacteria isolated from rice field in West Java

No	Isolate	N_2fixation activity (nM/hour/ml culture)	CH_4 oxidation activity (uM/day/ml culture)
1	BGM1	10,90	39,53
2	BGM3	7,10	56,62
3	BGM5	10,80	75,85
4	BGM9	15,30	59,60

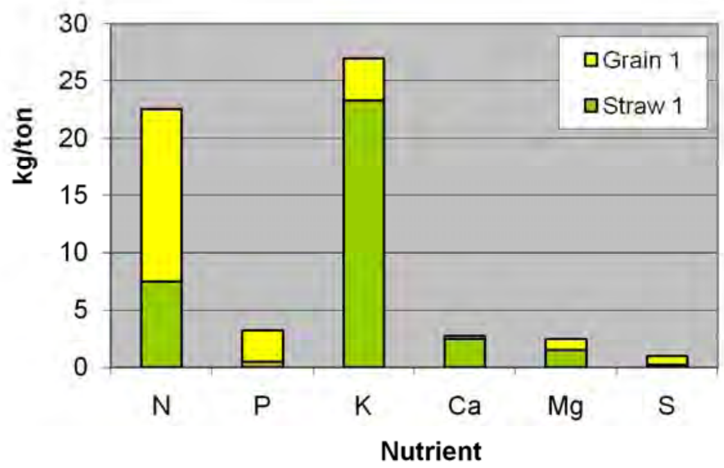
Research in progress: Application of methanotrophic bacteria as biofertilizer in rice cultivation (Conventional, SRI and organic farming)

Management of Rice Residues

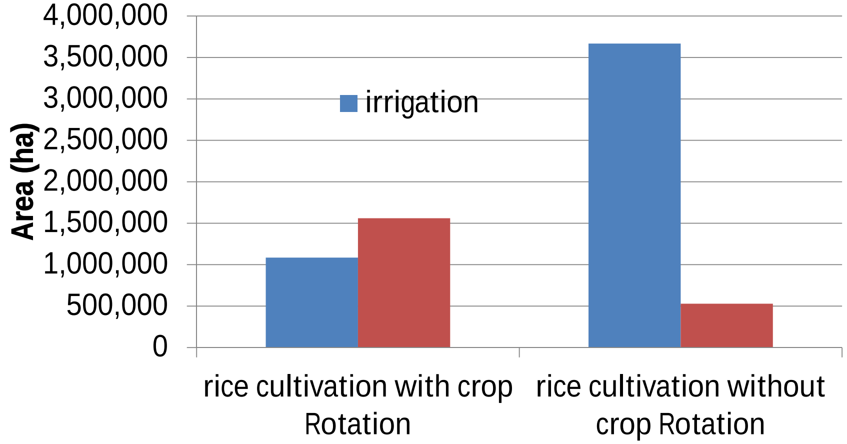
Estimation of biomass production on land use in Indonesia

Land use Types	Area (x1000Ha)	Biomass production (ton dry organic matter ha^{-1} $year^{-1}$	Total biomass production (million ton dry organic matter $year^{-1}$)
Paddy Rice Field	7 517	24	180
Upland crops	9 008	18	162
Estate crops	9 917	36	357
Agro forestry	4 062	10	41
Forest	137 366	23	3 159
Total	167 870		3 899

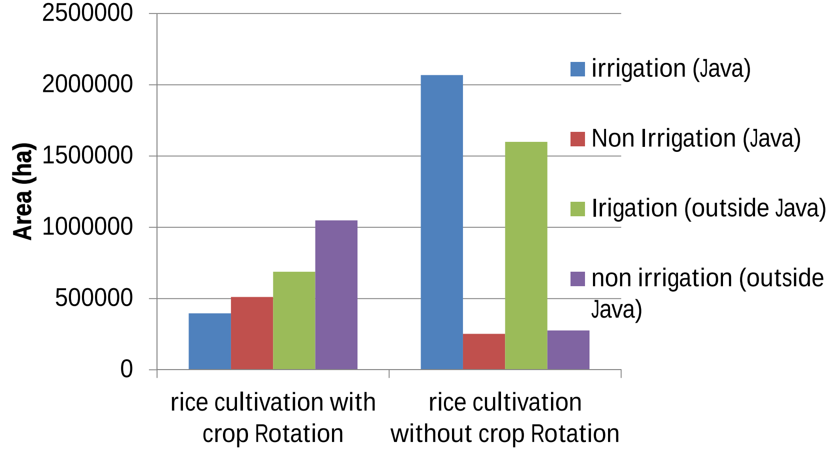
Nutrient content of rice straw and grain



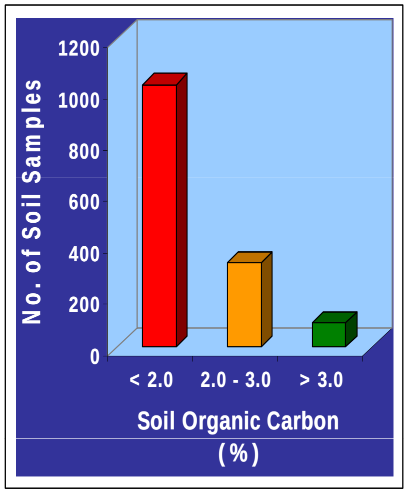
Total area of rice cultivation with and without rotation crops in Indonesia



Total area of rice cultivation with and without rotation crops



Soil organic carbon of intensified lowland rice areas in Indonesia



- 73% low soil organic matter content (<2%),
- 23% medium organic matter content (2-3%)
- 4% have more than 3% of soil organic matter

due to the intensive weathering process, high rainfall and temperature, land use change, and inappropriate management practices without returning organic matter to the field

Soil Organic Carbon

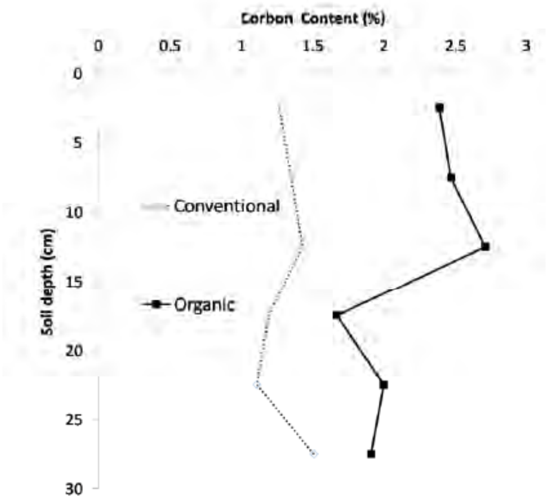
Case study in West Java

Comparison of soil carbon sequestration between organic and conventional rice fields in the top 10 cm soil depth (Komatsuzaki and Syuaib,2010)

	Soil Bulk Density $g\ mL^{-1}$	Carbon Content %	Soil Carbon Storage $Mg\ ha^{-1}$
Organic	0.88	2.89	25.0
Conventional	0.80	2.22	17.6
Significance	NS	*	**

**,* and NS indicate significance at 1% and 5% level and not significant, respectively.

Comparison of soil carbon content profile between organic and conventional rice fields in the top 30 cm soil depth. (Komatsuzaki and Syuaib,2010)



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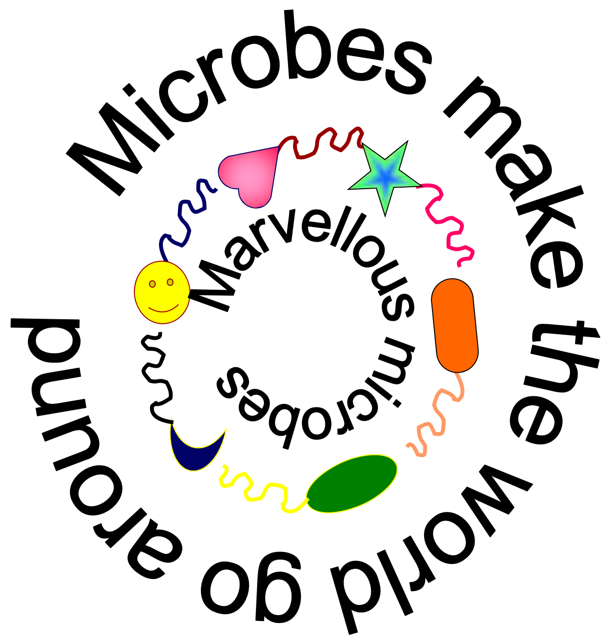


Country report on rice cultivation practice: Myanmar

Expert Meeting
2-3 June 2011
Bangkok, Thailand

Dr. Khin Lay Swe
Pro-Rector (Retd.)
Yezin Agricultural University

Country Profile:

- Export: US$ 6.8 billion*
- Import: US$ 4.5 billion*
- Main Exports: Agriculture, livestock and forestry products, natural gas
- Main Imports: Machinery, transportation and construction materials, industrial raw materials, consumer goods

Role of Agriculture sector

- 43% of GDP (including crops (35%), livestock & fisheries (7%) and forestry (1%))
- 61% of Labor Force
- 44% of Export Earnings (crops (17%), livestock & fisheries (20%) and forestry (7%))

*Ministry of Commerce, Myanmar (2008-09)

Sown Area of Major Crops (,000 ha)

Sr. No.	Crop Name	2009-2010	Percentage
1.	Paddy	8067	47.5
2.	Sesamum	1634	9.6
3.	Green gram	1077	6.3
4.	Black gram	1023	6.0
5.	Sunflower	883	5.2
6.	Groundnut	866	5.1
7.	Pigeon pea	616	
8.	Other Pulses	706	
9.	Wheat & Maize	466	
10.	Rubber	463	
11.	Cotton	359	
12.	Sorghum	224	
13.	Sugercane	160	
14.	Oil Palm	112	
15.	Coffee	24	
16.	Vegetables	270	
17.	Others	19	
	Total Crop Area	16969	

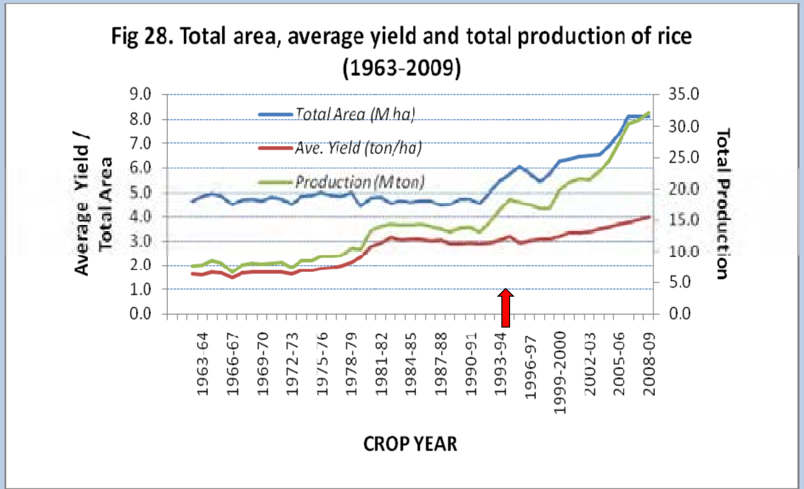
Country Profile:

- Area **676,557** Km^2, between 9° 32' N to 28° 32'N; 92° 10' E to 101° 11'E
- Population: **57.5** Millions
- Growth rate of 1.75 %,
- **135** nationalities

Ayeyarwady Region is the rice bowl of Myanmar

Major Rice Producing Areas

Divisions	Share in rice area (%)	Share in population (%)
Ayeyarwady	29	14
Bago	16	10
Sagaing	12	11
Yangon	9	12
Others	34	53



- **The sharp increase in rice area after 1993 attributed to the additional rice area for summer rice.**
- **The increase summer rice area, coupled with the yield increase, resulted in a significant increase in rice production after 1993**

"Lowland Rice-based Ecosystems in Nyaungdon Township of Ayeyarwaddy" Garcia, et.al. 2010, ASEAN Round Table Meeting, Myanmar

Rice Ecosystems in Myanmar

Sr.	Type	%
1	Irrigated	30
2	Favorable Rain-fed Area	38
3	Drought Prone Area	12
4	Deepwater, submerged and salt affected Rice	17
5	Upland rice	3


Irrigated rice fields in Northern Shan State


Terrace upland rice fields in Northern Shan State

Construction of New Reservoirs and Dams


Irrigation Facilities installed in the last 2 decades: 228 Large and Small Rural Dams

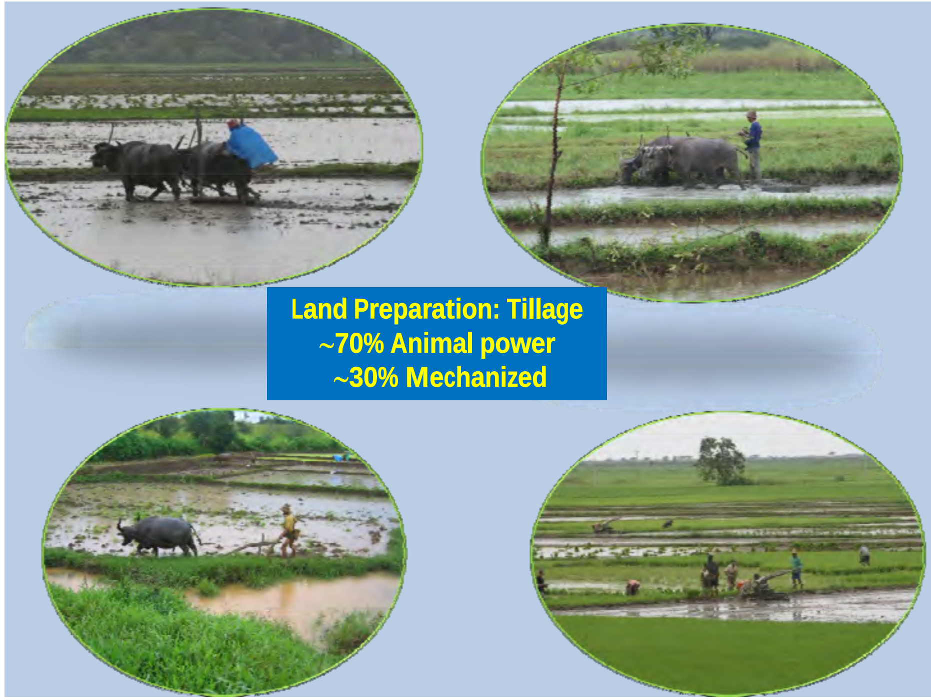

Lifting water from rivers:
322 river-pump stations established
to area of 0.47 m ac

Promoting Ecosystem Based-Adaptation

Supplementary Water for Rice Production, Central Myanmar

A Total of 7974 tube wells: Shallow / Deep tube wells - for > 100,000 acres, after 2007-08

Treadle-pump/ Tripod pump


Land Preparation: Tillage
~70% Animal power
~30% Mechanized


Transplanting in Flooded Areas
Lowland Areas


Rice Harvesting :
Harvested manually
Sun dry: Flooded Rice in Nyaungshwe Township, Southern Shan State
Lowland Rice in Mandalay Region
Combine harvester are not common; Some seen in Muse Township, Northern Shan State


Paddy Harvest Time in Central Myanmar
Paddy harvest time – short stubble left
Paddy straw for animal feed

Rice Straw mainly for Cattle Feed

Only a few cases of burning for next crop

Dry Seeding Practice of Rice under Rain-fed Ecosystem

Rice Growing Method:

1. Transplanting (~80% of the rice area)
2. Direct Seeding(~20%; Double Rice growing area)
3. Dry Seeding (A few areas in central dry zone)

Central Myanmar:
Yamethin Township, lower rainfall in 2010, Taking for Cattle Feed

Traditional Cropping Patterns: Adaptation Technologies in Central Myanmar

Double Crop in Central Myanmar:
Black gram after Rice

Blackgram Harvest in Lower Myanmar: Zero tillage for conservation of residual soil moisture: Post monsoon black gram after rice

Crop Rotation and Double Cropping

Some plots are prepared for Rice after Rice, and some for Garlic after Rice

Zero Tillage for Garlic after Rice: Double Cropping in Southern Shan State

MIX CROPPING IN NORTHERN SHAN STATE

Mix-cropping with Sunflower

Mix-cropping with Pigeonpea

Orange, Pineapple and Rice

% of farmers who applied fertilizers and average rice yield

Fertilizers applied	1994-95 (Monsoon) % of Farmers	1994-95 (Monsoon) Grain Yield (kg/ha)	2003-04 (Monsoon) % of Farmers	2003-04 (Monsoon) Grain Yield (kg/ha)
Urea only	6	2191 b	22	2575 ab
Urea+FYM	32	2566 a	29	2631 a
FYM only	28	2212 b	25	2445 bc
Others	21	2745 a	5	2746 a
No Fertilizer	13	1075 c	19	2178 c

Fertilizers applied	1994-95 (Summer) % of farmers	1994-95 (Summer) Grain Yield (kg/ha	2003-04 (Summer) % of farmers	2003-04 (Summer) Grain Yield (kg/ha)
Urea only	41	2254 b	75	3001 b
Urea+FYM	19	2901 a	12	3666 a
Others	12	3482 a	13	2822 b
No fertilizer	28	1403 c	-	-

"Lowland Rice-based Ecosystems in Nyaungdon Township of Ayeyarwaddy" Garcia, et.al. 2010, ASEAN Round Table Meeting, Myanmar

Major Cropping Patterns and Share of Cultivated Area

CROPPING PATTERNS	CY 1994-95 (%)	CY 2003-04 (%)
Rice - Pulses	35	34
Rice - Fallow	13	18
Fallow - Rice	11	8
Fallow - Pulses	11	14
Rice - Rice	11	3
Rice - Oilseed	7	9
Fallow - vegetable	1	7
2 Rice - Fallow	2	0
Others	9	7
TOTAL	100	100

"Lowland Rice-based Ecosystems in Nyaungdon Township of Ayeyarwaddy" Garcia, et.al. 2010, ASEAN Round Table Meeting, Myanmar

Rice Varieties and Yield (t/ha) in Ayeyarwaddy Region

RICE VARIETY	1994-95	2003-04
Monsoon Season		
HYV Varieties	2.64 (67%)	2.57 (83%)
Traditional Varieties	1.70 (33%)	2.24 (17%)
Summer Season		
HYV Varieties	2.07 (96%)	3.06 (100%)
Traditional Varieties	1.14 (4%)	-

Percent Share of Cost for Monsoon Rice

ITEMS	1994-95	2003-04
Hired Labor	44	57
Fertilizer cost	23	25
Animal & Mechanical power	21	11
Seeds	7	7
Irrigation	5	0

Comparison of Cost & Return for Monsoon Rice Production

ITEMS	1994-95	2003-04
Rice Yield (kg/ha)	2301	2515
Area Harvested (ha)	477	428
Number of farm households	305	268
TOTAL COSTS (Kyats/ha)	19,497	16,605
Cash cost	6,639	7,815
Non-cash cost	2,509	1,972
Imputed cost	10,349	6,818
GROSS RETURNS (Kyats/ha)	29,891	31,016
Returns over cash costs	23,252	23,201
Returns over cash & non-cash costs	20,743	21,229
NET RETURNS (Kyats/ha)	10,394	14,411
NET PROFIT-COST RATIO		
Cash cost	1.57	1.84
Cash & Non-cash	1.14	1.47
All cost	0.53	0.87
(Note: Prices deflated to 1996 prices)	1000 K = 1 USD	

Comparison of Cost & Return for Summer Rice Production

ITEMS	1994-95	2003-04
Rice Yield(kg/ha)	2,018	3,058
Area Harvested (ha)	191	92
Number of farm households	141	51
TOTAL COSTS (Kyats/ha)	15,202	30,325
Cash cost	7,125	22,342
Non-cash cost	1,753	2,068
Imputed cost	6,324	5,915
GROSS RETURNS (Kyats/ha)	28,517	39,796
Returns over cash costs	21,392	17,454
Returns over cash & non-cash costs	19,639	15,386
✓ NET RETURNS (Kyats/ha)	13,315	9,471
NET PROFIT-COST RATIO		
Cash cost	1.87	0.42
Cash & Non-cash	1.5	0.39
All cost	0.88	0.31

Mitigation Options of GHG Emission

Rice fields produce CH4 emissions, which can be reduced by improved management measures:

Improved Rice Production Practices

- – Irrigation management
- – Nutrient management
- – New cultivars

Successful implementation of mitigation technologies will depend on demonstration that:

- Grain yield will not decrease or may increase;
- There will be savings in labor, water and other production costs; and
- Rice cultivars that produce lower CH4 emissions are acceptable to local consumers

Mitigation of CH4 emissions from rice fields:

Method of rice plant establishment: The System of Rice Intensification (SRI)

- Rice plants are transplanted 8- 15 days after germination
- Water management practice: Alternate Wet and Dry (AWD)
- 3- 5 days of flooding and 10 - 14 days of drainage
- Save water, to get more nutrient absorption, improved root growth
- Reduce the use of irrigation water without compromising the rice yield
- Short duration of flooding condition will reduce the CH4 emission from the field

The System of Rice Intensification (SRI), and Alternate Wet and Dry Rice (AWD):

- Introduction into the existing farming systems for mitigation of GHG (CH_4 and N_2O) emissions from rice fields; **introduced in 2000** but not yet popular in Myanmar,
- **Good drainage system** is a necessity and an application of a drainage system in a rice field increases oxygen and methane oxidation, decreasing CH_4 emission. Besides, some findings showed that controlled irrigation may reduce N_2O emissions.

Improve Nitrogen Management:

Decrease the amount of nitrogen lost to the environ. through gaseous losses of ammonia or N_2O, or leaching of nitrate into the subsoil

- **Improvements in farm technology, such as use of controlled-release fertilizers, nitrification inhibitors,**
- **Timing of nitrogen application (better matching nitrogen supply to crop demand)**
- **Water management for improvements in nitrogen use efficiency and further limit N_2O formation**
- **More integrating animal waste and crop residue management**
- **Control biomass burning**

Nutrient Management Practices Method of Urea Application:

- **FYM blended urea:. Same amount of Urea and FYM are thoroughly mixed, put in a plastic bag. After one night of incubating, the FYM blended urea will be used as top-dressing, can save urea as much as 30 – 45 % of total application without reducing yields, sometimes giving even better yields, N_2O emission will be lower than the conventional method**
- **Split application method (e.g. 3 - 4 times for rice) to match nitrogen supply with crop demand**
- **Foliar application of urea solution and growth regulators (plant growth hormones) will be an alternative way of improving productivity with less negative environmental effects.**

Method of Organic Manure Application

- A common practice : apply organic fertilizers in the form of residues from the previous rice crop, stubbles are ploughed and integrated into the soils.
- Apply farm yard manure (cow dung/ compost)
- Under rice - upland cropping pattern, farmers usually apply cow dung manure before rice growing in wet season
- This practice will favor the CH4 emission from land preparation time as well as flooded rice fields
- Applying organic manure only just before upland tillage preparation can be carried out to minimize the methane emission.. The time of application will be after the harvest of wet season rice.

Compost making with rice straw and other farm wastes:

- **Burning rice straw**: not popular; previous crop residues and weeds before land preparation will not only emit the GHG to the atmosphere but also it loses the valuable organic matter source.
- **Adoption of compost making** and applying compost after rice harvest would be alternative ways of climate change mitigation through reducing CO_2 emission.
- Since incorporation of un-decomposed organic C residues has been reported as the sources of CH_4 emission, **well-decomposed organic manures** should be used

Rice-based Cropping Patterns

- In the irrigated area, farmers are encouraged to grow double rice cropping system
- In stead of Rice - Rice cropping pattern, rice with upland crops (pulses, cotton, energy crops) ; will be advantageous for reducing CH4 emission and for less water requirement of next crop

Conclusion

- Multidisciplinary research (development of rice crop management practices/ climate-resilient rice varieties, etc.)
- Cooperation with international and regional partners and seek technology transfer for development of sustainable low carbon society


THANK YOU

CEE-PERDO Center for Energy Technology and Environment
APN
JGSEE The Joint Graduate School of Energy and Environment
CCRD

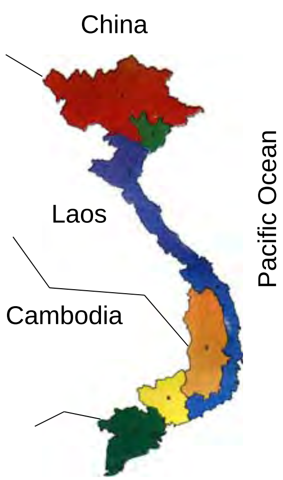
Country report on rice cultivation practice: **Vietnam**

Expert Meeting
2-3 June 2011
Bangkok, Thailand

Outline

- **General Information**
- **Rice Variety**
- **Ecosystem**
- **Rice cultivation practice**
- **Management of Rice Residues**
- **Rotation Crops**
- **Soil Organic Carbon**
- **Socio-economic Status of Rice Farmer**

General Information



Vietnam:

- - **Population: 86 mil.people**
- **Total area: 331.000 km2**
- **¾ of area is mountains**
- **Cultivation land occupies ~ 28%**

- **Cultivation Land per capita:**
  In Mekong Delta and
  East-Southern regions: 1,000m2/person
  In other regions: 400 m2/person

General Information

- Rice is the most important food plant in Vietnam
- **Before 1975** (period of the wars):
  Total rice cultivation land: **4.5 mil.ha**
  low productivity: **0.7 tons/ha**.
  Total yield: **less than10 mil. tons**.

- **After 1975**: Total rice cultivation land **5.5 – 5.7 mil.ha**.
  1975-1986: low productivity
  because of: low quality of soil, disaster, pestilent, insect
  National Economy:Centrally Planned and Subsidy based
  1/3 Rice consumption: **Imported from other countries**

General Information

- **From1986**: National Economy = Market Orientation

  Important policy: Allocating land to farmers

  Rice productivity:

  in 1980s: 3.0 tons/ha/year

  in 2000s: 4.9 tons/ha/year

  Total yield: ~ **30 mil.tons/year**

  (3 times more, compared to 1975)

  1989: Exported rice to other countries

  From 1997 to present:

  Average annual export of rice: **4 mil.tons/year**

  (Vietnam became the Second position rice exporter in the World)

General Information

Area, Productivity and Yield of Rice in Vietnam during the period from 1955- 2009

Year	Area (mil.ha)	Productivity (tons/ha)	Yield (mil.tons)
1955	**4.42**	**1.44**	**6.36**
1965	**4.83**	**1.94**	**9.37**
1975	**4.94**	**2.16**	**10.54**
1980	**5.54**	**2.11**	**11.68**
1985	**5.70**	**2.78**	**15.87**
1990	**5.96**	**3.21**	**19.14**
1995	**6.77**	**3.69**	**24.96**
2000	**7.67**	**4.24**	**32.53**
2005	**7.33**	**4.89**	**35.79**
2009	**7.44**	**5.23**	**38.89**

General Information

- However, rice productions are differently distributed in the country:
  - **Red river Delta** & **Mekong Delta**: main country Rice Production areas
  - **Other regions**: Self-sufficient rice production

General Information

Areas, Productivity and Yield distributed by Regions in Vietnam

Region	Area (Million ha)	Productivity (tons/ha)	Yield (Mil.tons)
Total the Country	**7.44**	**5.23**	**38.89**
1.RedRiver Delta	**1.16**	**5.88**	**6.80**
2. Northern Mountain	**0.67**	**4.55**	**3.05**
3.Northern Central	**1.22**	**5.12**	**6.25**
4.Central HighLand	**0.21**	**4.65**	**0.99**
5.East Southern	**0.31**	**4.31**	**1.32**
6.MekongDelta	**3.87**	**5.29**	**20.48**

Rice Variety

- **Rice seeds are important.**

  Improvement of Rice seeds have been achieved through different periods:

- **In '60-'70s:** The criteria on selection of rice seeds have been based on outward aspect (physical) of rice plants.
- **In '80s:** Change on research objective by stabilization of productivity towards seeds having good resistance to pestilent insect.
- **In '90s:** Concentration of efforts on Improving Productivity and Quality of rice seeds.
- **In 2000s:** Research on rice seeds based on improved rice seed quality in combination with improved resistant capacity .

Rice Variety

- **Depending on Local Specific Climates, Soils & Traditions: Different areas – Different rice varieties.**

1. In the North (Red River Delta, Mountainous & Northern Central) mainly used the following varieties:

- **Local varieties:** Tam Xuan Đai, Tam Xoan Thai Binh, Tam Den Hai Phong, Tam bang Phu Tho, Du Huong, Nep cai Hoa vang, Tep lai…
- **Imported Chinese or Originated Chinese varieties**: Short Moc Tuyen, Short Bao Thai, M90, Bac Yu 64, Cross-Breeding 5, Nhi Yu 63, Khang Dan 18, Short Ay 32…
- **Originated IRRI' varieties**: Selected or Cross-Breeded from: IR24, IR 17494, IR 1820, IR 36, IR 46, IR 2053-26-3-5-2, IR 2588, IR 19746-11-33, IR 8423-132-622,…

Rice Variety

2. In the South (East-Southern, Mekong Delta, Central HighLand) there're following varieties:

- **Local varieties**: Early Thom, Nang Thom Nha Be, Thom Binh Chanh, Nang thom Đuc Hoa, Nang thom cho Dao, Nang Huong, LC90-4, …

- **Varieties originated from IRRI**: Selected or Cross-Breeded from: **IR 49517-23**, **IR 59606**, **IR 64**, **IR 68**, **IR 66**, **IR 66707**, **IR 56279**, **IR 32893**, **IR 48**, **IR 8423**, **IR 50401**, **IR 44592**, **IR 9729-6-7-3**, **IR 62032**…

Rice Cultivation Practices

- **In Northern Mountainous (region 1):**

- **"Milpa" cultivation**: Depends on raining water, using dry varieties, without fertilizers & insecticide/Plant protection – Very Low productivity.
- **Terraced fields:** Depends on raining water, using dry varieties, without chemical fertilizers & insecticide/Plant protection, Very few compost - Very Low productivity.

Rice Cultivation Practices

- Red River Delta (Region 2)
- ✓ **Paddy rice cultivation: Based on active irrigation water provision; High intensification; Using high productive varieties; Overuse of chemical fertilizers & Pesticide : High productivity.**
- ✓ **Almost 90% of growing time: the rice plants are in 10-15cm of field water.**
- ✓ **Some recent new practices, applied for mitigating Climate change:**
- In the Period of rice seedling transplanting growth: keeps rice filed dry/damp in 2 periods:
  - First period: during 7-10 days after 10 days from rice transplantation.
  - Second period: during 7-10 days after 30 days from rice transplantation.
- In the Period of rice seedling Reproducting growth:
  Keeps rice filed in 4-5cm water in the period of time from 45 days after transpantation until 15-20 days before the harvest.

Rice Cultivation Practices

- **The Central/Coastal region (Region 3):**
- **In Mountainous areas:**
  Depends on raining water, using dry varieties, without chemical fertilizers & insecticide/Plant protection, Very few compost - Very Low productivity.
- **In coastal plain areas: Paddy rice cultivation Based on active irrigation water provision; High intensification; Using high productive varieties; Overuse of chemical fertilizers & Pesticide: Main & High productivity**

Rice Cultivation Practices

- **Mekong Delta region (Region 6):**
- 75% cultivation area in Active irrigation water provision: **High intensification; Using short-term & high productive varieties; Overuse of chemical fertilizers & Pesticide: High & very high productivity;**
  During most of growing time rice plants are filled with water.
- 25% cultivation area depends on raining water (Cultivation during March-April to Nov.-Dec.) ; Main intensification; Extremely Short-term varieties; Main level of use of **Overuse of chemical fertilizers & Pesticide: High productivity**
  During 100% growing time rice plants are filled with water.

Management of Rice Residues

Rice Residues: Rice husk, Bran, Rice straw

1. **Rice husk:** Using rice husk as fuel, paving material for raising chicken/poultry, energy for burning bricks or pottery and porcelain…
2. **Bran:** Using bran for raising animal/pigs, chickens, ducks…
3. **Rice straw:**

- In Northern and Central parts of the country people using rice straw as fuel, food for cattle or burning on the field. Some areas: Using rice straw for production of bio-fertilizer.
- In Mekong Delta rice straw is using as food for cattle and normally burying on the field

Rotation Crops

- ***Northern Mountains (region 1)***
- ✓ 2 rice crop: 50% area
- ✓ 1 rice crop + 1 subsidiary/vegetable crop: 20% area
- ✓ 1 rice crop: 30% area (Terraced field & "Milpa cultivation")
- ***Red River Delta (region 2):***
- ✓ 2 rice crops: 50% cultivation area
- ✓ 2 rice crops + 1 subsidiary/vegetable crop: 40% area
- ✓ 1 rice crop + 1-2 subsidiary/vegetable crops: 10% area
- ***Northern Central (region 3)***
- ✓ 2 rice crops: 50% cultivation area
- ✓ 1 rice crop + 1 subsidiary/vegetable crops: 30% area
- ✓ 1 rice crop: 20% area

Rotation Crops

- ***Central Highlands (Region 4)***
- ✓ 2 rice crops: 30% cultivation area
- ✓ 1 rice crop + 1 subsidiary/vegetable crop: 30% area
- ✓ 1 rice crop: 40% cultivation area

- ***East-Southern region (region 5):***
- ✓ 2 rice crops: 60% cultivation area
- ✓ 2 rice crops + 1 subsidiary/vegetable crop: 30% area
- ✓ 1 rice crop + 1 subsidiary/vegetable crop: 10% area

Rice crops

- ***Mekong Delta region (region 6)***

In Alluvial soil & freshwater: 40-45% area

- ✓ 2-3 rice crops
- ✓ 2 rice crops + 1 subsidiary/vegetable crop
- ✓ 2 rice crops + fish/shrimp integration

In raining water with salty contamination: 55-60% area

- ✓ 2 rice crops
- ✓ 1 rice crops + fish/shrimp integration
- ✓ 1 rice crop

Soil Organic Carbon

Socio-economic Status of Rice Farmer

What's income from rice cultivation ?

Regions	Cultivation land per capita (m2 or ha)	Average rice Productivity per ha/year (tons/ha)	5.9 tons/ha productivity based Rice Yield (tons) per capita/year (tons)	Average price USD/ton (supposed)	Total income/ person (USD)
1, 2, 3, 4	400m2 = 0,04ha	5.29	0.212	1,000	212 $
5, 6	1000m2 =0.10ha	5.29	0.529	1,000	529 $

Income of rice farmers in Mekong Delta: **529$/year**
Income of rice farmers in other regions: **212$/year**
(including input costs, in the situation without disease, natural disaster…)

Conclusion

Rice farmers are facing lot of challenges regarding Annual Natural disasters, Diseases…and others relevant to different issues such as: FDI, WTO, Industry Development ... They are most vulnerable while have less access to a good education system, information, less opportunities, and less power…

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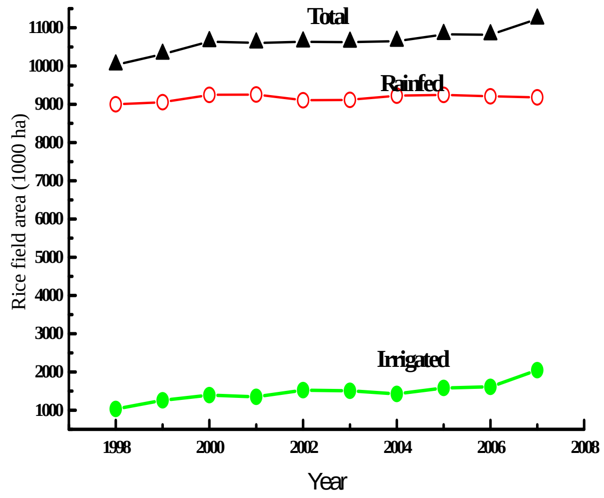
Position: Director

Country report on rice cultivation practice: Thailand

Amnat Chidthaisong, Kanittha Kanokkanjana, Savitri Garivait, Sebastian Bonnet and Sirinthornthep Towprayoon

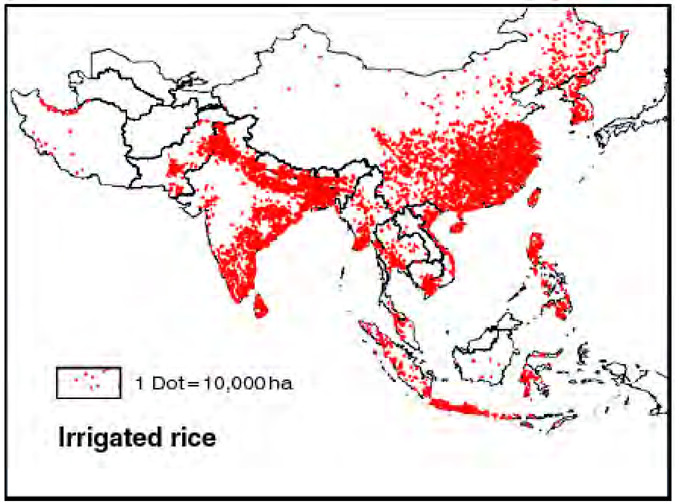
Expert Meeting, 2-3 June 2011
Bangkok, Thailand

Rice cultivation area 1998-2008



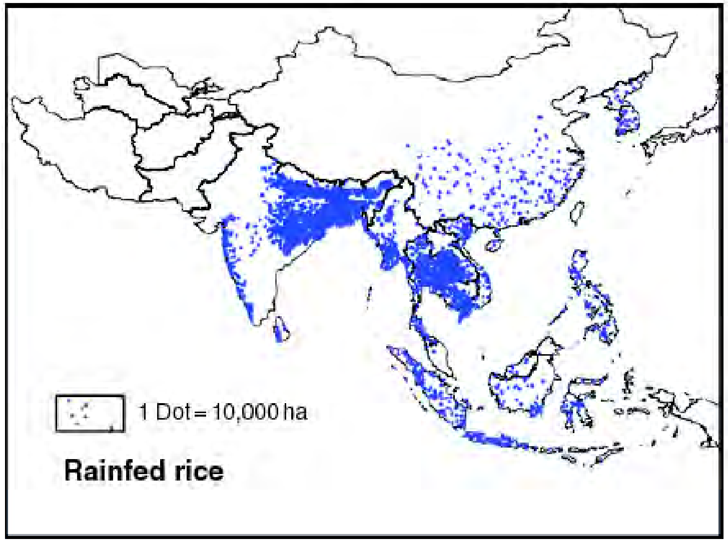
➡ **deep-water rice**

Irrigated rice



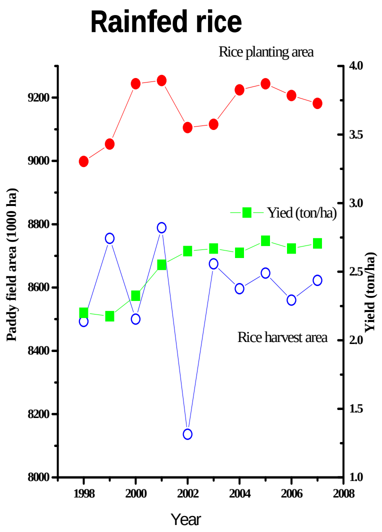
Wassmann et al., 2009b

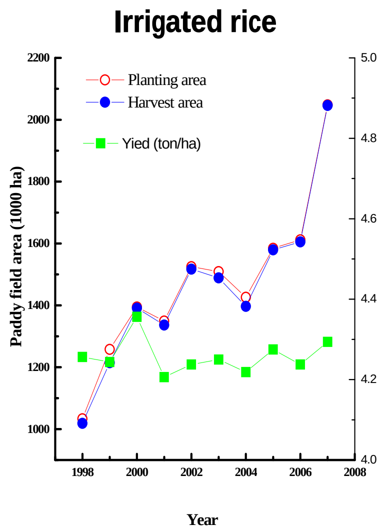
Rainfed rice

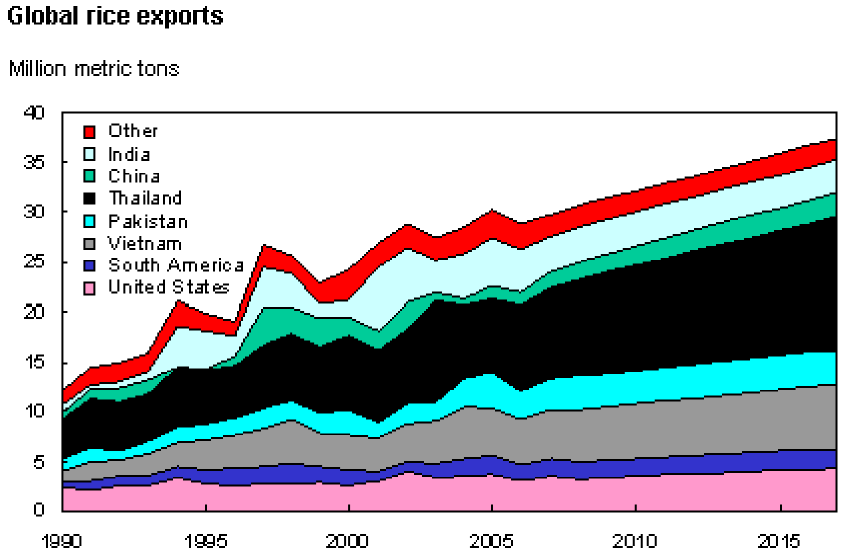


Wassmann et al., 2009b

Yield vs. Ecotypes

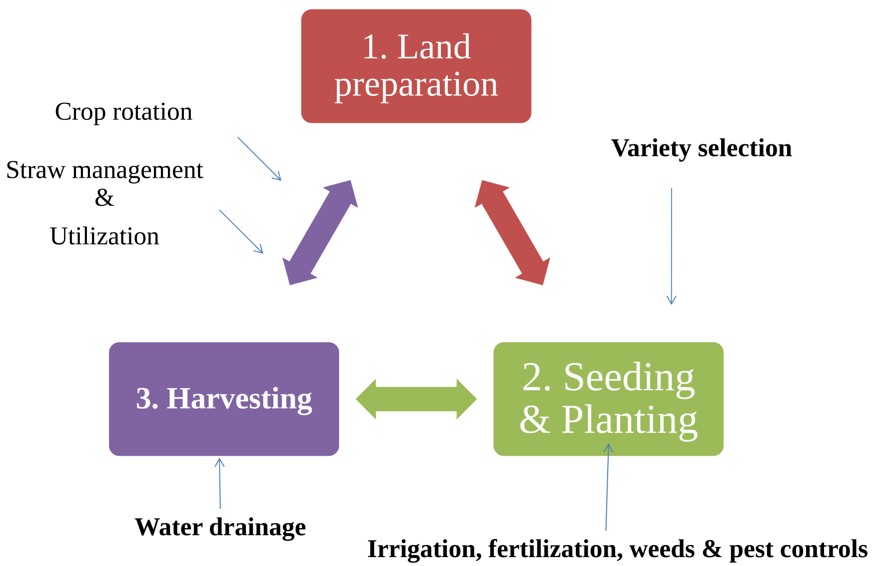






Source: *USDA Agricultural Projections to 2017*, February 2008.
USDA, Economic Research Service.

Typical rice cultivation cycle in Thailand



1. Land preparation

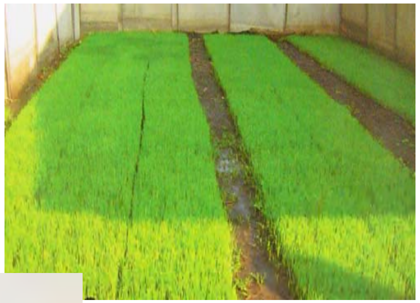
Harrowing


2. Seeding & Planting

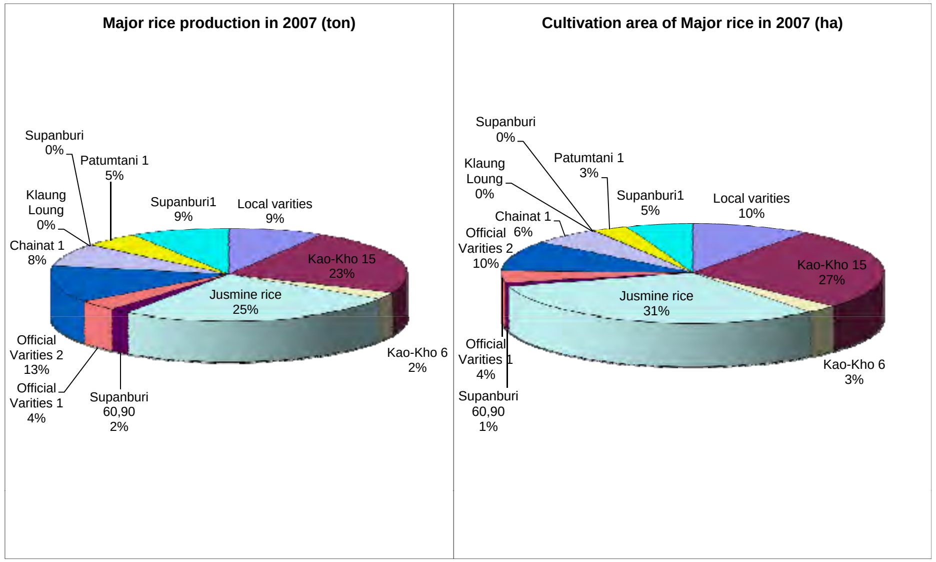


Pre-germinated broadcasting rice:
96.47% in second rice and 28.85% in major rice (2009)

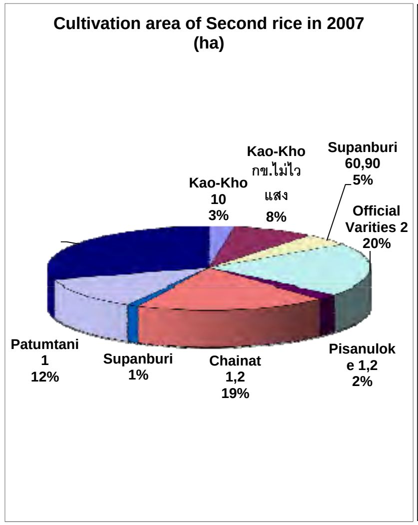
Parachuting

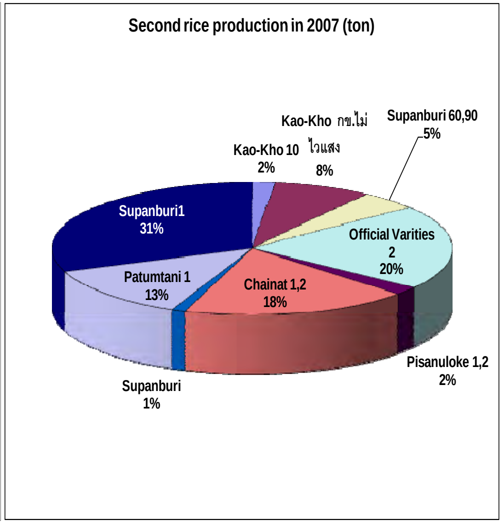




Rice variety: Major rice



Rice variety: Second rice



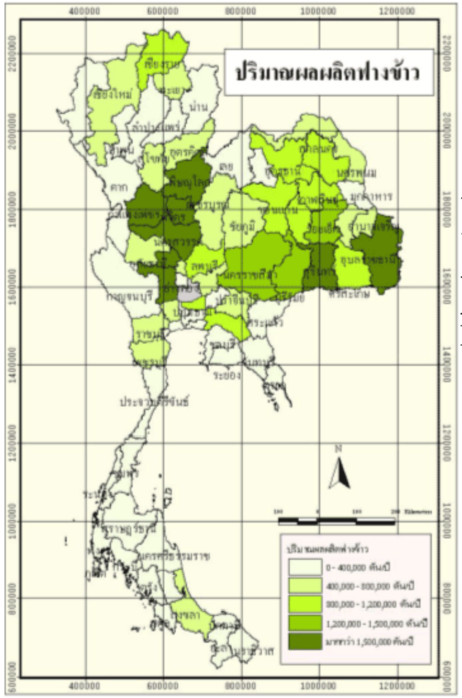


Fertilization

Cultivation method	Basal Fertilizer Type or N-P-K (kg/ha), timing of applying fertilizer after planting	Topdressing Fertilizer Type or N-P-K (kg/ha), timing of applying fertilizer after planting
Transplanting	16-16-8 (125)	AS (187.5), 20 days
	CMP (630)	Urea (93.75), 64 days
Transplanting Seedling Planting 1) Photoperiod-sensitive 2) Photoperiod-insensitive	Manure/Compost (5000) 16-16-8 (100) 16-16-8 (156), -1-0 day or 15 days or AS (156) and KCl (30-60), -1-0 day or 15 days 16-16-8 (187.5), -1-0 day or 15 days or AS (187.5) and KCl (3-6), -1-0 day or 15 days	16-16-8 (NA), 15 days Urea 46-0-0 (40), flowering or AS (21-0-0) (78.75), flowering Urea 46-0-0 (78), flowering or AS (21-0-0) (156.25), flowering
Broadcasting Pre-germinated seed broadcasting	-	16-20-0 (137.5), 15 days Urea (18.75), 15 days Urea (39), 57 days

lime is applied for 3 bags/rai (5 kg/bag, or 94 kg/ha)

3. Harvesting



Rice straw production,
DEDE 2009

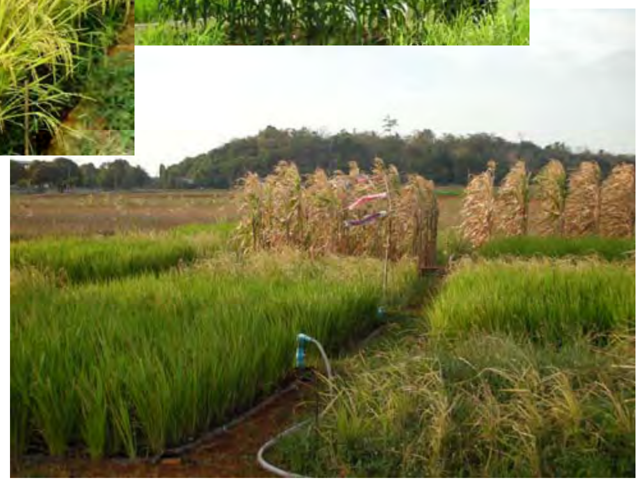
Rotation crop

Crotalaria juncea

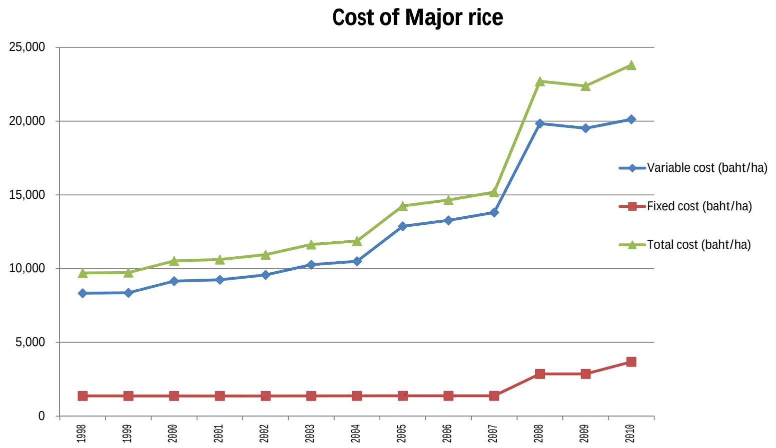
Crotalaria juncea

Canavalia ensiformis

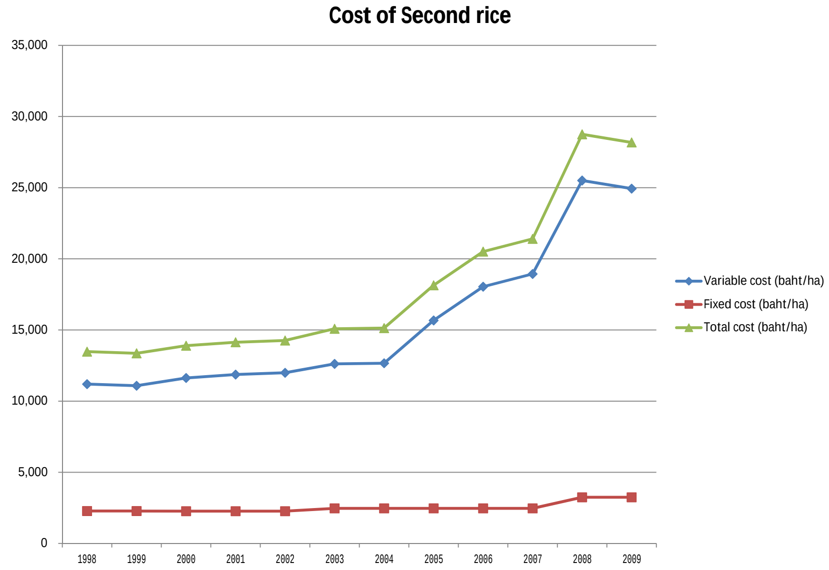
Maize-Rice rotation



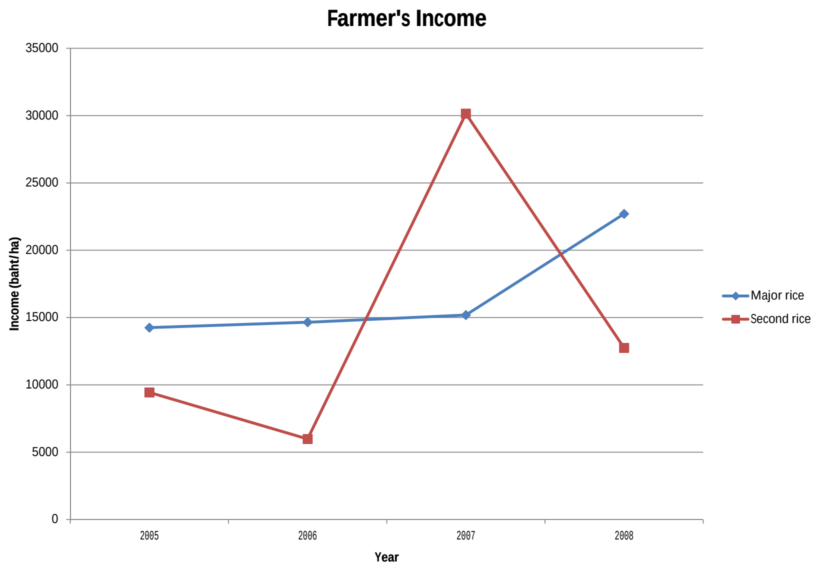
Socio-economic aspects



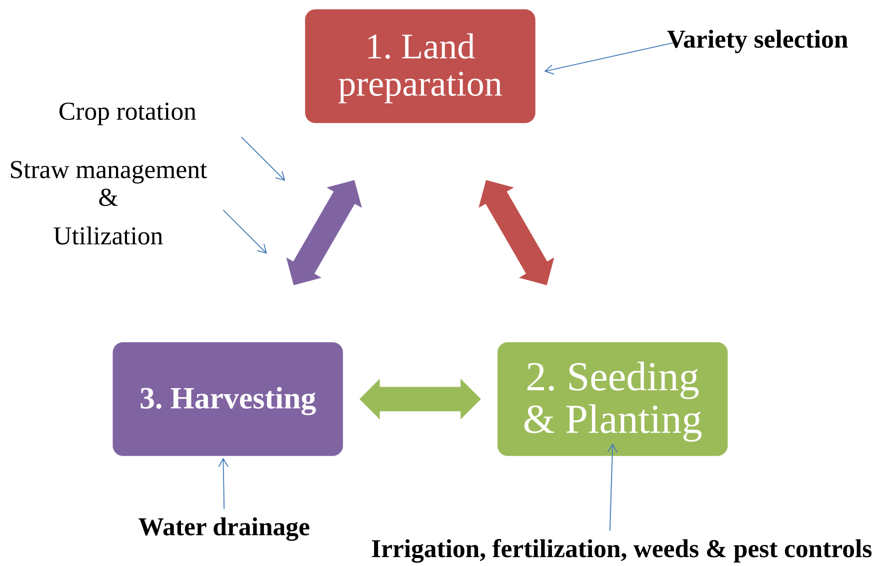
OAE, 2010



OAE, 2010



(BOI, 2008)



Mitigation options of GHG emission from rice field

Sirintornthep Towprayoon and

Tassanee Jiaphasuanan

Historical and Projection of GHG Emission from Agricultural sector

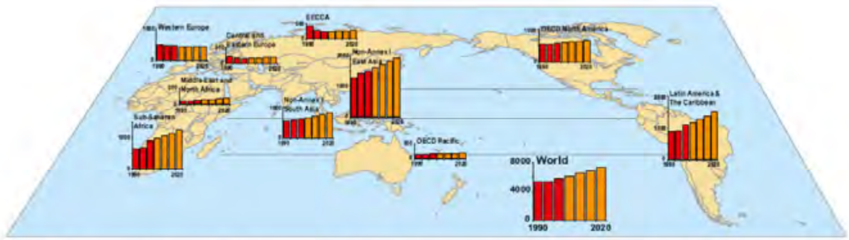
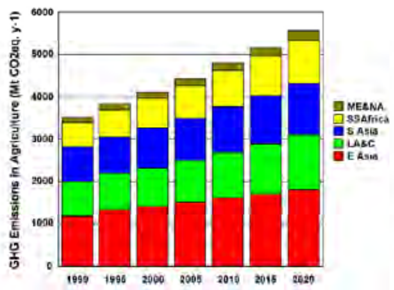
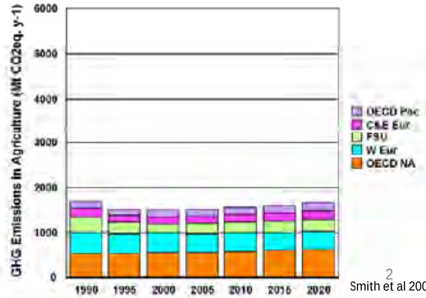


Figure TS.19: *Historic and projected N_2O and CH_4 emissions ($MtCO_2$-eq.) in the agricultural sector of ten world regions, 1990–2020 [Figure 8.2].*

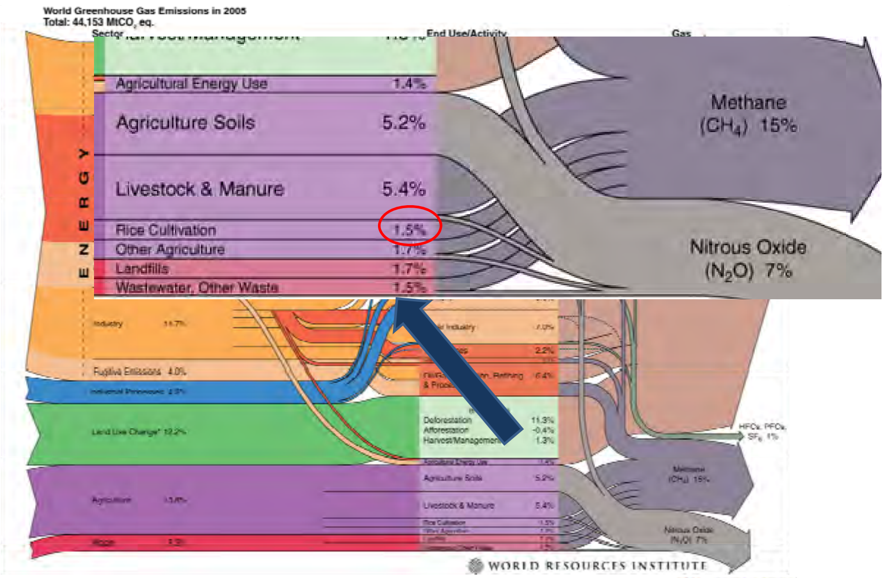
Note: EECCA=Countries of Eastern Europe, the Caucasus and Central Asia.



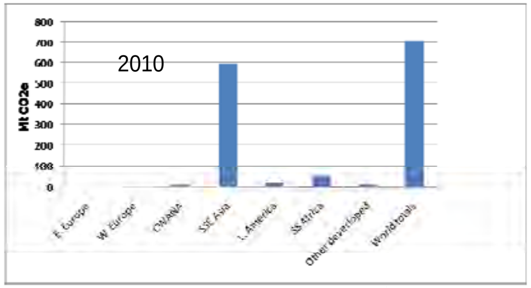


Smith et al 2007

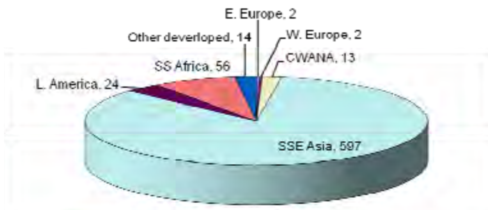
World Emissions in 2005 = 44,153 $MtCO_2$ equivalent



Who is the contributor of rice field emission

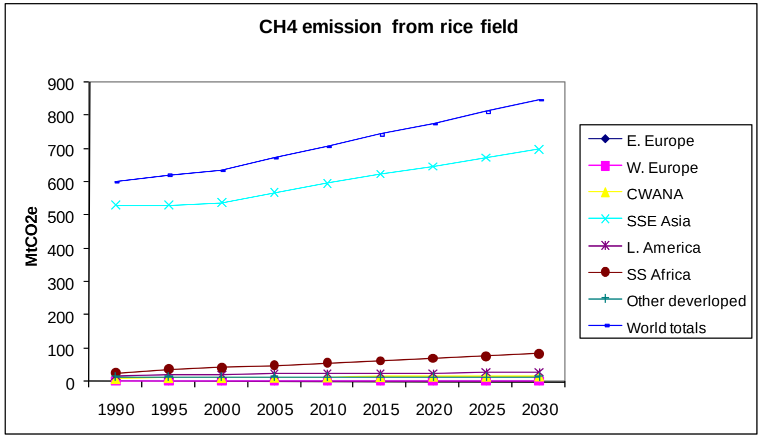


Contribution of CH4 emission from rice field



Verchot, L.V.,2007

GHG Emission trend of rice field



Verchot, L.V.,2007

Suggested Mitigation Options by gas types

CO_2

- increasing C input by organic amendment, such as manure, compost, and plant residues
- no tillage or minimum tillage
- rotation including cover crops

CH_4

- altering water management with mid-season aeration
- improving organic matter management, such as composting and promoting aerobic decomposition of crop residues
- others

N_2O

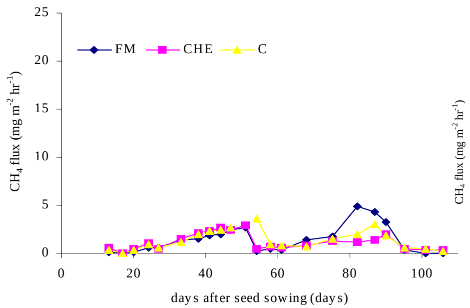
- improving N fertilizer application to match with crop demand
- appropriate management of animal wastes and manure
- introducing advanced fertilizers, such as slow- or controlled release fertilizers and inhibitors

Mitigation options

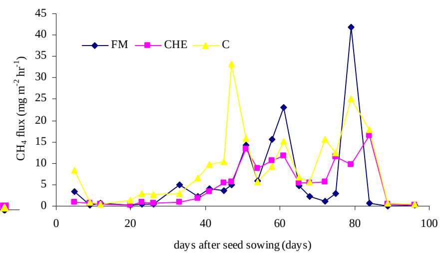
The possible mitigation option should be selected according to climate, type of paddy field and cultivation practices differ from site to site.

Mitigating GHG from rice cultivation and mitigation GHG from agricultural soil

Emission can be different in various location and practices : Seasonal Effect

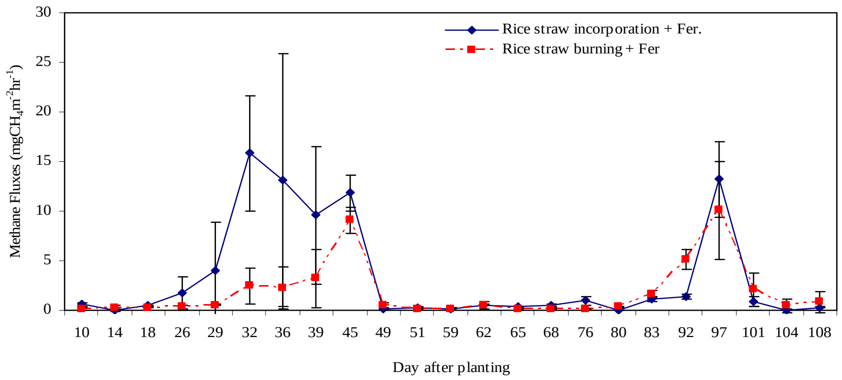


Dry season

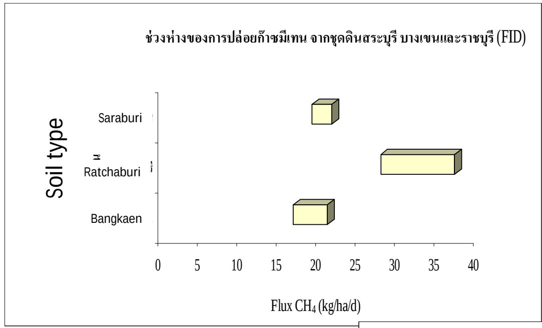


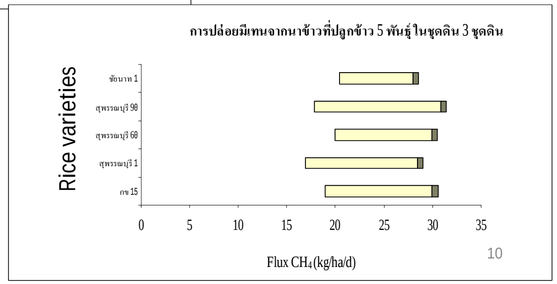
Wet season

Emission can be different in various location and practices : straw management



Factor affecting methane emission





Mitigating GHG from rice cultivation

- Water management
  - Mid-season drainage
  - SRI (system of rice intensification)
  - AWDI (Alternate wet/dry irrigation in rice cultivation)
- Inhibitor use
  - Ammonium sulfate
  - Iron supplement
  - phosphogypsum
- New cultivars
- other cultural practices
  - Direct seeding replace transplanting
- Nutrient management
- Site-Specific Nutrient Management (SSNM)
- Soil carbon stock
- Rotation cultivation

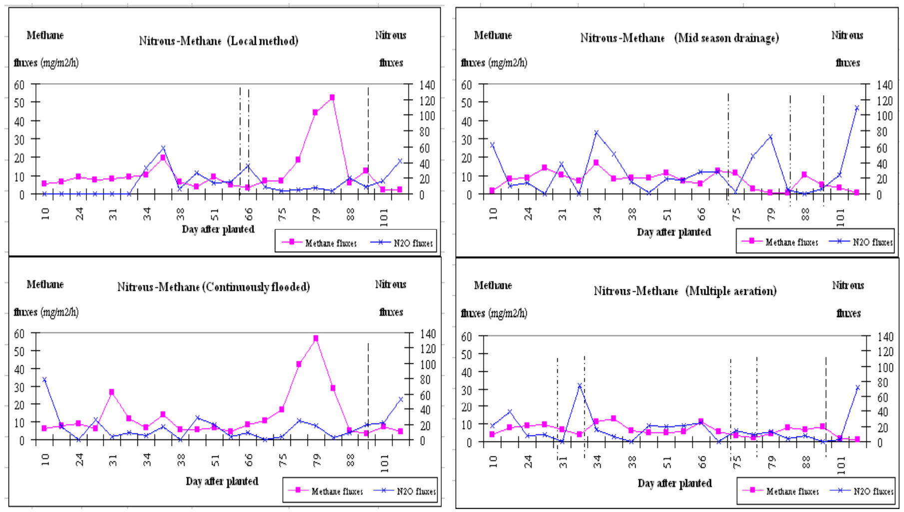
Mitigation potentials

Mitigation option/technology	Baseline	Mitigation option	Mitigation potential*	Reference
Water management	continuous flooding 5-15cm	3-5 days Mid season drainage	36.7% CH4 reduction	Tyagi et al,2009
			5 TgCH4/yr	IPCC 1996
			-(8-10)% from BAU	Erda et al.,1997
	continuous flooding	Mid-season and shallow flooding drainage	35 MtCO2e in 2030	Indonesia’s greenhouse gas abatement cost curve,2010
	continuous flooding	tillering stage drainage	9% CH4 reduction	Tyagi et al,2009
	continuous flooding	multiple drainage	41% CH4 reduction	Tyagi et al,2009
SRI (system of rice intensification)	continuous flooding 5cm	intermittent irrigation 2cm	37.5% CH4 reduction	Hidayah et al.,
AWDI (Alternate wet/dry irrigation in rice cultivation)	continuous flooding	using the criterion of -20 kPa	70% CH4 reduction	IRRI
New cultivars and other cultural practices		Control the diffusion of CH4 from root and shoot aerenchyma	-(4-26)% from BAU	Erda et al.,1998
		Reduce root exudation	5 Tg CH4	Metz et al.,2000
cultural practices	transplanting	Direct seeding replace transplanting	16-22% CH4 reduction	wassmann et al.,2000
	continuous flooding, urea, rice straw burn	TechnoGAS เป็นการจัดการ น้ำ ฟาง ปุ๋ย ปลูก	8-51% GWP reduction	Pathak and wassmann 2007

Mitigation potentials

Mitigation option/technology	Baseline	Mitigation option	Mitigation potential*	Reference
Inhibitor use		Ammonium sulfate application	-(9-15)% from BAU	Erda et al.,1999
		- Surface application	6% CH4 reduction	Schutz et al., 1992
		- Incorporation into soil	62% CH4 reduction	Schutz et al., 1993
		Use ammonium sulfate to replace urea	24-36% CH4 reduction	Corton, 2000
		Iron supplement		
	Urea	Addition of phosphogypsum	1 tCO2/ha	Wassmann and Pathak,2007
	Urea	Addition of phosphogypsum	0.29 tCO2/ha	Wassmann and Pathak,2007
	Urea	Addition of nitification inhibitor	0.7 tCO2/ha	Wassmann and Pathak,2007
Nutrient management			-(5-13)% from BAU	Erda et al.,2000
			10 Tg CH4	Metz et al.,2000
Site-Specific Nutrient Management (SSNM)	nitrogen-based fertilizers	phosphor- or sulfate based fertilizers	10 MtCO2e in 2030	Indonesia's greenhouse gas abatement cost curve, 2010

Emission can be different in various location and practices ： Waster management



Methane and nitrous oxide emission from different drainage system. (Towprayoon et al, 2005)

Comparison to local method

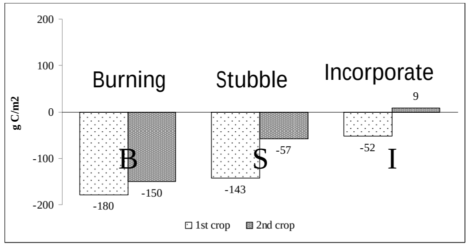
	Net GHGs	Methane Emission	Nitrous oxide Emission	Grain yield
Mid season drainage	<25.86%	<27.52%	>55.5%	<6.86%
Multiple Drainage	<33.53%	<34.55%	>16.47%	<11.43%

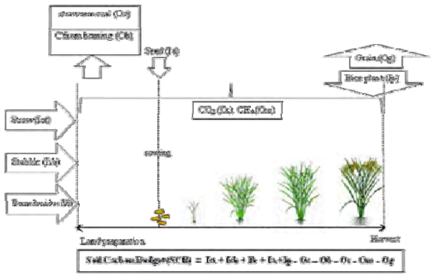
Mitigating GHG Emission from Agricultural Soils

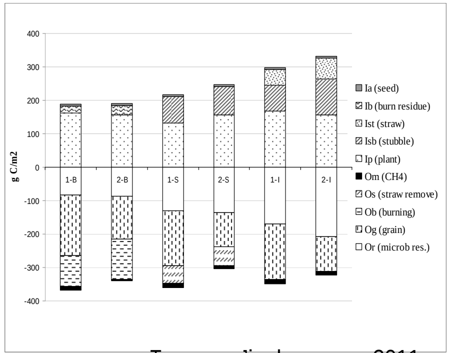
- **To decrease C output**
  - **no tillage or minimum tillage**
  - **minimizing fallow period**
- **To increase C input**
  - **applying organic amendment, such as manure, compost, and plant residues**
  - **rotation including cover crops**

Increase Carbon Input

Carbon budget in rice field
with straw incorporate and straw burning



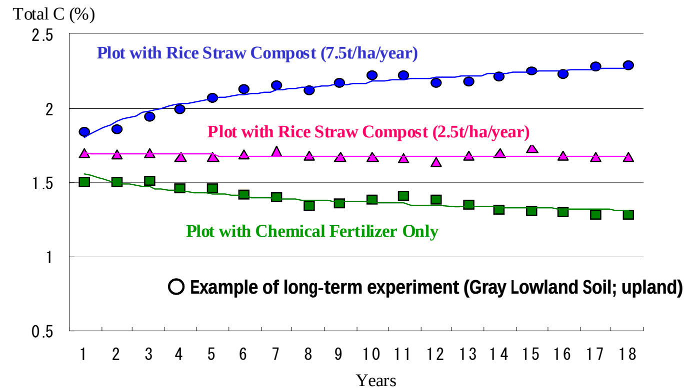




Tassanee Jiaphasuanan 2011

Long-term experiments in Japan

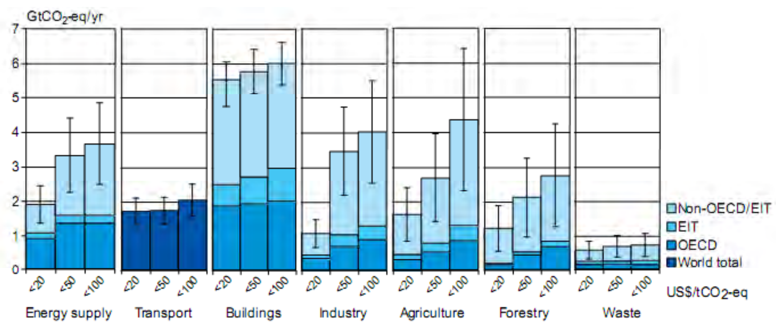
○ Since 1975, the MAFF has conducted long-term experiments with continuous organic matter application under typical soil type and cropping system of each prefecture (over 150 sites in total), which demonstrated that soil carbon stock increased through organic matter application such as compost.



Data : "Basic Survey of Soil Environment (Benchmark Survey)" Yamaguchi Pref. Agricultural Research Institute. Figure for a year is the three-year average including the previous and the next year to that year.

Source : Dr. Yagi NAIES

Values and cost of agricultural mitigation

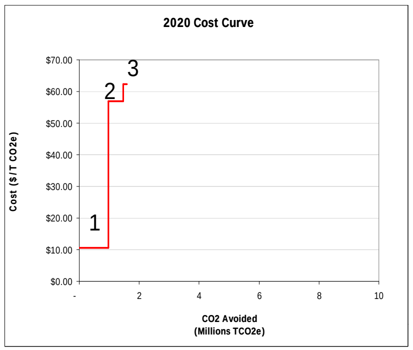


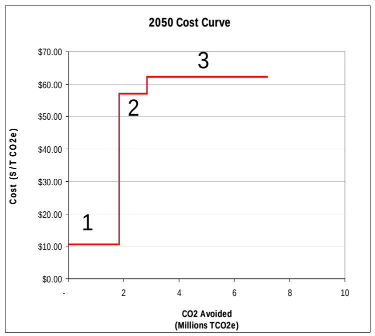
Energy supply	Transport	Buildings	Industry	Agriculture	Forestry	Waste
(potential at <US$100/ tCO_2-eq: 2.4 - 4.7 Gt CO_2-eq/yr)	(potential at <US$100/ tCO_2-eq: 1.6 - 2.5 Gt CO_2-eq/yr)	(potential at <US$100/ tCO_2-eq: 5.3 -6.7 Gt CO_2-eq/yr)	(potential at <US$100/ tCO_2-eq: 2.5 - 5.5 Gt CO_2-eq/yr)	(potential at <US$100/ tCO_2-eq: 2.3 -6.4 Gt CO_2-eq/yr)	(potential at <US$100/ tCO_2-eq: 1.3 - 4.2 Gt CO_2-eq/yr)	(potential at <US$100/ tCO_2-eq: 0.4 - 1 Gt CO_2-eq/yr)

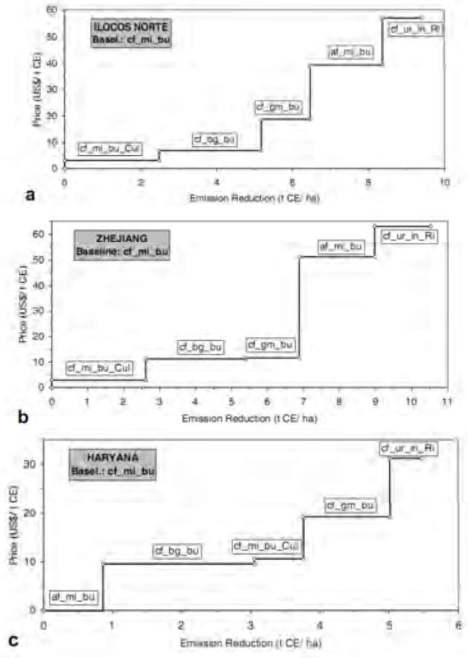
IPCC AR4 WGIII SPM

Abatement cost in rice field : case of Thailand 10-60 $per tonnes CO2e

1 water drainage
2 Change fertilizer
3 combination of 1 and 2





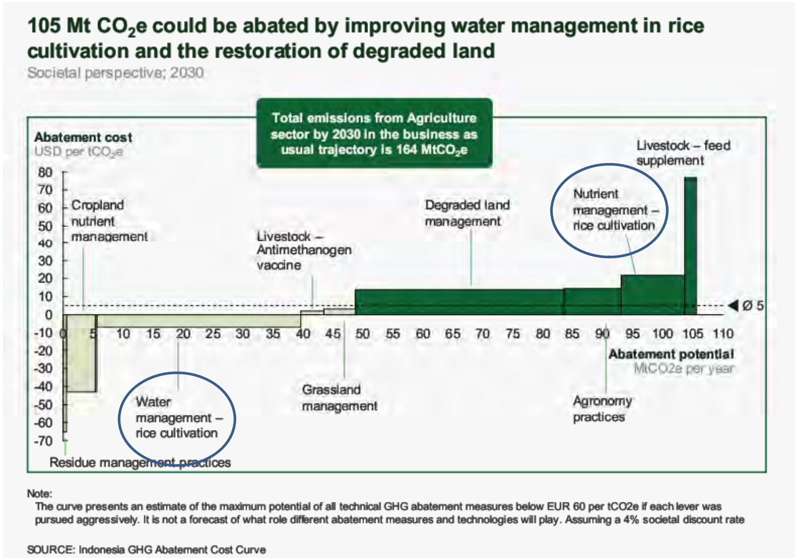


Marginal abatement cost curves for 3rd
Baseline technology: continuous flooding ,
Mixed FYM/urea: straw burning

10-60 US$ /tCe

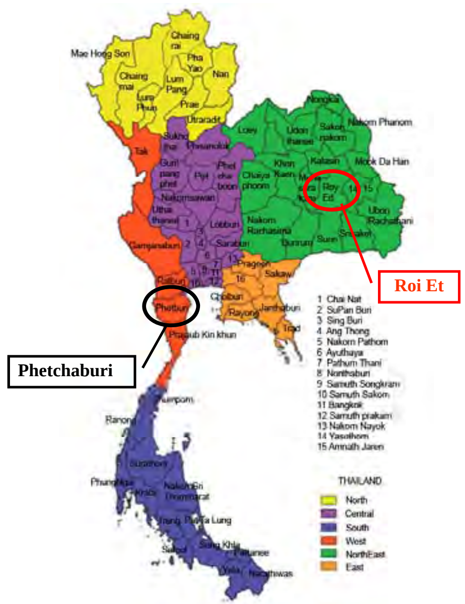
Wassman et al 2007

Abatement cost curve in agriculture sector of Indonesia



Mitigation and trade

Example of Carbon footprint study



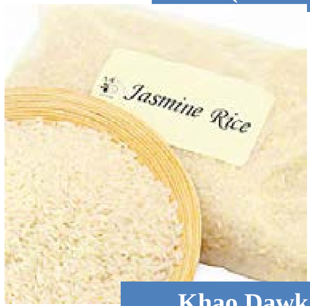
Roi Et province

- **rains-fed system**
- **Khao Dawk Mali 105 (jasmine rice)**
- **seed broadcasting and transplanted methods**

Phetchaburi province

- **irregated system**
- **Leuang Pratew 123 (ordinary rice)**
- **seed broadcasting**

Leuang Pratew 123 (ordinary rice)



Khao Dawk Mali 105 (jasmine rice)

Seed broadcasting Method

Transplant Method

Cultivation practice at Roi Et and Phetchaburi province

Location	Cultivation practice				
	Rice Cultivar	Soil preparation	Planting Method	Fertilizer	Harvesting Method
Roi Et (Rt)	Khao Dawk Mali 105	Machinery	Transplanted Method	Organic fertilizer	Man power
Roi Et (Rs)	Khao Dawk Mali 105	Machinery	Seed broadcasting Method	Chemical fertilizer	Machinery
Phetchaburi	Leuang Pratew 123	Machinery	Seed broadcasting method	Organic fertilizer	Machinery

Flux measurement and calculation

Methane from rice cultivation

$$F = \frac{dc}{dt}\frac{V}{A} \quad \text{x } 21$$

Close chamber method

Nitrous oxide from cultivation

$$F = \frac{dcV}{dt\,A} \quad \text{x } 310$$

Close chamber method

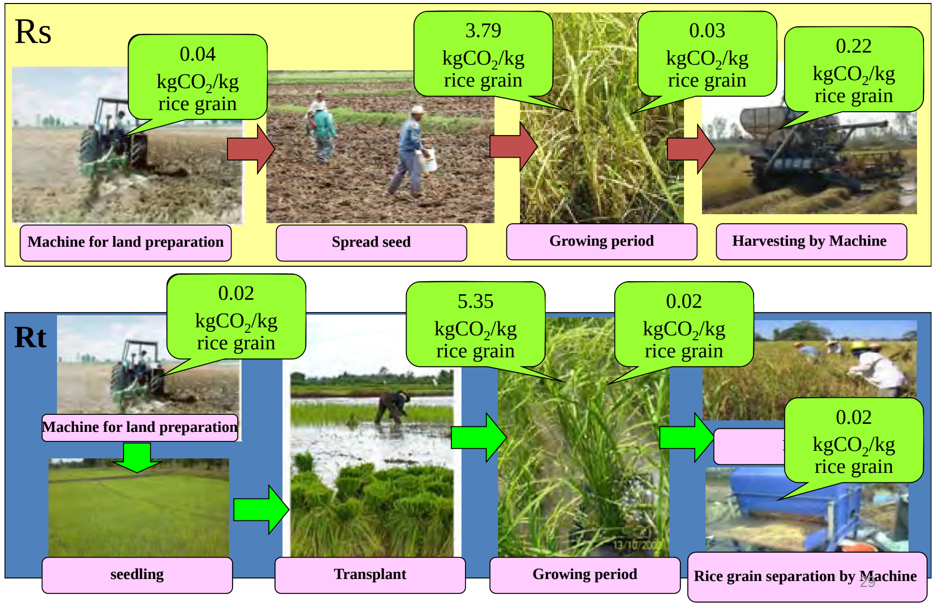
Carbon dioxide from machinery

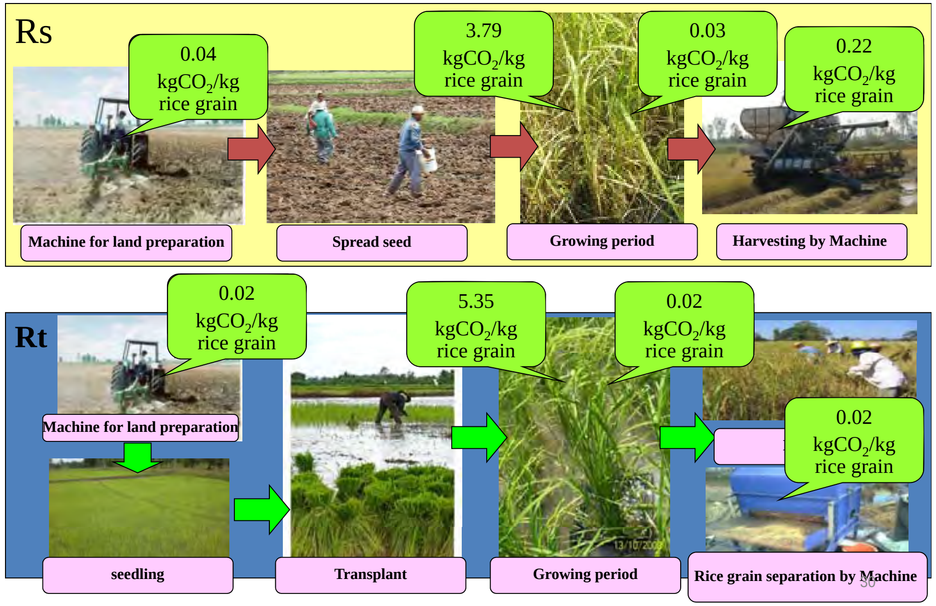
Carbon emission = ∑ fuel consumption expressed in energy units (TJ) x carbon emission factor x fraction oxidized (IPCC, 1996)

Collected data and calculated

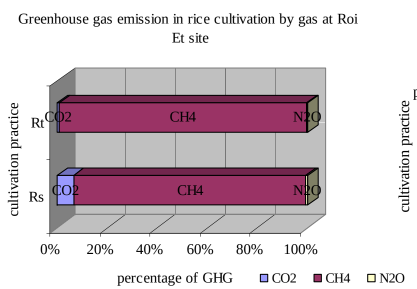
CO_2 equivalent emission from rice cultivation

Cultivation Practice at Roi Et site

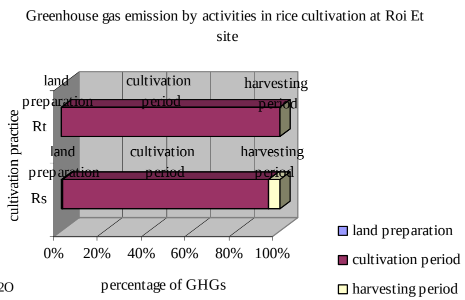




Percentage of GHGs emission released in the rice field at Roi Et site



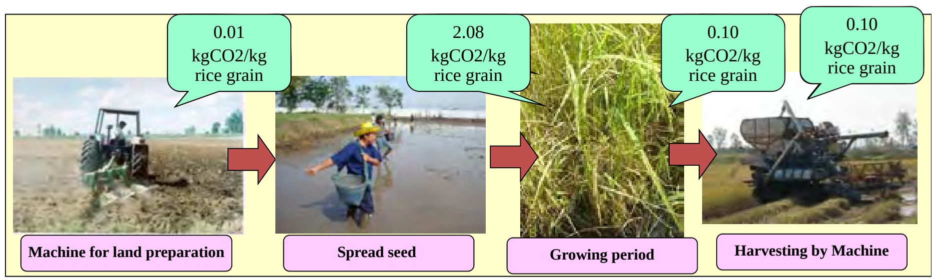
By gases



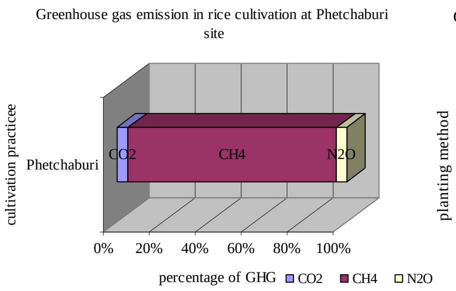
By activities

Cultivation Practice at Phetchaburi site

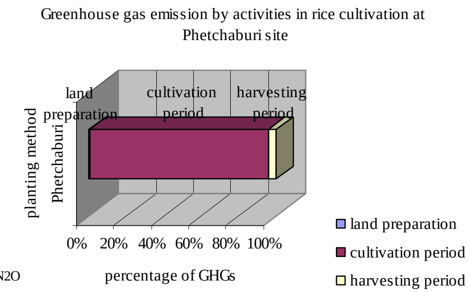
Phetchaburi site



Percentage of GHGs emission released in the rice field at Phetchaburi site



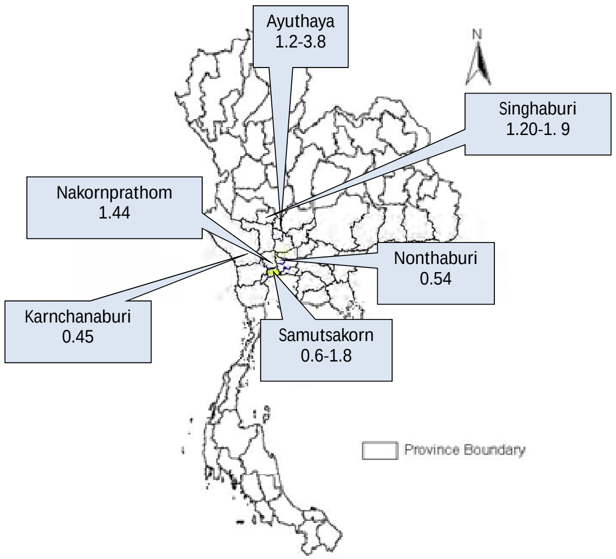
By gases



By activity

Carbon footprint of rice cultivation at Roi Et and Phetchaburi site

Location	Planting method	Rice grain yield (kg/rai)	CH_4 from rice field (kg CO_2/kg rice grain)	N_2O from rice field (kg CO_2/kg rice grain)	CO_2 from machinery (kg CO_2/kg rice grain)	Total (kg CO2/kg rice grain)
Roi Et	Seed broadcasting (Rs)	207	3.79	0.03	0.26	4.08
	Transplant (Rt)	336	5.35	0.02	0.04	5.41
Phetchaburi	Seed broadcasting	654	2.08	0.10	0.11	2.29



Mitigation and Carbon Credit

- Direct emission reduction
  - cultivation practice
- Indirect emission reduction
  - Rice straw removal and rice husk to produced heat and electricity
  - Rice straw removal for composting

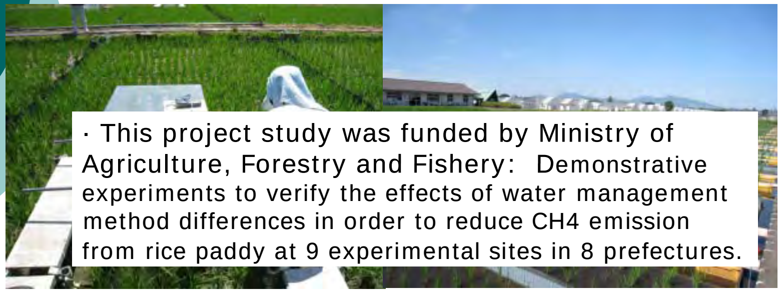
Conclusion

- There are several factors involved in GHG emission and mitigation from rice field
- Emission reduction is between 10 up to 70 percent of base case due to options and area used
- GHG mitigation in rice field can be implemented with low cost
- mitigation is likely to be involve with trade in the future




Implications of rice cultivation practices on GHG emissions

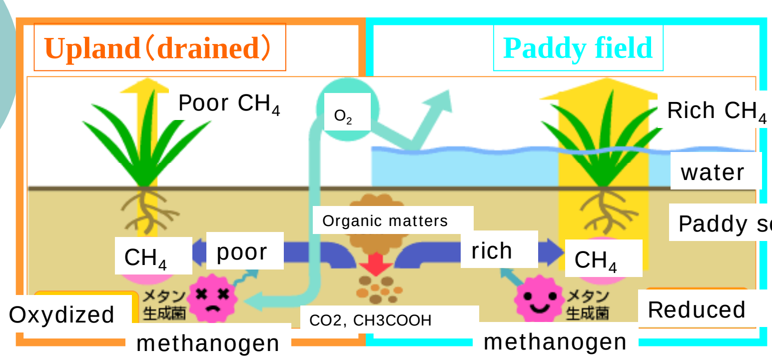
Project ‘NAKABOSHI’ = mid-season-drainage



· This project study was funded by Ministry of Agriculture, Forestry and Fishery: Demonstrative experiments to verify the effects of water management method differences in order to reduce CH4 emission from rice paddy at 9 experimental sites in 8 prefectures.

Shigeto Sudo, Masayuki Itoh and Kazuyuki Yagi

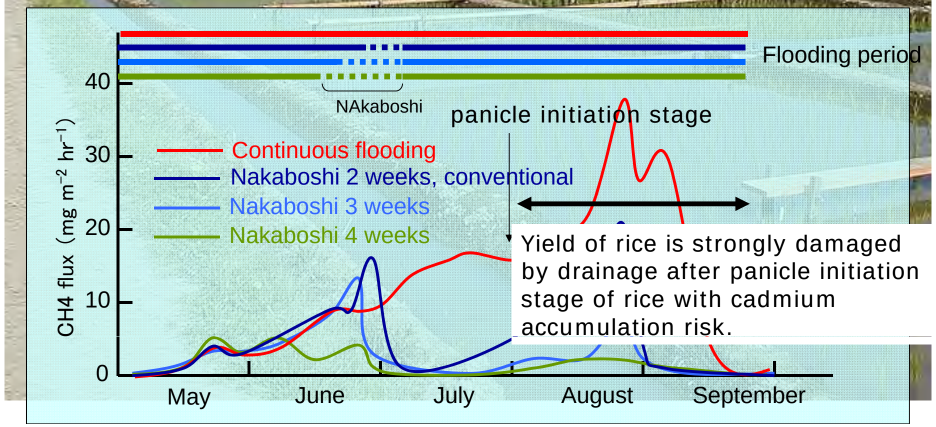
Mechanisms of CH4 emission from rice paddy field



- CH4 in paddy soil is emanated by the activities of anaerobic bacteria which is called methane producer through reduction of CO2 or decomposition of acetic acid
- It is effective to control methane emission from rice paddy that period is prolonged on intermittent irrigation drainage, composted rice straw is incorporated as fertilizer instead of flesh one, or other.

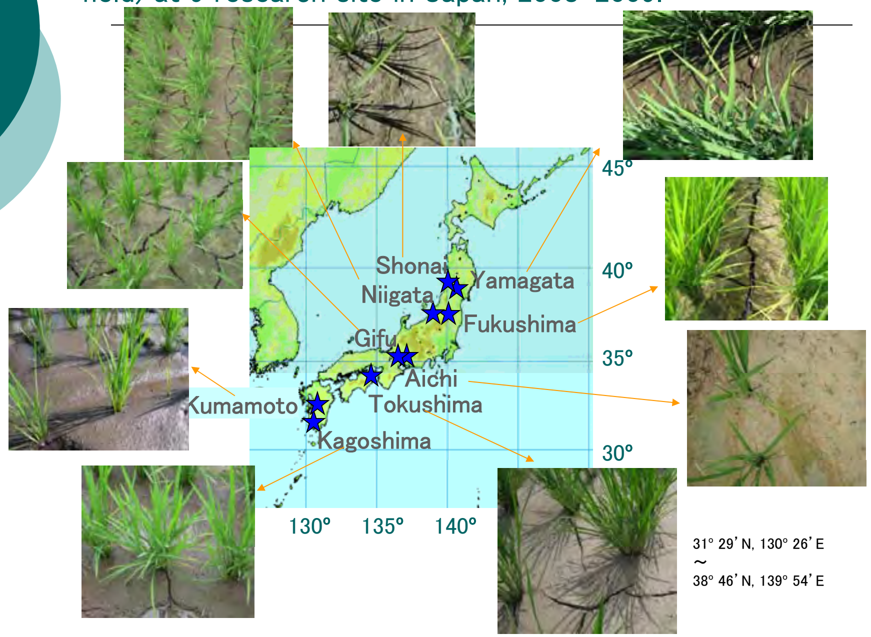
Reduction of CH_4 emission by prolonged Nakaboshi (mid-season-drainage) period; Fukushima Prefectural Agricultural Center in 2004.

●CH4 emission in paddy field is able to reduce prolonged ‘Nakaboshi’ treatments.



Yield of rice is strongly damaged by drainage after panicle initiation stage of rice with cadmium accumulation risk.

Photos of Nakaboshi (mid– season– drainage in rice paddy field) at 9 research site in Japan, 2008–2009.



Overview of the Study

- To verify the effect of prolonged Nakaboshi (mid-season-drainage) period for methane reduction in paddy field in order to find realistic solution of CH_4 reduction for each site.
  - Methane flux observation once per week.
  - 3 treatments, 3 replications per site.

Points:

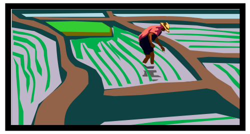
1. How much amount of CH_4 is reduced by modified water management compared with BAU (business as usual = conventional management in each prefecture) method?
2. Can we go uniformed water management improvement for all paddy fields in Japan？
3. How can we change water management policy if reduction or emission patterns of CH_4 result are different？

BAU is different in each prefecture!

BAU: Business As Usual = conventional water management at each site guided by the prefecture government.

- Recommended rice variety is different in each prefecture.
  - Each rice variety is original brand of each prefecture which has a fierce competition with others in yield, taste, etc.
    - Niigata – Koshihikari
    - Yamagata – Haenuki
    - Gifu – Hatsushimo
    - Kumamoto – Morinokumasan
    - Kagoshima – Hinohikari
    - etc.

- Each variety has each suitable cultivation method of fertilization, water management, soil type, cultivation period, harvesting season etc.
  - It is impossible to unify cultivation method beyond prefecture border.
- It is necessary to find suitable cultivation method one by one to elucidate win-win solution to obtain the best harvest yield and taste with minimum methane emission from paddy field.

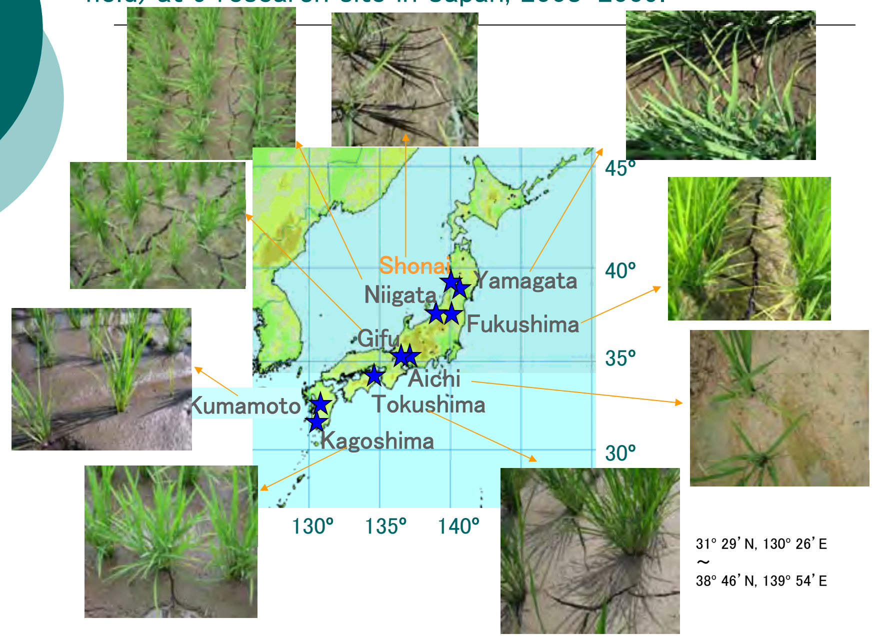


Options of alteration of Nakaboshi water management.
(Nakaboshi = mid-season-drainage)

1. Length of extend of Nakaboshi period
   e.g. 1 week -> 2 weeks (7days extend)
   Prefectures: All 9 sites
2. Timing of drainage extend (forward or backward)
   e.g. 1 week ahead (backward: July 1 – July 7→ June 24 – July 7)
   1 week extend (forward: July 1 – July7 → July 1 – July 14)
   Prefectures: both → Yamagata, Aichi
   ahead → Fukushima, Shonai
   extend→Niigata, Kumamoto,
3. Times of drainage
   e.g. 2 times (July 1 – July 7 → June 20-25 and July 1 –July7)
   Prefectures: Gifu, Tokushima
4. Intermittent drainage
   e.g. (continuous flooding → 3days flood - 4days drainage – 3days flood – 4 days drainage ------)
   Prefectures: Kagoshima, Gifu

<u>We do not have single solution.....</u>
<u>Best solution should be found one by one respectively for each site.</u>

Photos of Nakaboshi (mid- season- drainage in rice paddy field) at 9 research site in Japan, 2008-2009.



Options of alteration of Nakaboshi water management.
(Nakaboshi = mid-season-drainage)

1. Length of extend of Nakaboshi period
   e.g. 1 week -> 2 weeks (7days extend)
   Prefectures: All 9 sites

2. Timing of drainage extend (forward or backward)
   e.g. 1 week ahead (backward: July 1 – July 7→ June 24 – July 7)
   1 week extend (forward: July 1 – July7 → July 1 – July 14)
   Prefectures: both → Yamagata, Aichi
   ahead → Fukushima, Shonai
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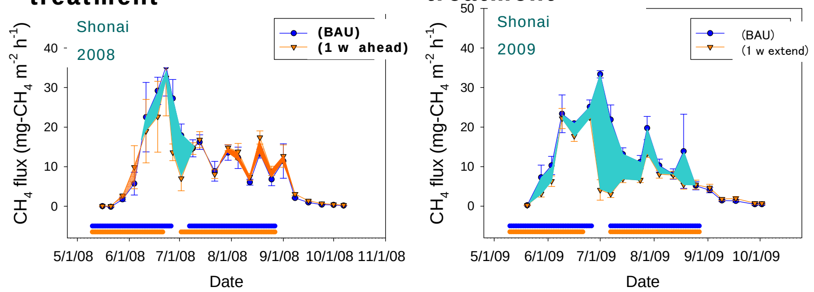
3. Times of drainage
   e.g. 2 times (July 1 – July 7 → June 20-25 and July 1 –July7)
   Prefectures: Gifu, Tokushima

4. Intermittent drainage
   e.g. (continuous flooding → 3days flood - 4days drainage – 3days flood – 4 days drainage ------)
   Prefectures: Kagoshima, Gifu

CH_4 emission in paddy field (Shonai)

1 week ahead Nakaboshi treatment | **5 days prolonged Nakaboshi treatment**

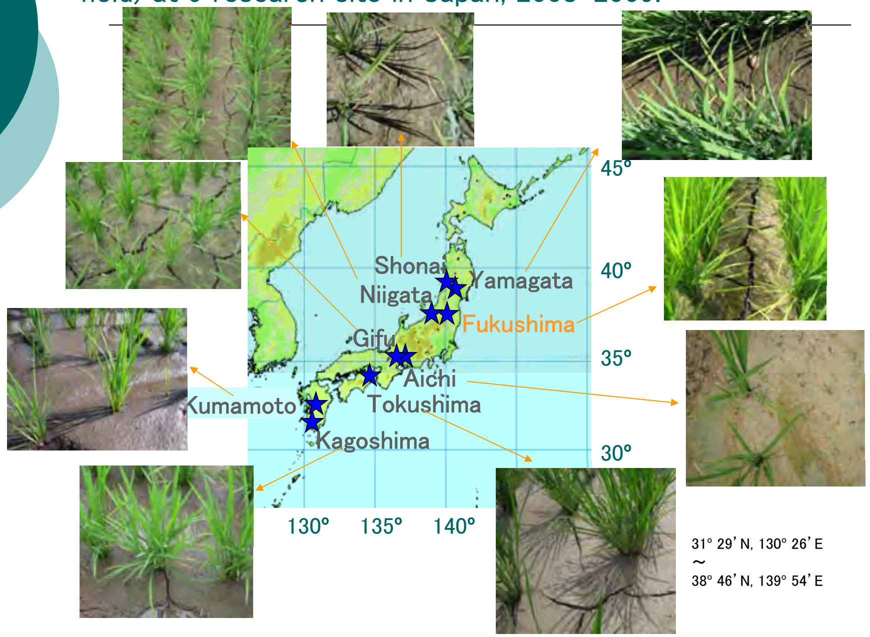


			2008			2009	
CH4 flux	(BAU)	7d	37.0		10d	38.0	
(g–CH_4/m^{-2})	(1 week ahead)	7d	34.8	− 6 %	15d	24.1	− 37 %
Rice yield	(BAU)		614				
(Kg/10a)	(1 week ahead)		603	− 2 %			

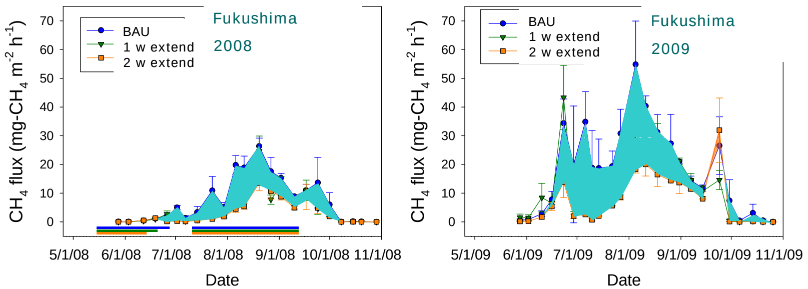
Haenuki

** p <0.01

Photos of Nakaboshi (mid– season– drainage in rice paddy field) at 9 research site in Japan, 2008–2009.



CH_4 emission in paddy field (Fukushima)



		2008		2009	
CH_4 flux	(BAU)	28.3		68.4	
(g–CH_4/m^{-2})	(1 w extend)	18.6	− 34 %	45.2	− 34 %
	(2 w extend)	11.8	− 58 %**	35.9	− 52 %
Rice yield	(BAU)	701			
(Kg/10a)	(1 w extend)	662	− 6 %		
	(2 w extend)	587	− 16 %		

Koshihikari

Options of alteration of Nakaboshi water management.
(Nakaboshi = mid-season-drainage)

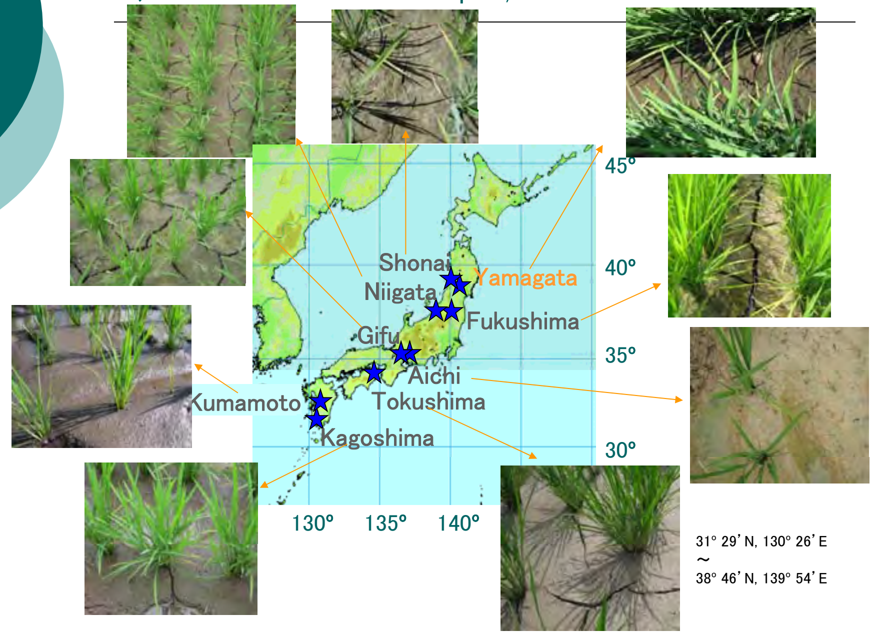
1. Length of extend of Nakaboshi period
   e.g. 1 week -> 2 weeks (7days extend)
   Prefectures: All 9 sites

2. Timing of drainage extend (forward or backward)
   e.g. 1 week ahead (backward: July 1 – July 7→ June 24 – July 7)
   1 week extend (forward: July 1 – July7 → July 1 – July 14)
   Prefectures: both → Yamagata, Aichi
   ahead → Fukushima, Shonai
   extend→Niigata, Kumamoto,

3. Times of drainage
   e.g. 2 times (July 1 – July 7 → June 20-25 and July 1 –July7)
   Prefectures: Gifu, Tokushima

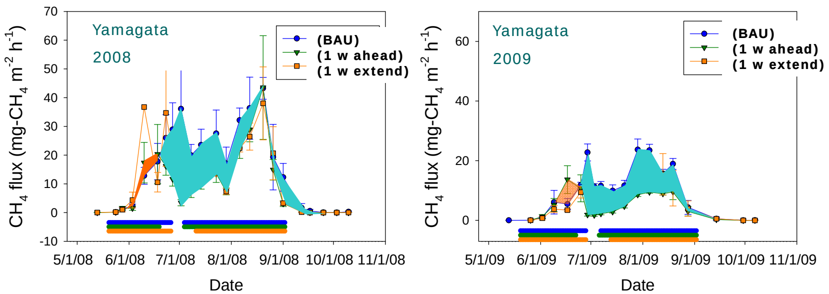
4. Intermittent drainage
   e.g. (continuous flooding → 3days flood - 4days drainage – 3days flood – 4 days drainage ------)
   Prefectures: Kagoshima, Gifu

Photos of Nakaboshi (mid– season– drainage in rice paddy field) at 9 research site in Japan, 2008–2009.



CH4 emission in paddy field (Yamagata)

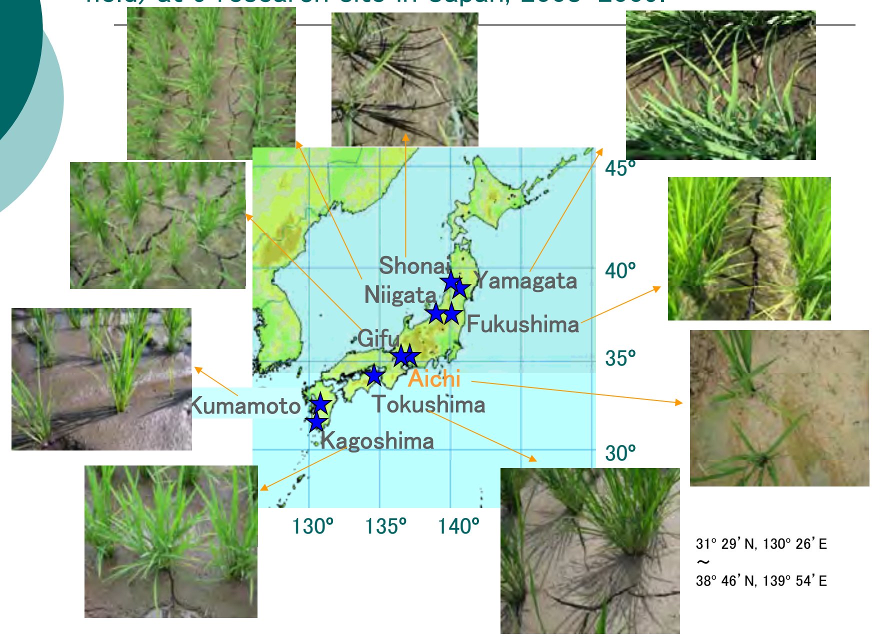
Same treatments in 2008 and 2009



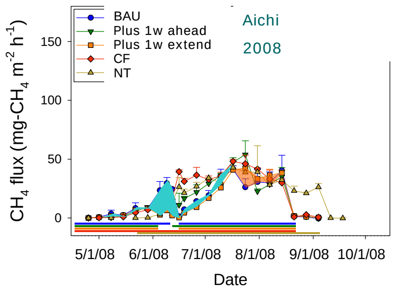
		2008		2009	
CH_4 (g–CH_4/m^{-2})	(BAU)	57.0		28.7	
	(1 week ahead)	36.1	– 37 %	14.8	–
	(1 week extend)	48.2	– 16 %	18.0	48 % – 37 %
Yield (Kg/10a) Haenuki	(BAU)	667			
	(1 week ahead)	643	– 4 %		
	(1 week extend)	673	+ 1 %		

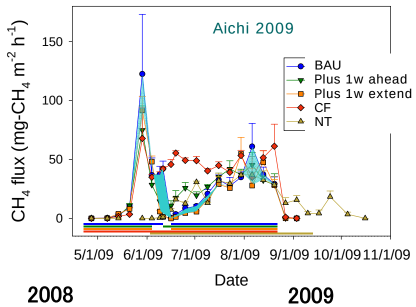
BAU: 1 week Nakaboshi, while other 2 are 2 weeks (ahead and extend)

Photos of Nakaboshi (mid– season– drainage in rice paddy field) at 9 research site in Japan, 2008–2009.



CH_4 emission in paddy field (Aichi)





		2008		2009	
CH4 flux	(BAU)	54.0		78.6	
(g-CH_4/m^{-2})	(plus1w ahead)	55.2	+ 2 %	71.7	− 9 %
	(plus 1w extend)	45.1	− 17 %	64.7	−
	(CF)	66.2		104.4	18 %
	(NT)	64.8			
Rice yield	(BAU)	581			
(Kg/10a)	(plus 1w ahead)	497	− 10 %		
Koshihikari	(plus 1w extend)	520	− 6 %		

BAU: business as usual, CF: continuous flooding, NT: non tillage

Options of alteration of Nakaboshi water management.
(Nakaboshi = mid-season-drainage)

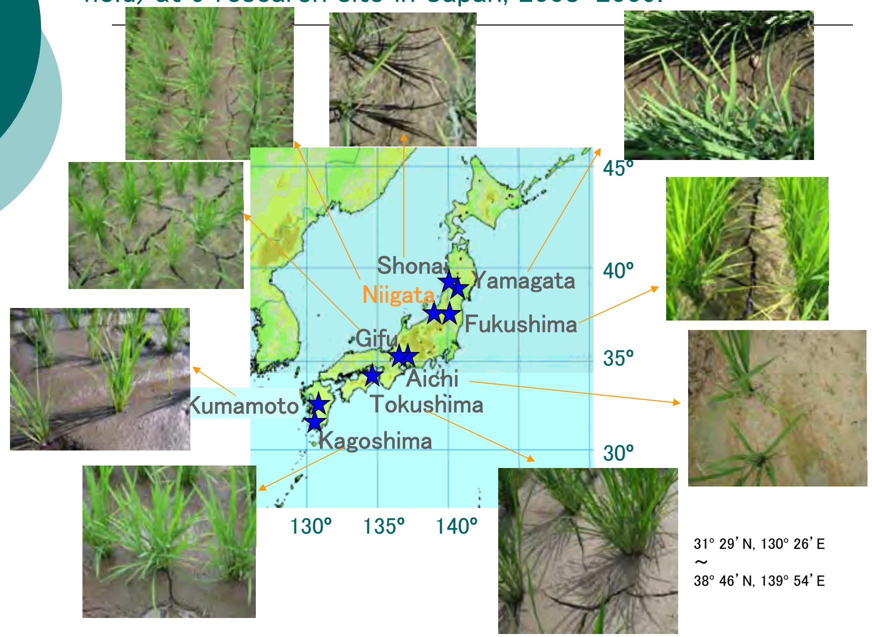
1. Length of extend of Nakaboshi period
   e.g. 1 week -> 2 weeks (7days extend)
   Prefectures: All 9 sites

2. Timing of drainage extend (forward or backward)
   e.g. 1 week ahead (backward: July 1 – July 7→ June 24 – July 7)
   1 week extend (forward: July 1 – July7 → July 1 – July 14)
   Prefectures: both → Yamagata, Aichi
   ahead → Fukushima, Shonai
   extend→Niigata, Kumamoto,

3. Times of drainage
   e.g. 2 times (July 1 – July 7 → June 20-25 and July 1 –July7)
   Prefectures: Gifu, Tokushima

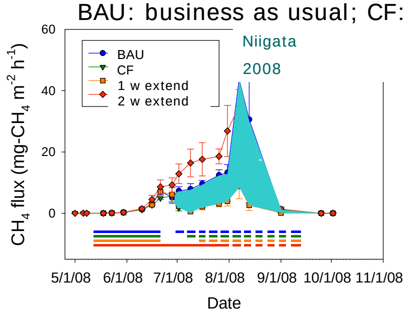
4. Intermittent drainage
   e.g. (continuous flooding → 3days flood - 4days drainage – 3days flood – 4 days drainage ------)
   Prefectures: Kagoshima, Gifu

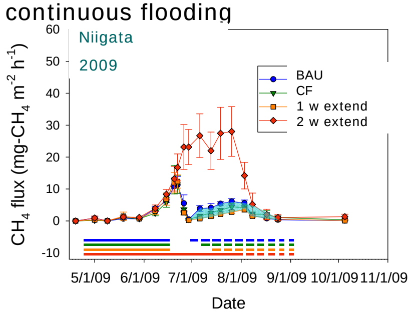
Photos of Nakaboshi (mid– season– drainage in rice paddy field) at 9 research site in Japan, 2008–2009.



CH_4 emission in paddy field (Niigata)

BAU: business as usual; CF: continuous flooding

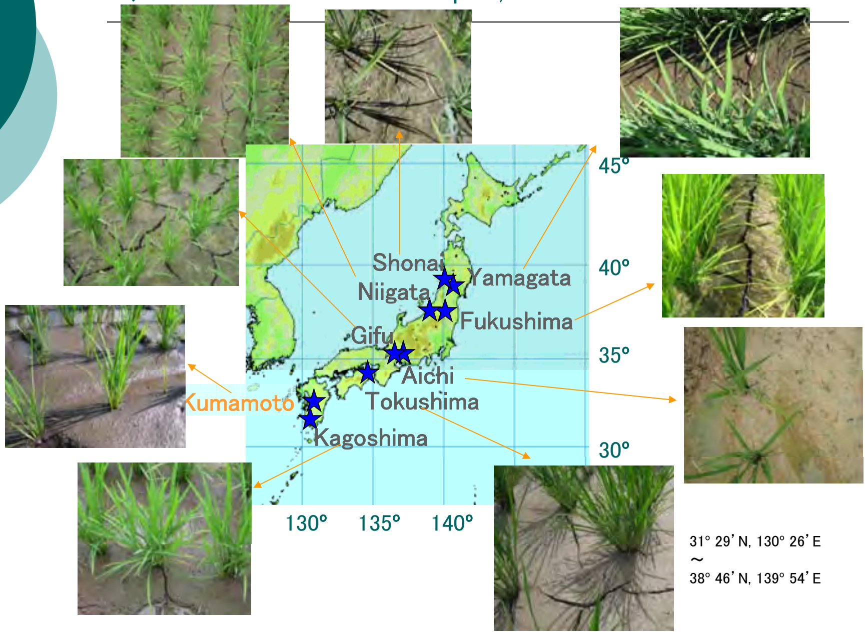




		2008		2009	
CH4 flux	(BAU)	24.9		9.2	
(g-CH_4/m^{-2})	(1 w extend)	12.4	− 50 %	8.2	−
	(2 w extend)	6.9	− 72 %	6.9	11 %
	(CF)	30.6		31.8	−
Rice yield	(BAU)	621			25 %
(Kg/10a)	(1 w extend)	597	− 4 %		
	(2 w extend)	609	− 2 %		
	(CF)				

Koshihikari

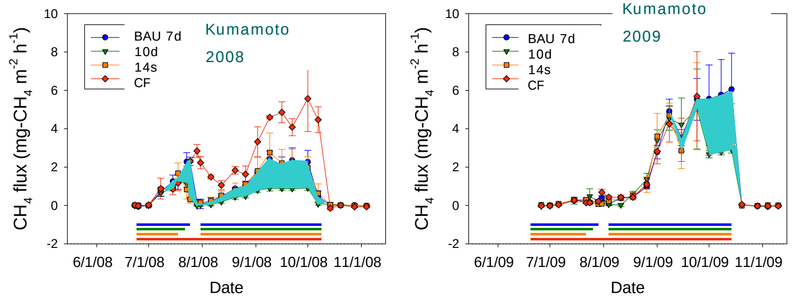
Photos of Nakaboshi (mid- season- drainage in rice paddy field) at 9 research site in Japan, 2008-2009.



31° 29' N, 130° 26' E
~
38° 46' N, 139° 54' E

CH_4 emission in paddy field (Kumamoto)

BAU: 7days nakaboshi, 10d: 10 days, 14d: 14days
CF: continuous flooding



		2008		2009	
CH4 flux	(BAU 7d)	3.1		6.1	
($g-CH_4/m^{-2}$)	(10d)	1.4	− 55 %**	4.9	−
	(14d)	2.9	− 6 %	5.0	21 %
	(CF)	6.5		5.2	−
Rice yield	(BAU 7d)	715			19 %
(Kg/10a)	(10d)	649	− 9 %		
	(14d)		− 2 %		
Morinokumasan	(CF)				

Rice straw residue was not incorporated in 2008 and 2009 before flooding

Options of alteration of Nakaboshi water management.
(Nakaboshi = mid-season-drainage)

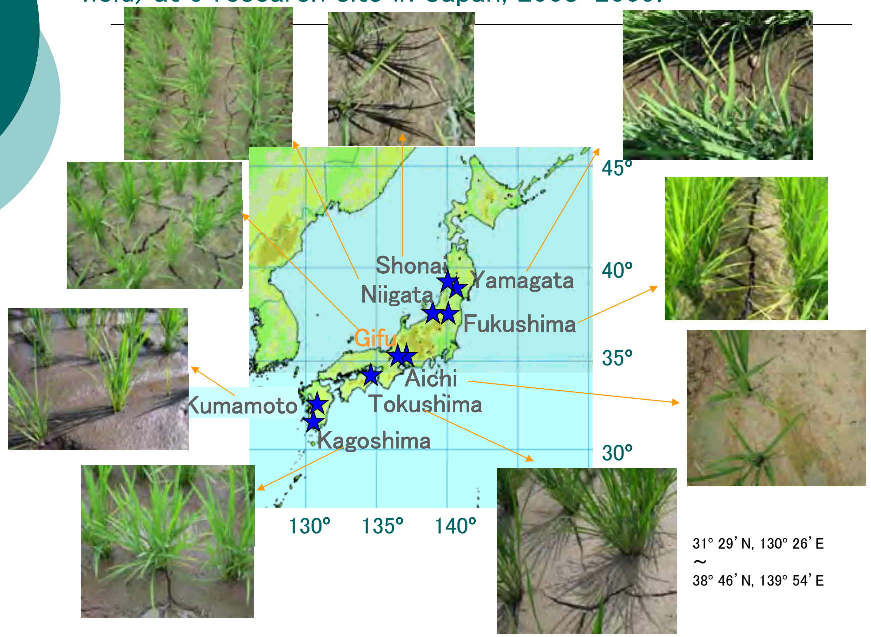
1. Length of extend of Nakaboshi period
   e.g. 1 week -> 2 weeks (7days extend)
   Prefectures: All 9 sites

2. Timing of drainage extend (forward or backward)
   e.g. 1 week ahead (backward: July 1 – July 7→ June 24 – July 7)
   1 week extend (forward: July 1 – July7 → July 1 – July 14)
   Prefectures: both → Yamagata, Aichi
   ahead → Fukushima, Shonai
   extend→Niigata, Kumamoto,

3. Times of drainage
   e.g. 2 times (July 1 – July 7 → June 20-25 and July 1 –July7)
   Prefectures: Gifu, Tokushima

4. Intermittent drainage
   e.g. (continuous flooding → 3days flood - 4days drainage – 3days flood – 4 days drainage ------)
   Prefectures: Kagoshima, Gifu

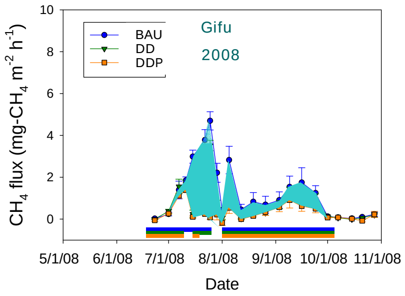
Photos of Nakaboshi (mid- season- drainage in rice paddy field) at 9 research site in Japan, 2008-2009.

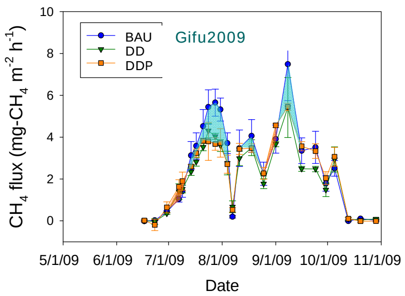


31° 29' N, 130° 26' E
~
38° 46' N, 139° 54' E

CH_4 emission in paddy field (Gifu)

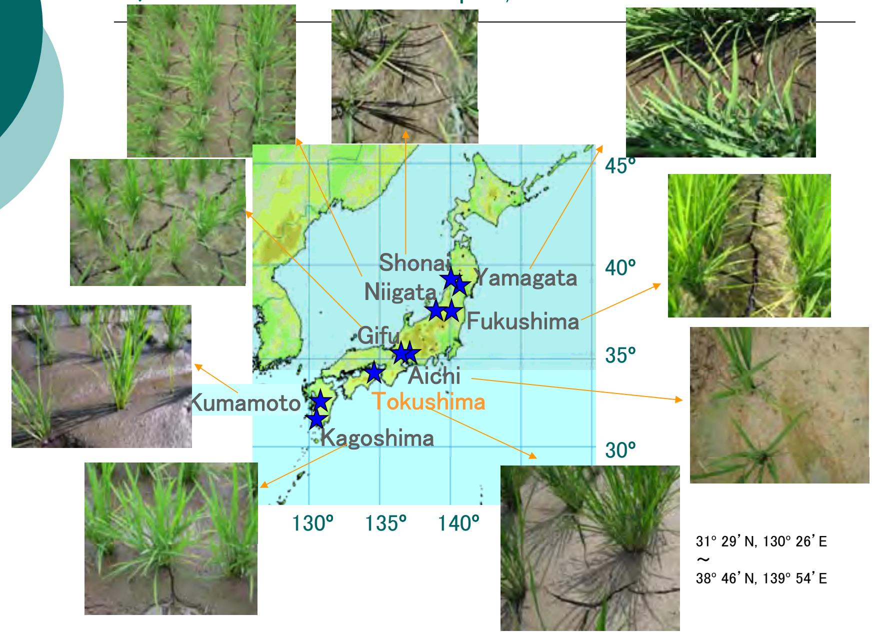
BAU: business as usual, DD: double drainage,
DDP: double drainage plus 1week





		2008		2009	
CH4 flux	(BAU)	3.9		8.4	
(g−CH_4/m^{-2})	(double drainage)	2.4	− 40 %	6.8	−
	(double drainage plus 1w)	1.1	− 73 %**	7.6	19 %
					− 9 %
Rice yield	(BAU)	499			
(Kg/10a)	(double drainage)	429	− 14 %		
	(double drainage plus 1w)	407	− 18 %		

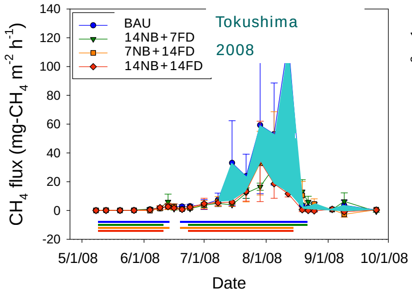
Photos of Nakaboshi (mid- season- drainage in rice paddy field) at 9 research site in Japan, 2008-2009.

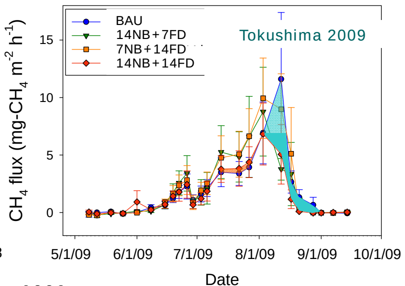


31° 29' N, 130° 26' E
~
38° 46' N, 139° 54' E

CH_4 emission in paddy field (Tokushima)

BAU: Business as usual (7days nakaboshi + 7days final drainage)
14NB+7FD: 14days nakaboshi + 7days final drainage
7NB+14FD: 7days nakaboshi + 14days final drainage
14NB+14FD: 14days nakaboshi + 14days final drainage





		2008		2009	
CH4 flux	(BAU)	53.5		6.7	
(g−CH_4/m^{-2})	(14NB+7FD)	23.3	− 56 %	6.7	+ 18 %
	(7NB+14FD)	26.8	− 50 %	7.9	− 0.4 %
	(14NB+14FD)	16.7	− 69 %	5.4	− 19 %
Rice yield	(BAU)	700			
(Kg/10a)	(14NB+7FD)	663	− 5 %		
	(14NB+14FD)				
	(14NB+14FD)	666	− 5 %		

In 2008 astragalus residue was incorporated before tillage and flooding.

Options of alteration of Nakaboshi water management.
(Nakaboshi = mid-season-drainage)

1. Length of extend of Nakaboshi period
   e.g. 1 week -> 2 weeks (7days extend)
   Prefectures: All 9 sites

2. Timing of drainage extend (forward or backward)
   e.g. 1 week ahead (backward: July 1 – July 7→ June 24 – July 7)
   1 week extend (forward: July 1 – July7 → July 1 – July 14)
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   ahead → Fukushima, Shonai
   extend→Niigata, Kumamoto,

3. Times of drainage
   e.g. 2 times (July 1 – July 7 → June 20-25 and July 1 –July7)
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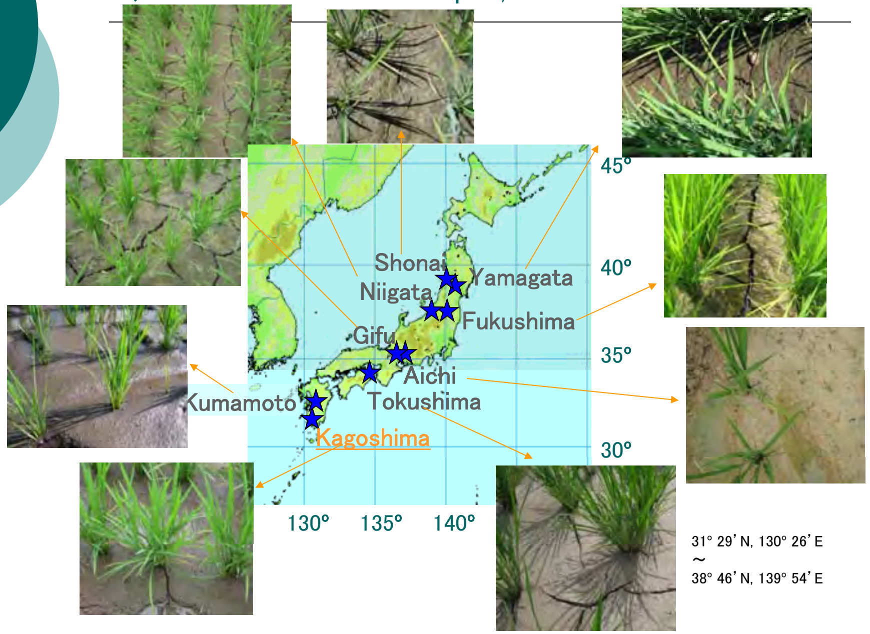
4. Intermittent drainage
   e.g. (continuous flooding → 3days flood - 4days drainage – 3days flood – 4 days drainage ------)
   Prefectures: Kagoshima, Gifu

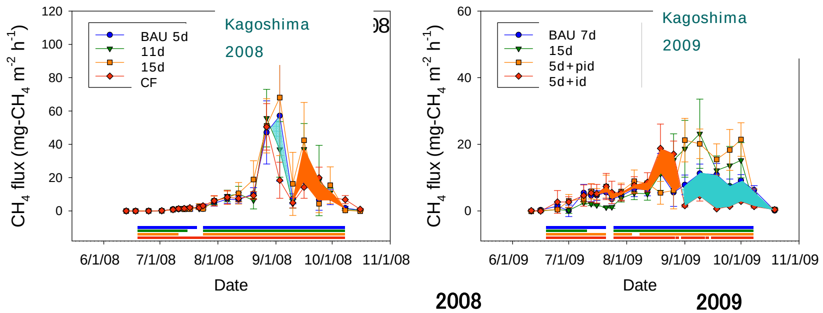
Photos of Nakaboshi (mid- season- drainage in rice paddy field) at 9 research site in Japan, 2008-2009.



31° 29' N, 130° 26' E
~
38° 46' N, 139° 54' E

CH_4 emission in paddy field (Kagoshima)

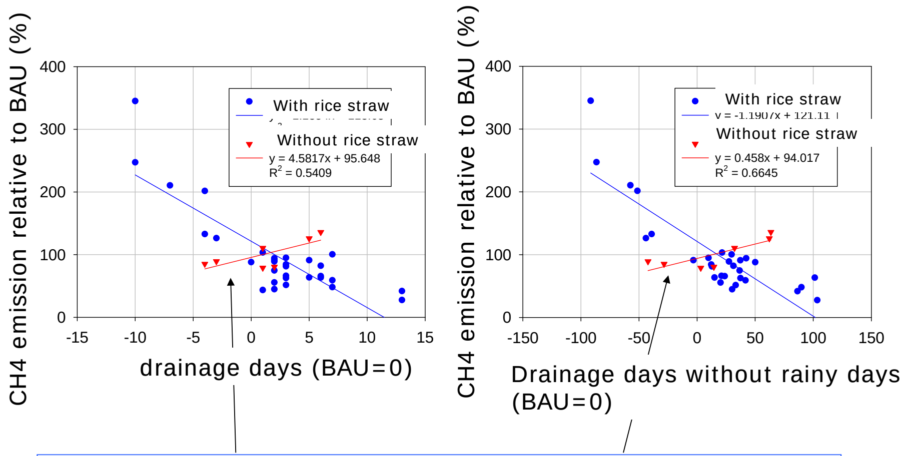
BAU: 5days nakaboshi, 11d: 10 days, 15d: 15days
CF: continuous flooding,, pid: drainage at panicle initiation stage
id: intermittent drainge



		2008		2009	
CH4 flux ($g\text{-}CH_4/m^{-2}$)	(BAU)	30.6		18.1	
	(11d)	33.8	+ 10 %	22.8	+
	(15d)	41.4	+ 35 %	26.7	25 %
	(CF)	27.0		15.5	+
Rice yield (Kg/10a)	(BAU)	415			47 %
	(11d)	453			–
	(15d)	443			15 %
	(CF)				

Rice straw residue was not incorporated in 2008 and 2009 before flooding

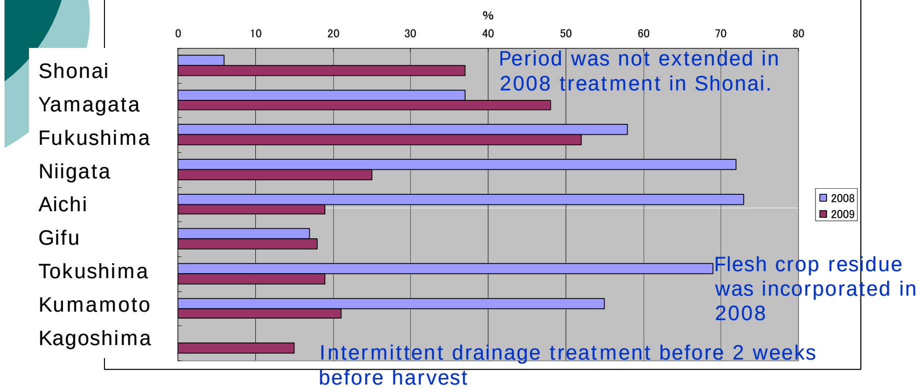
Change of methane emission from BAU by drainage (Nakaboshi) length (horizontal: BAU is 0, vertical: BAU is 100)



No linear relationship was revealed in the plots in which rice straw residue were not incorporated.

Summary of positive results to reduce CH_4 in paddy field.

CH4 reduction ratio of modified Nakaboshi to BAU



Average reduction recovery in 2008: 48.4%, in 2009:31.5%

High reduction potentials were observed although differences of experimental sites, inter-annual variations were shown.

Conclusion

- We conducted tests to verify the improvements of water management in order to reduce CH_4 emission from rice paddy at 9 experimental sites in 8 prefectures.
- The longer length of Nakaboshi (mid-season-drainage) period was prolonged, the lesser amounts of CH_4 emitted even after when Nakaboshi period lasted, as a whole.
- In some cases, for example in Kagoshima, exceptional phenomena of that significant high emission were observed at a later stage of cultivation season (around the end of August). Adjusting of Nakaboshi periods was not effective in such cases.
- In most of cases, emission of N_2O was not increased during prolonged Nakaboshi period.

Thank you for your attention!

中干し延長の効果の適用可能性

※中干によるメタン削減が見込める地点

地点	年度	慣行中干し 日数	慣行中干し 発生量 ($g-CH_4/m^2$)	改良中干 処理	日数	対慣行比	平均	発生量 ($g-CH_4/m^2$)	メタン発生比率(%) (対慣行比)	平均
庄内	2009	11	38.0	中干前後延長	22	2.0		24.1	63	
山形	2008	7	55.7	中干前延長(7日延長)	14	2.0		35.4	64	
	2009	7	28.7	中干前延長(7日延長)	14	2.0		14.8	52	
福島	2008	14	28.3	中干前延長(7日延長)	21	1.5		18.6	66	
	2009	14	68.4	中干前延長(7日延長)	21	1.5		45.2	66	
新潟	2008	17	12.4	中干後延長(7日延長)	24	1.4		6.9	56	
	2009	14	9.2	中干後延長(7日延長)	21	1.5		8.2	89	
				中干後延長(14日延長)	28	2.0		6.9	75	
岐阜	2008	7	3.6	早期中干(6日)＋通常中干(計7日延長)	13	1.9	1.8 ± 0.45	2.1	59	74.4 ± 20.9
	2009	14	8.4	早期中干(5日)＋通常中干(計7日延長)	19	1.4		6.8	81	
愛知	2008	6	52.5	中干延長(7日延長)	13	2.2		46.2	88	
	2009	6	78.6	中干延長(7日延長)	13	2.2		64.7	82	
熊本	2008	7	3.1	中干延長(3日延長)	10	1.4		1.4	45	
	2009	7	6.1	中干延長(3日延長)	10	1.4		4.9	79	
※中干延長のみではメタン削減が見込めない地点										
徳島	2009	中干7+落水7	6.7	中干延長	21	1.5		6.7	100.5	
鹿児島	2009	5	18.1	中干前延長(10日延長)	15	3.0		22.8	126	

マニュアル山形

籾数制御技術として有効な中干しは、水田から発生する温室効果ガスであるメタンの発生を抑制する技術として有効である。土壌の還元化が進行するに従ってメタン発生量も増加することから、中干しの開始時期を早くする、中干し期間を延長する等により中干し程度を強め土壌を酸化的にする程、メタン発生の抑制効果がある。慣行よりも中干しの開始時期を早める、または1週間程度延長することにより、メタン発生量を約4割削減できる。しかし、生育量が過剰な場合は中干しの延長により籾数制御とメタン発生抑制が両立できるが、生育量が適正量以下の場合は収量が低下することがあるため十分留意する。

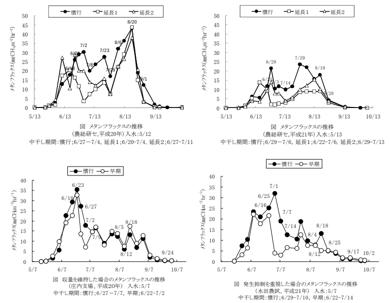


図 収量を維持した場合のメタンフラックスの推移 (庄内支場、平成20年) 入水:5/7 中干し期間:慣行;6/27－7/7, 早期;6/22-7/2

図 発生抑制を重視した場合のメタンフラックスの推移 (水田農試、平成21年) 入水:5/7 中干し期間:慣行;6/29-7/10, 早期;6/22-7/14

表 栽培期間中のメタン発生量

試験場所	年次	試験区	中干し期間	中干し日数	メタン総発生量 gm^{-2} 栽培期間	慣行対比	中干し期間	慣行対比
農総研セ	H20	延長1	6/20-7/4	14	35.5	64	4.9	38
		延長2	6/27-7/11	14	41.9	76	9.6	74
		慣行	6/27-7/4	7	55.0		13.0	
	H21	延長1	6/22-7/6	14	14.2	52	2.1	34
		延長2	6/29-7/13	14	17.1	63	4.3	67
		慣行	6/29-7/6	7	27.4		6.4	
庄内支場 (現水田農試)	H20	早期	6/22-7/2	10	33.9	94	6.0	78
		慣行	6/27-7/7	10	35.9		7.7	
	H21	早期	6/22-7/14	22	23.0	63	7.4	48
		慣行	6/29-7/10	11	36.5		15.4	

※中干し期間:延長1(または早期)の中干し開始から慣行中干し終了まで

表 中干し試験区の収量・収量構成要素・品質

試験場所	年次	試験区	最高分げつ期茎数 本/m^2	穂数 本/m^2	収量 kg/10a	収量 比	籾数 粒/1穂	籾数 ×100粒/㎡	千粒重 g	粒数歩合 %	玄米品質 整粒%	玄米品質 未熟粒%
農総研セ	H20	延長1	671	518	648	97	67.9	352	22.3	82.4	84	14
		延長2	644	516	673	101	69.6	358	22.5	83.4	85	14
		慣行	637	520	667	100	73.0	380	22.4	78.2	85	13
	H21	延長1	555	492	592	90	62.7	308	22.7	84.1	82	11
		延長2	538	464	630	95	71.5	331	22.7	83.1	82	10
		慣行	571	494	660	100	71.6	354	22.6	82.4	80	12
庄内支場 (現水田農試)	H20	早期	648	515	603	98	58.6	302	22.7	84.2	81	12
		慣行	618	499	614	100	63.6	317	22.4	82.8	79	14
	H21	早期	621	464	506	87	53.9	250	23.1	89.9	82	11
		慣行	568	457	583	100	67.8	310	23.2	83.1	76	16

福島マニュアル

水田から発生するメタン

温室効果ガスであるメタンは、二酸化炭素の約25倍の温室効果を持つガスで、二酸化炭素に次いで地球温暖化に影響を与えています(図1)。

水田に水を湛えることで、土壌が還元状態となり、嫌気性のメタン生成菌の活動が活発になります。メタン生成菌は、稲わらなどの有機物を基質として、メタンを生成します。生成したメタンは、水稲が自身の根に酸素を輸送する器官を通じて、大気中に放出されます。メタン生成菌が活性化するには、還元状態と有機物が必要となります(図2)。

図1 世界中で人間活動によって発生する温室効果ガスの排出量の割合（CO2換算値）(IPCC AR4 2007)

図2 水田でメタンが発生するメカニズム
嫌気条件下でメタン生成菌は土壌中の有機物を分解し、メタンを生成します。生成されたメタンの大部分はイネの通気組織を酸素と逆向きに通過し、大気中へ放出されます。
((独)農業環境技術研究所資料、つくばリサーチギャラリー農業技術ヴァーチャルミュージアムより)

日本において人間活動で排出されるメタンのうち水田から発生するメタンは25%を占めます。温室効果ガスの増加に伴う地球温暖化の進行を抑制するため、水田から発生するメタンの抑制が重要となってきています(図3)。

図3 日本で排出されるメタンの発生源と排出量の割合
(日本国温室効果ガスインベントリ報告書 2009)

新たな水管理による水田からのメタン発生抑制技術

水田から発生するメタンの抑制技術としては、まず水管理が上げられます。中干しや間断灌漑を行うことで、土壌を酸化的な状態にすることで発生は大きく減少します。

通常の中干しよりも期間を延長することで、さらにメタンの発生を抑制することが可能となります(図4)。

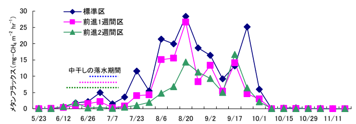


図4 水稲栽培期間中のメタン発生の推移（2008年測定）

技術の解説

中干し期間を通常より1週間から2週間ほど早く開始(前進化)し、通常の中干しの終了時期まで中干しを行います。本試験においては、通常の中干し期間である2週間に対し、1週間及び2週間の前進・延長化を行い、試験を実施いたしました(図5)。

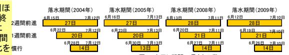


図5 中干し期間の長さと日数

本試験の結果、中干し期間を1週間前進・延長化した場合37%程度、2週間前進・延長化した場合で59%程度のメタン発生量が削減されました（図6）。

この技術によって削減されるメタンを二酸化炭素に換算すると、1haの水田あたり、1週間の前進・延長化でおよそ1.1台分、2週間の前進・延長化およそ1.8台分の自家用車の年間排出量と等しくなります。

（1日旅客自家用普通車1台あたりの平均燃料消費量 4.06L（H19陸運統計要覧）より算出）

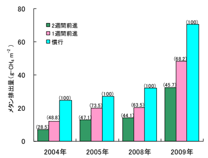


図6 中干し期間を変えた場合のメタンの総発生量の違い
()内は慣行区との比

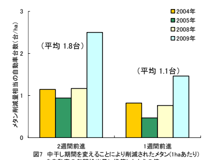


図7 中干し期間を変えることにより削減されたメタン(1haあたり)を自動車の年間排出量に換算したときの値
()内は2ヵ年の平均値

中干し前後の茎数の状況

中干しは、福島県中通り地域の水稲栽培暦を参考としながら、前倒しし、中干しを行いました。

中干し開始時の茎数は、2週間前進で約320本/㎡、1週間前進で約500本/㎡でした(表1)。

表1 試験ほ場における中干し以降の1㎡あたりの茎数及び穂数の状況(2005)

区名	6月16日 2週間前進 中干し開始時	6月23日 1週間前進 中干し開始時	6月30日 慣行 中干し開始時	7月22日 幼穂形成期	9月27日 成熟期
2週間前進	324	478	564	527	361
1週間前進	317	483	566	525	385
慣行	333	524	588	536	391

技術の留意点

1週間の前進化では、収量が5%程度(1～10%)、2週間の前進化では、11%程度(4～16%)低下する可能性があります(図8)。
中干し期間中に降水が多い場合や水はけの悪い水田では、溝きりをすることで効果が高くなります。

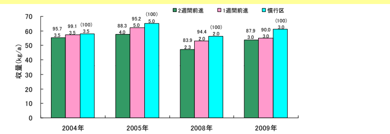


図8 各年の中干し期間の長さによる収量の比較

普及に向けたマニュアル・新潟

4　初中期の水管理

○　田植直後はやや深水として、保温的水管理とする。
○　活着後は浅水として、水温の上昇を図り分げつの発生を促し、良質茎の早期確保に努める。

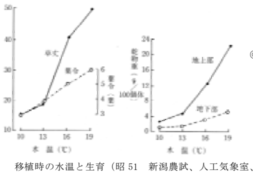
(1) 田植から活着期の水管理

良質米の安定生産のためには初期生育を促進し、良質茎を早期に確保することが重要である。初期生育促進には田植後の水管理が大きく影響する。

ア　田植後活着するまでは3～4cmのやや深水とし、保温的な水管理により低温や風による植え傷みを回避する。水温、気温が高いほど、発根、活着が早いので漏水を防止し、水温の上昇に努める。

イ　活着後は2～3cmのやや浅水とし、水温の上昇を図り分げつの早期発生を促す。

ウ　水を更新する場合は早朝に灌水し、日中は止水として水温の上昇を図る。



◎　活着・初期生育の促進には水温上昇が決め手である。

移植時の水温と生育（昭51　新潟農試、人工気象室、移植20日後調査）

(2) ワキの防止

田植後20日頃から好天時には地温が20～30℃に達し、生ワラ施用田では土壌の還元化が強まりワキの発生が多くなる。夜間落水や必要に応じて中耕を実施して（側条施肥は除く）ガス抜きを行い、土壌への酸素供給や有害物質の除去を図り根の健全化に努める。

ワキの成分の約30%は温室効果ガスであるメタンであるため、ワキの発生量削減は水田からの温室効果ガス発生量の削減につながる。

ワキの発生程度とその対策（昭55、新潟農試）

ワキの程度	ガスの発生量（ﾘｯﾄﾙ／a）	ワキの発生程度	水稲生育への影響	対策 5月下旬	対策 6月初旬
希	※15cc＞（200＞）	水田に足を踏み入れても気泡の発生がない。	なし	－	－
少	15～30cc（200～300）	水田に足を踏み込むと僅かに気泡の発生がみられる。	なし	－	－
中	30～50cc（300～400）	水田に足を踏み込むと気泡の発生が多い。	根の活力低下	用水の更新	用水の更新
多	50～70cc（400～500）	水田に足を踏み込むと盛んに気泡を発生する。	根張り不良	中耕と用水の更新	用水の更新を繰り返す
甚	70cc＜（500cc＜）	晴天時自然に気泡を発生し、音が聞こえる。また水田を歩くと著しく気泡を発生する。	根の伸長阻害 地上部黄化	中耕と用水の更新を繰り返す	間断かん水

※　ガスcc/30回転/容器、（ ）はﾘｯﾄﾙ/a
◎　水田に足を踏み込んだ時に気泡の発生が多いと初期生育が劣る。

エ　溝切り時期が遅くなると溝の形状も不完全となることが多く、十分な中干し効果が得られず、品質や作柄を不安定にしている場合があるので生育状況を把握して適期実施することが重要である。

地域別中干し時期のめやす

地域	移植期（栽植密度）	目標穂数（本/㎡）	中干し開始時期のめやす ㎡当たり茎数	時期
一般的な地域	5月10日（18株/㎡）	380	３００	6月10日
生育過剰になりやすい地域	5月10日（15株/㎡）	350	２５０	6月 5日

収量及び収量構成要素（平11　佐渡農技センター）

中干し時期 月日	穂数比	葉齢	稈長	穂長	有効茎歩合	㎡当たり穂数	1穂籾数	㎡当たり籾数	登熟歩合	精玄米千粒重	精玄米重
	%		cm	cm	%	本	粒	百粒	%	g	kg
早期(5/31)	42	5.9	93.0	18.8	62	378	70.5	266	89.2	22.2	51
標準(6/ 9)	85	7.6	96.3	18.0	64	410	70.2	288	84.3	21.8	50
遅期(6/21)	143	9.0	97.5	18.2	65	427	70.3	300	83.7	22.2	52

注）穂数比は目標穂数390本／㎡（佐渡）に対する比率。精玄米は篩い目1.85mm以上

◎　早期の中干し開始によって生育量の調節が可能であり、目標穂数の40%程度の早期に中干しを開始しても、その後の間断灌水により良質茎が得られ、登熟歩合や千粒重等の玄米品質が向上する。

(3) 溝切り・中干しの方法

溝の間隔は2.5m程度、深さは10cm以上を確保し、各溝の末端は必ず排水溝につなげる。

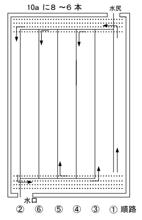
中干しの程度は田面に小さなヒビが入り、軽く足跡がつく程度まで行う。土壌が肥沃な地帯、生育量の大きな圃場では強めに、逆の条件では弱めとする。

大規模経営、大区画圃場では乗用管理機や田植機を利用した乗用溝切機を用いて、溝切り作業の労働力軽減が図られる。

溝切り・中干しの方法

実施手順	落水 ―溝切り― 走り水・間断灌水 ／ ←中干し→
溝切り間隔	2.5m間隔に1本、末端を排水路に接続
溝切り深さ	10cm以上を確保
中干し時期	目標穂数の80%を確保したら直ちに開始
中干し程度	小ヒビが入る程度（土壌水分60%）
間断灌水	走り水、間断灌水は溝切り実施で容易になる

新潟つづき

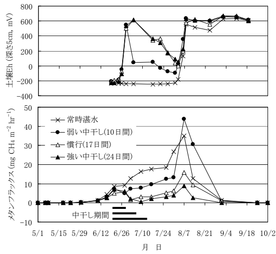


溝切りの順序

乗用型水田溝切り機の作業能率（昭62～平2）

項目		歩行型（比較）	乗用型		
ほ場面積	(a)	9	33	42	74
ほ場区画	(m)	17×54	32×105	40×405	59×125
作業間隔	(m)	2.4	5.3	5.0	7.4
作業速度	(m/S)	0.90	0.98	0.94	0.92
ほ場作業量	(a/h)	51	105	119	134
10a当り作業時間	(分)	11.7	5.7	5.0	4.5

◎　乗用型は歩行型に比べ、倍以上の作業能率である



中干し程度が土壌の還元程度とメタン発生に及ぼす影響（平成20年 新潟農総研）

新潟県における平年の中干し日数は17日間である。中干し期間を短くすると中干しの効果が不完全となり，無効茎の増加や倒伏を助長するばかりではなく，水田から発生する温室効果ガスであるメタンや一酸化二窒素(亜酸化窒素)の発生量が著しく増加する。

また，中干し期間を慣行よりもさらに一週間延長することによって，メタン，一酸化二窒素の発生量をそれぞれ40%程度削減することが可能である。

中干しを，溝切りを適期にしっかり行うことは，高品質・良食味米の生産につながるだけではなく，地球温暖化防止のためにも重要である。

適正籾数確保のための生育中期からの生育指標（平成8～12年、作物研究センター）

6月10日* 補正茎数	6月20日* 補正茎数	最高茎数（本／㎡）	茎数（本／㎡）	穂数（本／㎡）	1穂籾数（粒）	㎡当り籾数（粒）	出穂期 葉色（SPAD）	穂肥量のめやす 幼穂形成期葉色値 SPAD:32～35
20	32	326	316	287	81	23219	33	標準量
30	42	415	389	329	81	26637	33	標準量
35	47	459	425	346	81	28000	33	標準量
40	52	503	461	361	78	28000	32	標準量
45	57	548	498	374	75	28000	31	標準量
50	62	592	534	385	73	28000	30	2～3割減
55	67	636	570	395	71	28000	29	2～3割減
60	72	680	606	404	69	28000	29	5割減
70	82	769	679	420	67	28000	27	7割減

注1）＊：6月10日および6月20日の補正茎数はその時点の㎡当たり茎数を葉齢で除した値
注2）網掛け部分は理想的な生育パターンを示す。

◎　6月10日の㎡当たり茎数をその時点の葉令で除した値（以下補正係数）から6月20日の補正茎数が予測でき、6月20日の補正係数から最高茎数が予測できる。
6月10日の補正係数は40～45が適正となり、この値より大きい過剰生育の場合には中干しを強めに行い生育調節に努める。

中干し程度が温室効果ガス発生量に及ぼす影響(平成20年 新潟農総研)

	メタン g CH_4 m^{-2}	%*	一酸化二窒素 mg N_2O-N m^{-2}	%*
常時湛水	28.6	254.4	21.0	211.6
弱い中干し(10日間)	27.7	245.6	14.4	144.7
慣行(17日間)	11.3	100.0	9.9	100.0
強い中干し(24日間)	6.7	59.3	6.0	60.8

*; 慣行水管理を100とした場合の割合.

中干しが不十分であると生育が過剰傾向となって倒伏が助長される。中干し期間を慣行よりも一週間延長すると成熟期の穂数は減少するが，稈長が短くなるために倒伏が軽減される。

中干し程度が水稲生育に及ぼす影響(平成20年 新潟農総研)

	6月19日 草丈(cm)	茎数(本/㎡)	6月30日 草丈(cm)	茎数(本/㎡)	成熟期 稈長(cm)	穂長(cm)	穂数(本/㎡)	有効茎歩合(%)	倒伏程度
常時湛水	31	401	54	507	101	18.9	385	76.2	3.5
弱い中干し(10日間)	31	374	50	516	97	18.3	381	74.0	2.8
慣行(17日間)	31	394	52	525	96	18.8	360	69.1	2.5
強い中干し(24日間)	30	354	50	480	94	18.2	331	69.2	2.3

新潟つづき2

6　カドミウム吸収抑制対策に基づく水管理

○　カドミウムを吸収・蓄積する時期に湛水状態を保つことにより、米のカドミウム含有量を低減させることが可能である。

カドミウム含有米問題については、消費者の安全・安心志向の観点から関心が高くなっており、カドミウム吸収抑制技術対策の徹底は、農家経営の安定のみならず、新潟米の信頼性確保にとって不可欠である。

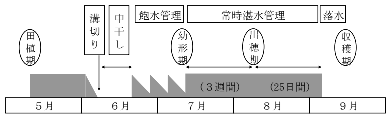
(1) 水管理のポイント

カドミウムは、土壌中の酸素が少ない状態（還元状態）になると、硫黄と結合して水に溶けにくくなる。このため、水稲がカドミウムを吸収・蓄積する時期に土壌の還元状態を保つことにより、米のカドミウム含有量を低減させることが可能である。この場合、土壌の還元状態を確保するには、必ず田面より水位が高い湛水状態であることが必要である。カドミウムの玄米含有濃度が0.2ppm以上検出される可能性のある地区では、温室効果ガスであるメタンの発生量削減よりも水稲のカドミウム吸収抑制を優先して次の水管理対策の徹底を図る。なお、これらの地域においてはメタンの発生を抑制するため、稲わらの秋すき込み、あるいは完熟堆肥の施用を励行する（参考 p.20）。

(2) 玄米含有濃度が0.2ppm以上検出される可能性のある地区の水管理

中干し・溝切りをやや早めに実施する（目標数の70%確保した時）。土壌の還元状態をできるだけ保つために、弱めの中干しにする。特に0.4ppm以上検出される可能性のある地域では、中干し期間を短くして飽水管理（水がなくなったら湛水の繰り返し）に入る。

中干し後から出穂前3週間（幼穂形成期）までは、飽水管理を行う。出穂前3週間から出穂後25日間までは、常時湛水管理を行う。収穫時期に水田がややぬかるみ、コンバインによる収穫作業がやりにくくなるので、収穫までの水田の水はけを良くすることが必要である。



水管理のイメージ
（カドミウムの玄米含有濃度が0.2ppm以上検出される可能性のある地区）

(3) 用水管理対策

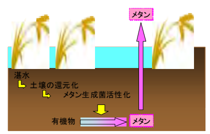
梅雨明けから登熟期にかけては、高温少雨により用水不足となる場合も想定されるので、効率的な水利用ができるように用水管理の徹底を図る。

普及に向けたマニュアル・愛知

愛知県

水田からのメタンガス発生量を抑制する水管理について

メタンガスは、地球温暖化の原因となる温室効果ガスの一つです。水田は主要な発生源の一つです。しかし、水田での水管理法を工夫することで、メタンガスの発生を抑制することができます。



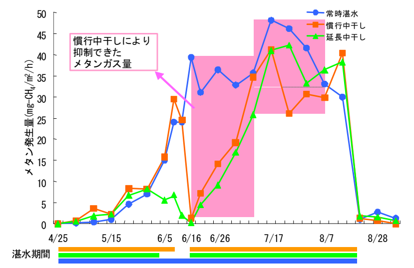
水田でメタンガスが発生するしくみ

水田は稲の栽培期間中、長期間湛水されます。そのため、土壌中の酸素が減少し(還元化)し、メタン生成菌のような嫌気性微生物の活動が活発になります。メタン生成菌は他の生物が有機物を分解して排出した低分子化合物からメタンガスを生成します。

我が国の水田からのメタン発生量は、人為活動によるメタン発生量の約30%を占めています。

移植栽培において、中干しには水田からのメタン発生を抑制する効果があります。

○中干しを行い、土壌中に酸素が供給されると、メタンの発生量が減少します。

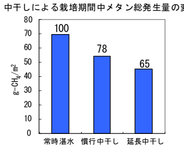


中干しによるメタン発生量の推移

品種：コシヒカリ　栽培方法：移植栽培　移植：4月24日　収穫：8月26日　窒素施肥：5.6kgN/10a

愛知県

中干しによる栽培期間中メタン総発生量の変化



注）棒グラフ上の数字は常時湛水100に対する比を示す。中干しの効果の大きさはほ場の状態により異なる。

中干し最終日の田面の乾き具合の様子

ただし、過度な中干しは収量や品質に影響を与える可能性があります。

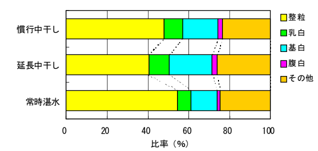
○延長中干しの収量（精玄米重）や整粒歩合が慣行中干しを下回りました（表・図）。

表　成熟期及び収量調査結果

試験区	稈長	穂長	穂数	精玄米重	整粒歩合	千粒重	㎡当たりもみ数
	cm	cm	本／㎡	kg/10a	%	g	×10⁴
慣行中干し	83.2	19.4	461	581	71.2	20.8	3.93
延長中干し	80.0	19.4	425	520	74.8	20.5	3.39
常時湛水	81.4	20.1	432	583	74.8	21.3	3.68

注　精玄米重は1.85mmの篩で選別し、水分換算（14.5%）した。

図　玄米品質



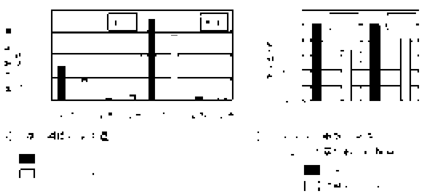
メタンガス発生を抑制するための水管理のポイント

○中干しには、水田からのメタン発生量を抑制する効果があります。
○収量や品質に影響を与える可能性がありますので、極端な中干し期間の延長は避けましょう。

注）資料内の図表は、すべて愛知県農業総合試験場の水田ほ場でのデータを基にする。

普及に向けたマニュアル・岐阜

「普及・啓発を図るための技術指導マニュアル(案)」について



(2) 生育ステージ別水管理

表23 生育ステージ別水管理の実際

生育ステージ	水管理	摘要
移植直後	やや深水	低温・強風時は特に深水
活着後	浅水更新	
分げつ期(移植15~20日後) 分げつ盛期	早期中干し(作溝) 間断灌水	足跡深5cm、高冷地を除く 3湛3~4落
有効茎確保後 幼穂形成期~穂ばらみ期	中干し 間断灌水	足跡深3cm(やや強めに干す) 5湛3落
出穂開花期	飽水状態	約1週間
登熟期	間断灌水~飽水状態	粒張りを良くし、高品質化のため水分補給が大切
登熟末期(黄熟始期)	落水期(適期落水)	出穂30~35日後、但し、落水後過乾の場合は走水を通す。

注)高冷地では、減数分裂期に最高気温23℃以下の時は深水として障害型冷害を予防する。

※畦マルチの実施…畦からの漏水防止や水管理を的確に行うために行う。

※早期中干し………土壌中の有害ガスの排出と、酸素の供給により根を健全にする。また、根の活力を維持にも繋がる。

※間断灌水…………中干しにより固めた土が戻らない程度に行う。間断灌水により深根化を促し、根系の広がりが多くなって健全となる。

(3) 作溝

早期中干し、間断灌水等的確な水管理を行うため、早期中干し時に溝切り機により作溝する。この場合、溝と排水路を必ずつなぐ。

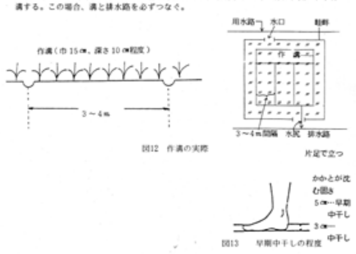


図12 作溝の実際

図13 早期中干しの程度

−19−

マニュアル徳島

環境にやさしい水田管理について(温室効果ガスメタンの発生低減)(案)

温室効果ガスであるメタンは,二酸化炭素の約20倍の強い温室効果があり,削減が求められている。日本での発生は水田からの発生が約30%を占めており,主要な発生源となっている。

水田で発生するメタンは,微生物であるメタン生成菌が土壌に含まれる作物残さ等の有機物や,肥料・堆肥として与えられた有機物を分解することによりつくられる。また,土壌が還元状態(酸素の少ない状態)だとメタン生成菌の活動が活発になりメタンの発生が多くなる。逆に酸化状態(酸素の豊富な状態)でメタンの発生は少なくなる。

有機物を秋にすきこむこと,中干しをしっかり行うこと,刈り遅れのないよう適期に落水を行うことでメタンの発生量を低減することができるため,適切な水管理を行うことが重要である。

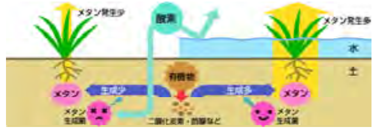


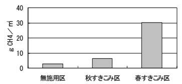
図 水田におけるメタン発生のしくみ(つくばリサーチギャラリーより引用)

(1)有機物の秋すきこみ

田植え直前に未熟な有機物や稲わらをすきこむと,水温の上昇に伴い土壌の還元化が強まりガスが発生しやすくなる。ガスは,水稲の根を痛め初期生育が悪くすると同時に,主成分はメタンであるため環境負荷も増大する。

稲わらの秋すきこみは春すきこみに比べ,有機物の分解が進んでいるためガスが発生しにくく,初期生育時の窒素供給力が高くなり,水稲の根の健全化を促進する。

また,メタンの主要な供給源は有機物とされ,とくに新鮮な有機物を施用することによりメタン発生は著しく増大することが知られている。このため,稲わらは秋に施用するとメタンガス発生の低減に有効である。



稲わらのすきこみ時期がメタン発生に及ぼす影響(1995 福島県農試)

(2)水管理によるメタンガスの低減

中干しは,無効茎の発生抑制による適正生育量の確保,硫化水素の発生防止,根の伸長や活力向上,倒伏抵抗性の増大等の効果があり,中干しを適切に行うことは収量の安定化や品質向上のために重要である。さらに,土壌が酸化状態になるとメタン生成菌の活動が抑制されるためメタンガス発生低減にも効果的である。

試験では,慣行よりも中干しを7日間長く行うことでメタンの発生量を約 16%削減でき,水稲の生育・収量・品質は慣行と差がない結果が得られた。

雨天が続いたり水はけの悪い圃場の場合,中干し期間の延長を行い,作物体の健全化とメタンガスの発生抑制を行うことが必要である。

中干し後は急激な湛水を避け,浅水の間断湛水により水稲の倒伏防止に努め,土壌を酸欠にしないように努める。

また,収穫前の落水を適期に行うことでメタンの発生は低減できるため,刈り遅れのないように落水,収穫を行うことが重要である。

図 水稲栽培期間中のメタン発生量(2009 徳島農研)

※グラフ内の数字は慣行水管理を100としたときの割合

表 水稲の生育(2009 徳島農研)

	中干し前(6/17)		中干し後(7/7)		成熟期		
	草丈 (cm)	茎数 (本/株)	草丈 (cm)	茎数 (本/株)	かん長 (cm)	穂長 (cm)	穂数 (本/株)
中干7日間・落水収穫7日前	36	25	71	31	91	18	22
中干14日間・落水収穫7日前	37	25	70	32	92	18	22
中干7日間・落水収穫14日前	37	26	72	34	95	17	24
中干14日間・落水収穫14日前	38	25	71	33	94	18	23

表 水稲の収量と品質(2009 徳島農研)

	わら重 (kg/10a)	精籾重 (kg/10a)	精玄米重 (kg/10a)	千粒重 (g)	整粒 (%)	タンパク質 (%)
中干7日間・落水収穫7日前	561	638	515	21.4	71	8.5
中干14日間・落水収穫7日前	583	668	542	21.4	72	8.5
中干7日間・落水収穫14日前	608	713	577	21.3	71	8.7
中干14日間・落水収穫14日前	609	695	560	21.2	71	8.4

(3)緑肥施用時の注意

緑肥は土壌を膨軟化し,気相率,透水性を高めるとともに,微生物活性により土壌の団粒化を促進する。また,窒素の補給により化学肥料の低減にも寄与する。

一方,土壌へ炭素が供給されるため,水田においてはメタンの発生量が増加するおそれがあるため,緑肥のすきこみを早めに行う必要がある。また,緑肥を施用した場合,施用しない場合より水管理によるメタン発生の低減効果が大きいため,中干しをしっかり行うとともに収穫前落水を遅れずに行い,土壌を還元状態にしないことが大切である。

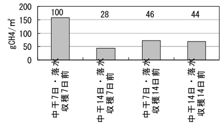


図 レンゲ施用水田の水管理の違いがメタンの発生に及ぼす影響(2008 徳島農研)

※グラフ内の数字は慣行水管理を100としたときの割合

マニュアル熊本

○ しかし、それ以上に受光態勢の良化によって、登熟歩合が向上して穂の総数は増加する。

(エ) 中干しの程度

第1表 条件別の中干し程度

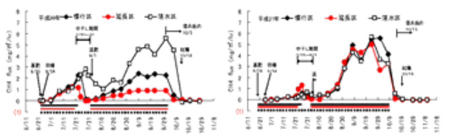
条件	強	中	弱
土性	埴壌土、泥炭土	壌土	砂土、砂壌土
地力	肥沃田	中位田	やせた田
乾湿	湿田	半湿田	乾田
用水量	多	中	少
生育量	過剰	中位	不足
草型	長稈・穂重型	中間型	短稈・穂数型
施肥量	多	中	少

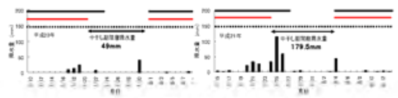
○ 中干し程度は諸条件に合わせて行う。

(オ) 中干しによる土壌環境の改善

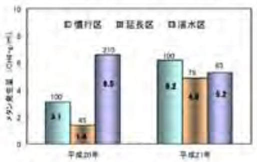
○ 落水期の延長が可能となり、また収穫時の地耐力が大きくなり、機械作業が容易となる。

(カ) 中干しがメタンガス発生抑制効果





第25図 中干し期間中の降水量(平成20、21年 熊農研)



第26図 年時期におけるメタンガス発生量(熊農研)

第6表 精玄米重と穂数の比較(熊農研)

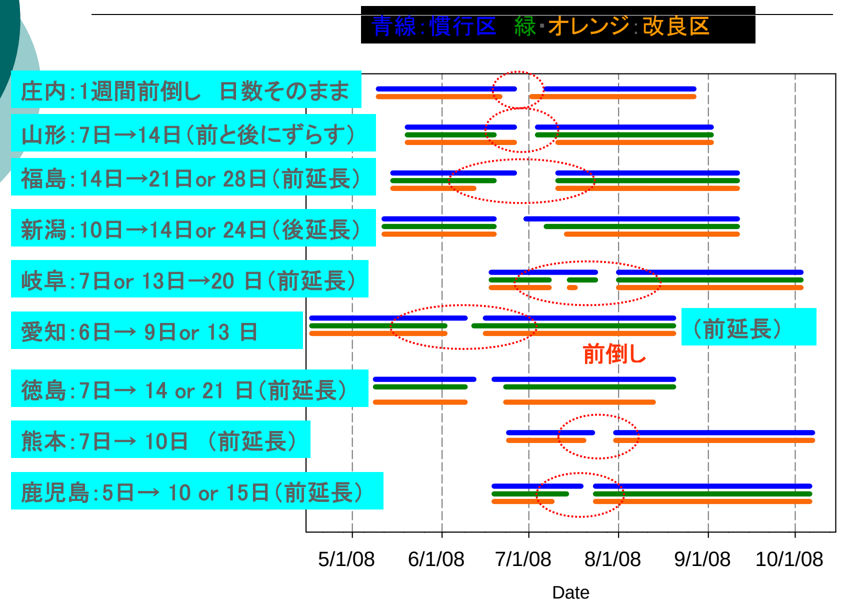
各県の対応状況

県	慣行中干し日数	提案中干し日数	メタン削減効果 対慣行%	備考 各県のマニュアルにおけるコメント
庄内	11	22	37	○早期中干しでは、通常の中干しより草丈が短く、茎数が多くなる特徴があるが、幼穂形成期以降の乾物重・窒素吸収量は少ない傾向になるため、早期中干しの期間延長は凋落を招く恐れがあるので適正な期間を守る。高地力条件下での中干し期間の目安は10日～12日間であり、土壌に小ひびが散見され、かかとが少し沈む程度になったら直ちに中干しを終了することが重要である。
山形	7	14	30 - 40	○生育量が過剰な場合は中干しの延長によりメタン発生抑制と籾数制御を両立できるが、生育量が適正量以下の場合は収量が低下することがあるため十分留意する。
福島	14	21	37	○1週間の前進化では、収量が5%程度(1～10%)、2週間の前進化では、11%程度(4～16%)低下する可能性があります。 ○中干し期間中に降水が多い場合や水はけの悪い水田では、溝きりをすることで効果が高くなります。
新潟	17	24	40	○中干し期間を短くすると中干しの効果が不完全となり、無効茎の増加や倒伏を助長する ○中干し、溝切りを適期にしっかり行うことは、高品質・良食味米の生産につながる
愛知	7	14	10	○中干しには、水田からのメタン発生量を抑制する効果があります。 ○収量や品質に影響を与える可能性がありますので、極端な中干し期間の延長は避けましょう
岐阜		早期中干し	30程度	・栽培指針の改訂予定は現在のところないが、改訂される場合には、栽培指針の「生育ステージ別水管理」に早期中干しによるメタン発生抑制効果について下記の(案)を追記する形になると考えている。ただし、減収となる干しの強度の境界が2 カ年の試験結果では不明のため、現段階では追記は難しいと考えられる
徳島	7	7	16	・中干し:適正生育量の確保, 硫化水素の発生防止, 根の伸長や活力向上, 倒伏抵抗性の増大等、収量の安定化、品質向上、メタンガス発生低減 ・慣行よりも中干しを7日間長く行うことでメタンの発生量を約16%削減 ・水稲の生育・収量・品質は慣行と差がない結果が得られた。 ・雨天が続いたり水はけの悪い圃場の場合, 中干し期間の延長が必要
熊本	7	10	21 - 55	○中干しはメタン発生を抑制する。 ○ 開始時期を3 日早めて10 日間に中干しを延長した場合で21～55%減少する。 ○ 中干しを行うことによって穂数が制限され玄米の品質は向上するが、過度に中干し行うと穂数が極端に減少し収量に影響が出る場合がある。
鹿児島	作成中	作成中	作成中	作成中

まとめ

- 2カ年分のメタン削減効果の検証の結果、全ての県で、水管理改良によるメタンの削減効果はあった
- 中干し延長による亜酸化窒素発生は極めて軽微であった。
- メタン削減の代償として減収が認められ、このことにより、普及が容易に進まない可能性はある
- 慣行の平均中干し日数の算定については、アンケート結果に基づき再検討中
- 各県ごとの栽培指針に基づくメタン削減マニュアル案を作成
- 年度内に上記マニュアルをまとめたリーフレット作成予定
- 1月8日に水管理事業の各県担当者が参集し、検討会を行う予定

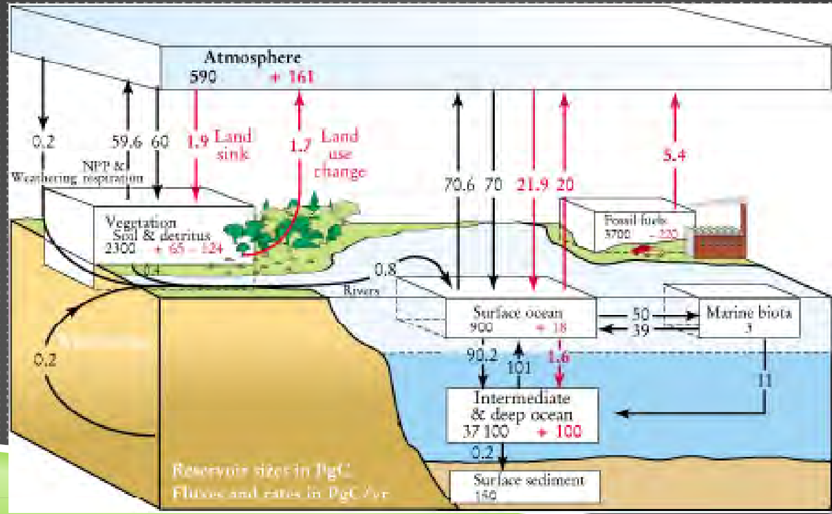
試験の設計（慣行区と改良区の湛水期間）



RICE CULTIVATION PRACTICE AND SOIL CARBON

Amnat Chidthaisong

THE GLOBAL CARBON CYCLE

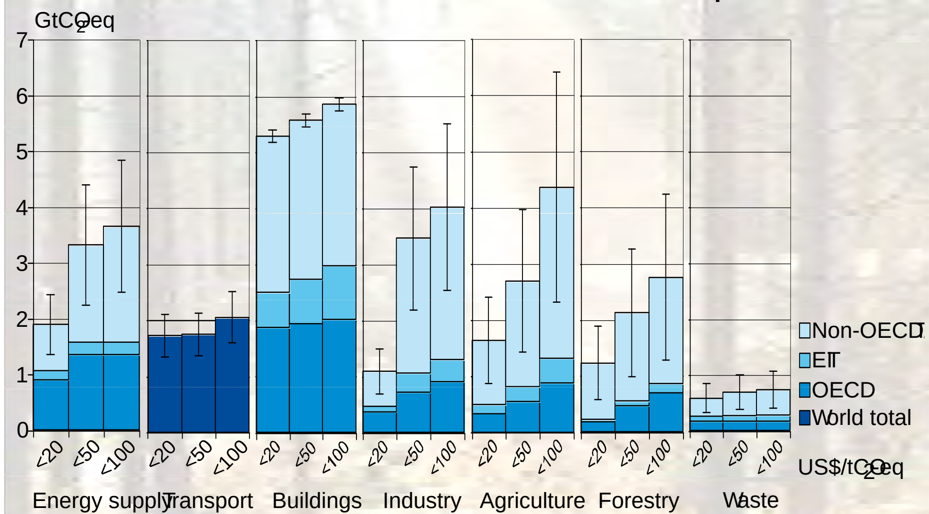


CAPACITY OF TERRESTRIAL CARBON SINK

- Historic Loss from Terrestrial Biosphere = 456 Gt with 4 Gt of C emission = 1 ppm of CO2
- The Potential Sink of Terrestrial Biospheres = 114 ppm
- Assuming that up to 50% can be resequestered = 45 – 55 ppm
  - Cropland Soils: 1 Gt/yr
  - Rangeland Soils: 1 Gt/yr
  - Restoration of Degraded/Desertified: 1 Gt/yr
- **Drawdown: 50 ppm of CO2 over 50 years**

Lal, 2009

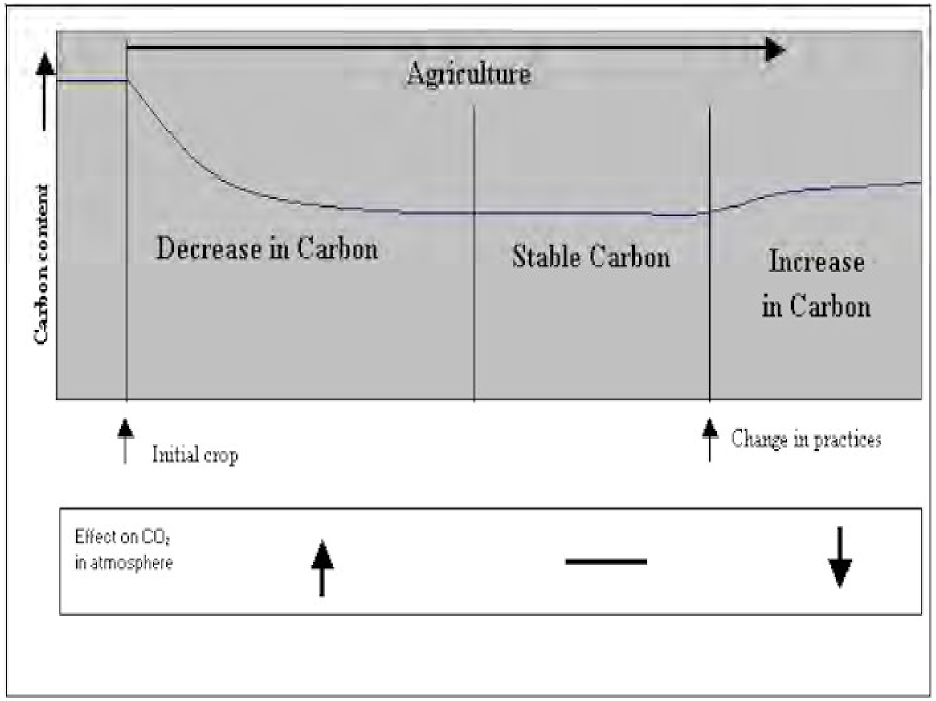
Global economic mitigation potential for different sectors at different carbon prices

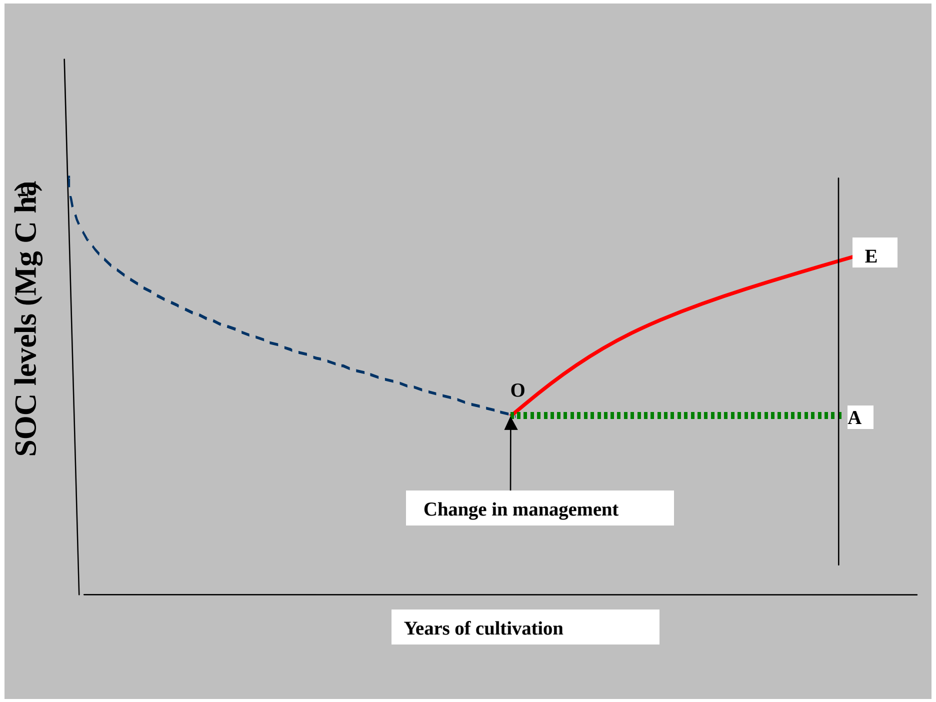


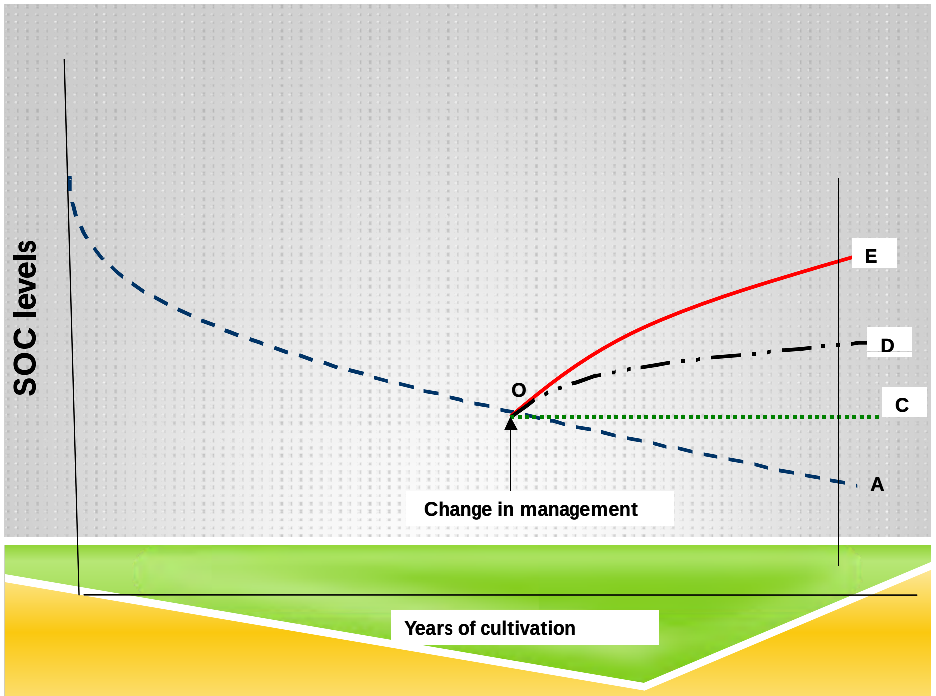
AGRICULTURE

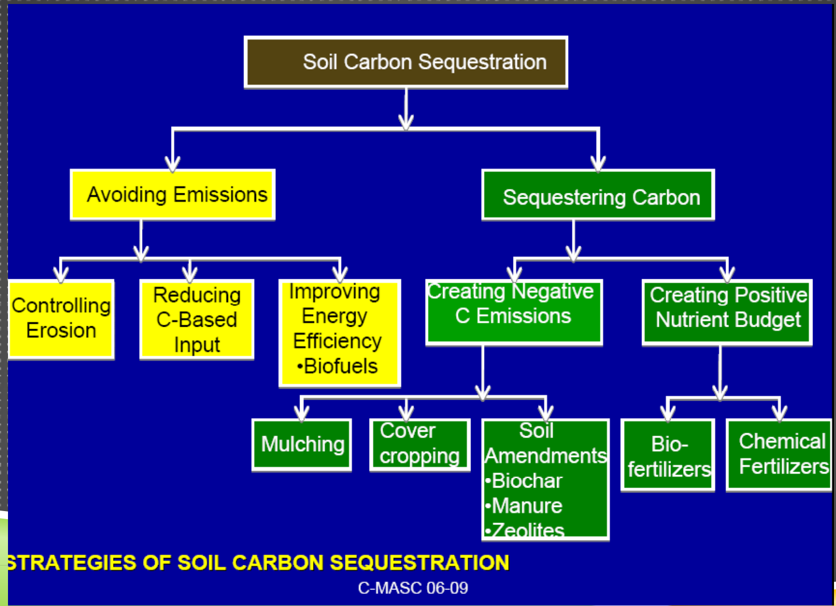
- A large proportion of the mitigation potential of agriculture (excluding bioenergy) arises from soil C sequestration, which has strong synergies with sustainable agriculture and generally reduces vulnerability to climate change.
- Agricultural practices collectively can make a significant contribution at low cost;
  - By increasing soil carbon sinks,
  - By reducing GHG emissions,
  - By contributing biomass feedstocks for energy use

Rice and Fabrizzi, 2008

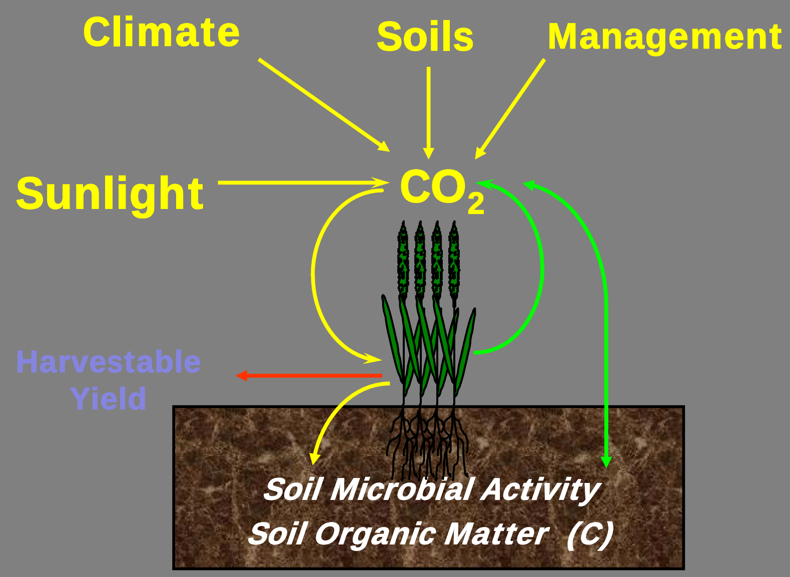








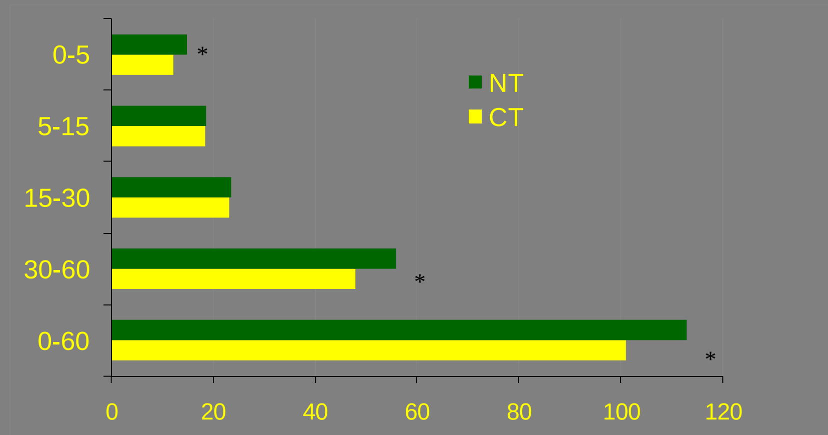
Lal, 2009



SOME EXAMPLE OF STUDY ON SOIL CARBON VS. CULTIVATION PRACTICES

- Till/No till
- Rotation crop
- Organic amendment

Soil C stocks after 18 years



Nicoloso et al., 2008

Soil C sequestration rates for 15 years (Mg C/ha/y)

Depth	Fertilizer N Tilled	Fertilizer N No-till		Manure N Tilled	Manure N No-till
cm					
0-5	0.161	0.351		0.393	1.182
0-15	0.254	0.497		0.792	1.402
0-30	0.336	0.717		0.839	1.387
0-60	0.146	1.325		0.733	1.141

- NT > Tilled, but tilled had some increase
- Added C (manure) is less conserved in tilled
- What is baseline?

Nicoloso et al., 2008

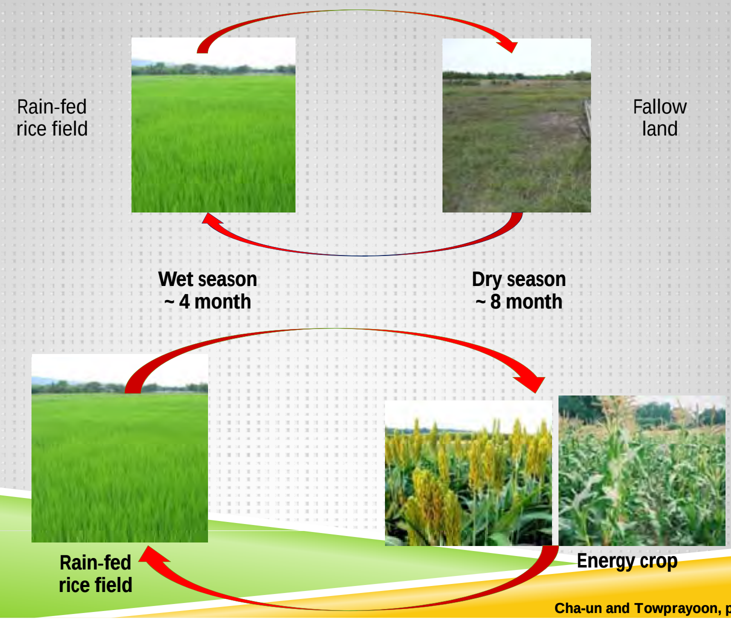
No till in paddy soil?

- **No till after harvest for rotation/addition cropping (Myanmar)**
- **Additional crop after rice—conventionally tilled, how this affects to soil carbon and soil property?**
- **Other countries? (none in Thailand)**
- **Full assessment in relation to adaptation and mitigation**

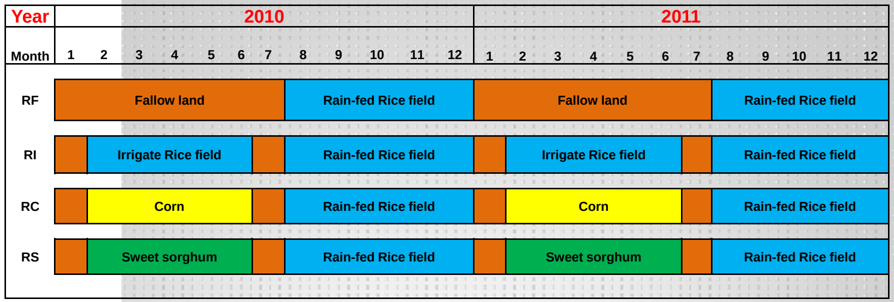
EFFECTS OF ROTATION CROP

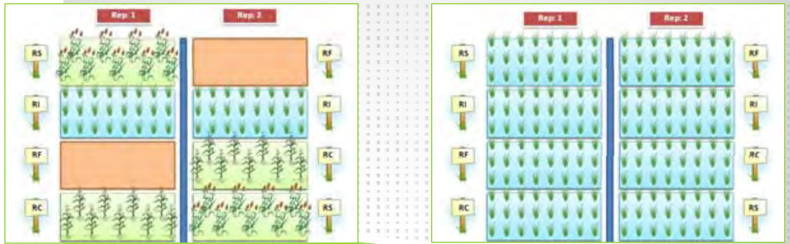
- **Common practice among SEA countries?**
- **Any results on;**
  - **GHG emissions**
  - **SOC**
  - **Agronomic aspects**

JGSEE



Cha-un and Towprayoon, pers. com

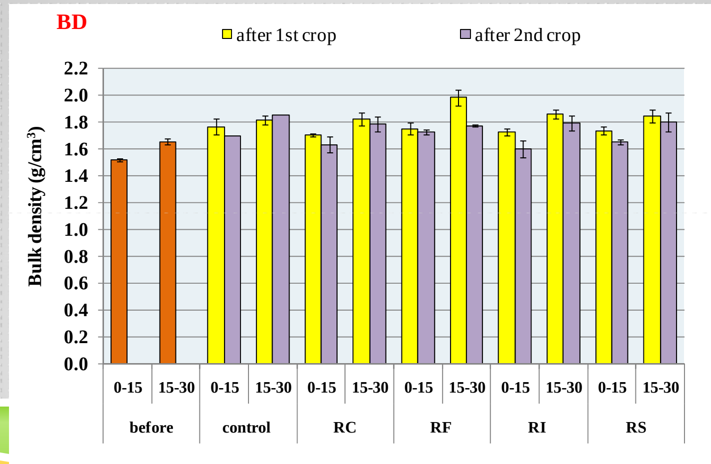




energy crop (February-June)

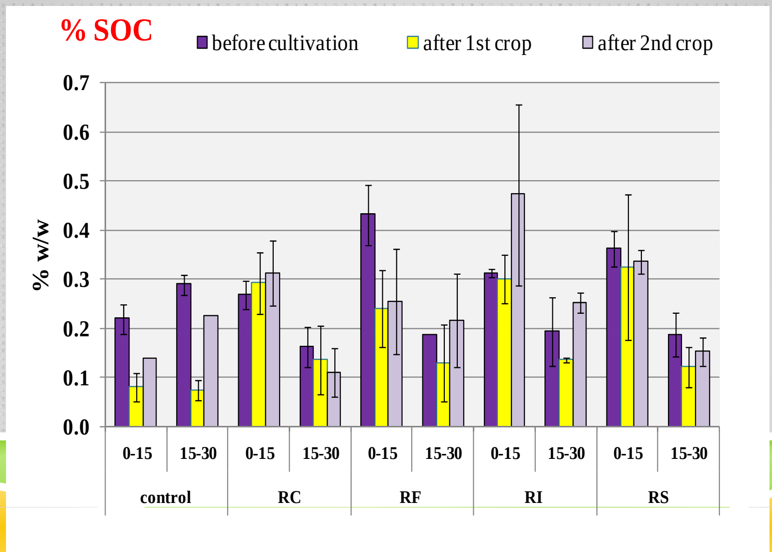
rain-fed rice field (August-December)

bulk density (BD) of soil before cultivation, after 1st and 2nd crop cultivation



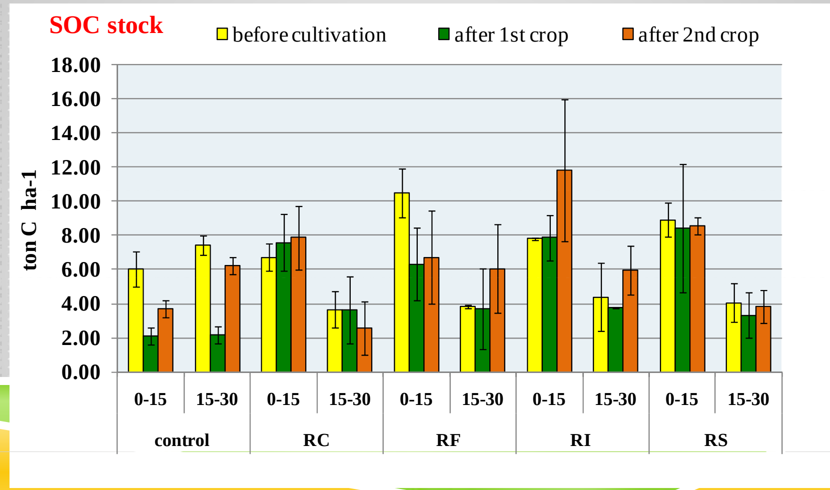
Cha-un and Towprayoon, pers. com

soil carbon content before, after 1st and 2nd crop cultivation



Cha-un and Towprayoon, pers. com

soil organic carbon stock before, after 1st and 2nd crop cultivation



Cha-un and Towprayoon, pers. com

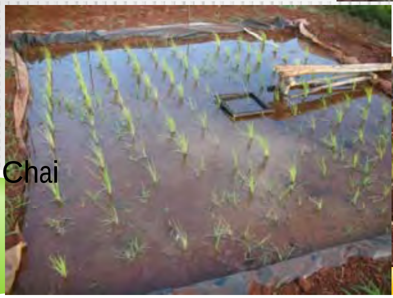
Maize-Rice rotation

Maize: 4901 variety

Upland rice: Sakon Nakhon variety

Plantation

Lowland rice: Chai Nat 1 variety



National Corn and Sorghum Research Center of Kasetsart University, Thailand.

Methane emission

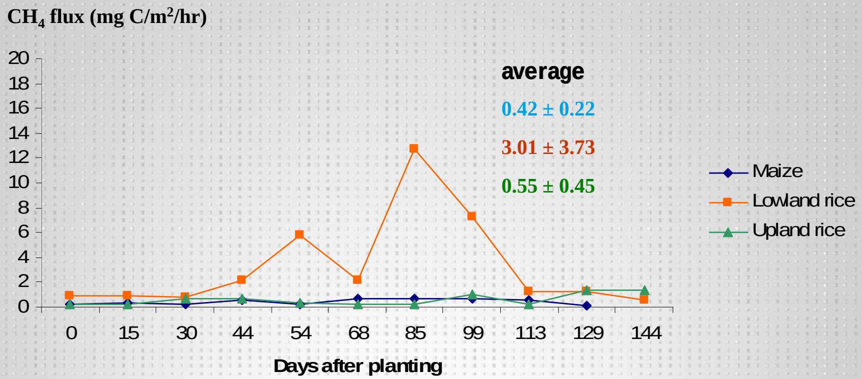


Figure 6: Methane emission during cultivation

Carbon dioxide emission

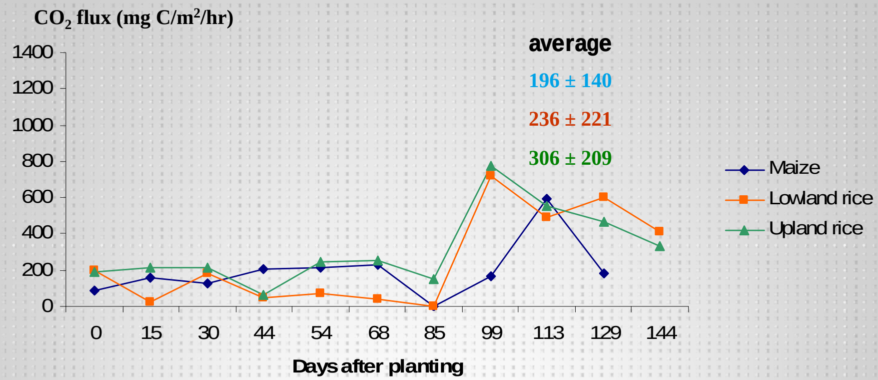


Figure 7: Carbon dioxide emission during cultivation

Total emission

Vegetation	CH_4	CO_2
	g/m²/crop	
Maize	1.60	2887.76
Lowland rice	15.7	3568.06
Upland rice	2.09	4661.01

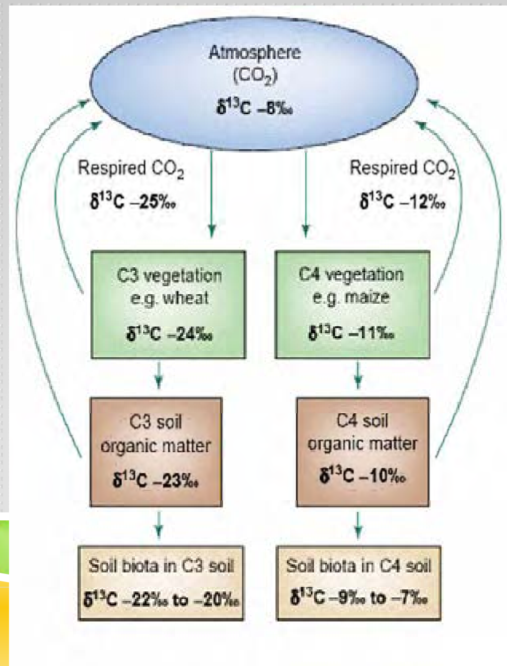
Changes of SOC in various particle sizes and bulk soil in continuous paddy rice and maize-rice rotation

Particle sizes (μm)	Changes of SOC comparing with continuous maize after the 2nd crop (%)	
	Continuous paddy rice	Maize-rice rotation
< 250	1.27 (0.39)	5.06 (0.22)
250-500	5.23 (0.46)	7.84 (0.26)
500-1000	4.64 (0.44)	17.22 (0.43)
>1000	9.68 (0.45)	19.36 (0.38)
Bulk soil	4.67 (4.38)	9.33 (2.85)

Carbon distribution in various soil particle sizes under different cultivation practices in the 4th week of 1st crop cultivation and after the 2nd crop cultivation.

Time	C-distribution percentage (%)		
	Continuous maize	Continuous paddy rice	Maize-rice rotation
At 4th week of 1st Crop			
< 250 μm	33.63 ± 0.72	32.54 ± 0.74	32.54 ± 0.74
250-500 μm	35.98 ± 0.81	36.76 ± 0.82	36.76 ± 0.82
500-1000 μm	28.50 ± 0.71	28.83 ± 0.70	28.83 ± 0.70
> 1000 μm	1.88 ± 0.03	1.88 ± 0.04	1.88 ± 0.04
After 2nd Crop			
< 250 μm	32.17 ± 0.69 (-4.34%)	31.37 ± 0.73 (-3.60%)	30.74 ± 0.71 (-5.52%)
250-500 μm	36.34 ± 0.80 (1.01%)	36.82 ± 0.82 (0.17%)	35.65 ± 0.81 (-3.02%)
500-1000 μm	29.72 ± 0.77 (4.28%)	29.94 ± 0.73 (3.86%)	31.69 ± 0.80 (9.91%)
> 1000 μm	1.77 ± 0.04 (-6.00%)	1.87 ± 0.03 (-0.73%)	1.92 ± 0.04 (2.06%)

JGSEE



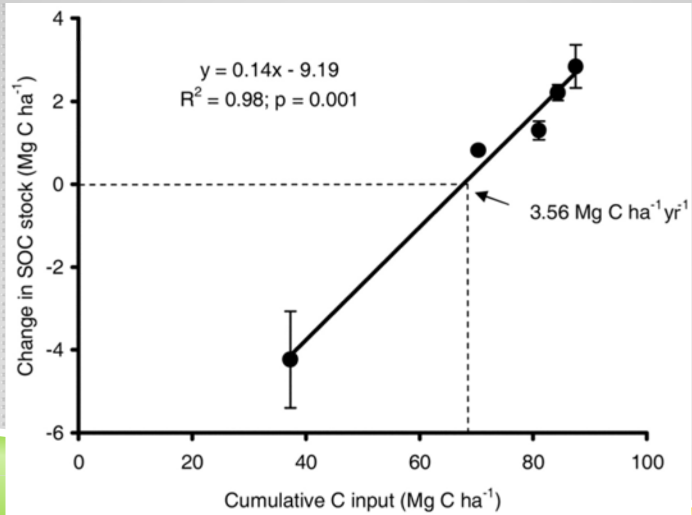
$\delta^{13}C$ values of soil organic carbon in various particle sizes and bulk soil (± of SD of 3 replicates).

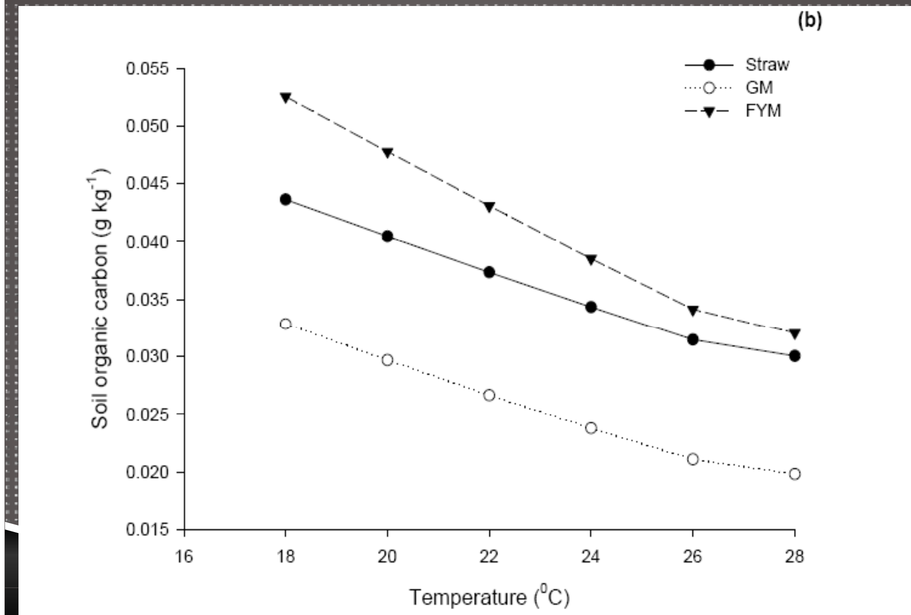
Treatments	δ13C (‰) Before cultivation	After the 1st crop cultivation	After the 2nd crop cultivation
Continuous maize			
< 250 µm	-19.473 ± 0.044	-18.926 ± 0.099	-18.899 ± 0.105
250-500 µm	-19.511 ± 0.101	-19.311 ± 0.078	-18.800 ± 0.147
500-1000 µm	-19.517 ± 0.087	-19.327 ± 0.117	-18.804 ± 0.098
Bulk	-19.477 ± 0.063	-19.065 ± 0.076	-18.598 ± 0.051
Continuous paddy rice			
< 250 µm	-19.163 ± 0.061	-19.520 ± 0.103	-20.388 ± 0.096
250-500 µm	-19.562 ± 0.077	-19.490 ± 0.088	-20.899 ± 0.100
500-1000 µm	-19.086 ± 0.094	-19.503 ± 0.091	-20.830 ± 0.089
Bulk	-19.508 ± 0.083	-19.632 ± 0.056	-20.820 ± 0.057
Maize-rice rotation			
< 250 µm	-19.163 ± 0.59	-19.520 ± 0.104	-20.375 ± 0.101
250-500 µm	-19.562 ± 0.081	-19.490 ± 0.075	-20.432 ± 0.096
500-1000 µm	-19.086 ± 0.063	-19.503 ± 0.096	-19.818 ± 0.079
Bulk	-19.508 ± 0.073	-19.632 ± 0.061	-19.481 ± 0.063

$\delta^{13}C$ values of soil organic carbon in Humic substances fractions and bulk soil (± of SD of 3 replicates).

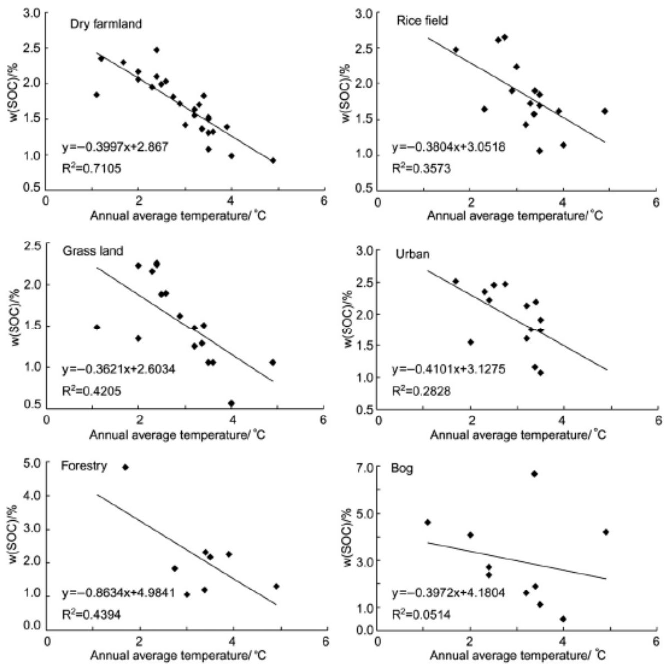
Treatments	δ13C (‰) Before cultivation	After the 1st crop cultivation	After the 2nd crop cultivation
Continuous maize			
Humic acid fraction	**-19.623 ± 0.066**	**-19.244 ± 0.109**	**-19.242 ± 0.146**
Fulvic acid fraction	**-19.700 ± 0.071**	**-18.729 ± 0.237**	**-17.902 ± 0.303**
Humin fraction	**-19.201 ± 0.058**	**-19.141 ± 0.129**	**-18.729 ± 0.156**
Bulk	**-19.477 ± 0.063**	**-19.065 ± 0.076**	**-18.598 ± 0.051**
Continuous paddy rice			
Humic acid fraction	**-19.597 ± 0.073**	**-20.722 ± 0.112**	**-21.350 ± 0.117**
Fulvic acid fraction	**-19.700 ± 0.080**	**-18.703 ± 0.286**	**-20.825 ± 0.280**
Humin fraction	**-19.191 ± 0.087**	**-20.097 ± 0.146**	**-20.678 ± 0.151**
Bulk	**-19.508 ± 0.083**	**-19.632 ± 0.056**	**-20.820 ± 0.057**
Maize-rice rotation			
Humic acid fraction	**-19.597 ± 0.069**	**-20.722 ± 0.131**	**-20.431 ± 0.171**
Fulvic acid fraction	**-19.700 ± 0.071**	**-18.703 ± 0.251**	**-19.093 ± 0.272**
Humin fraction	**-19.191 ± 0.068**	**-20.097 ± 0.153**	**-19.639 ± 0.180**
Bulk	**-19.508 ± 0.073**	**-19.632 ± 0.061**	**-19.481 ± 0.063**

ORGANIC AMENDMENT





Shibu et al., 2007



Xia et al., 2010

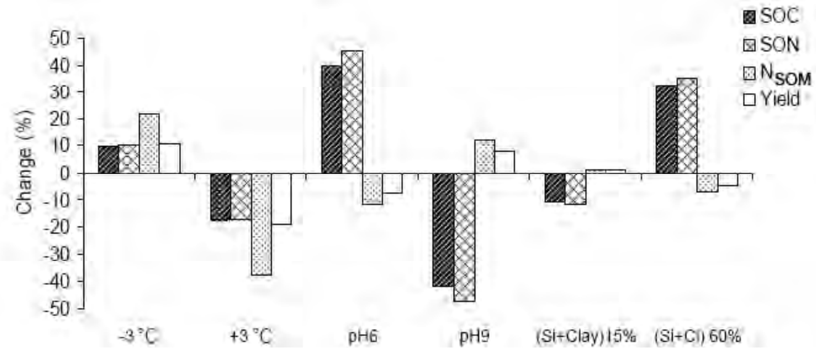
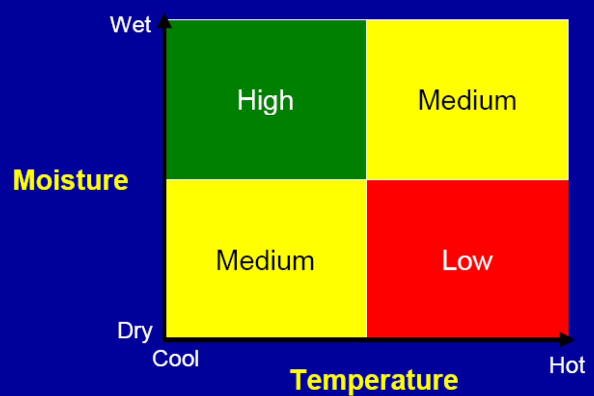


Figure 2. Cumulative changes after simulating for 100 years in soil organic carbon (SOC), soil organic nitrogen (SON), N supply from soil organic matter (N_{SOM}) and crop yield resulting from variations from ambient environmental and soil conditions (29 and 23 °C during summer and winter, respectively; pH 7.5; (silt + clay) 30%) under no-fertilizer application.

Xia et al., 2010

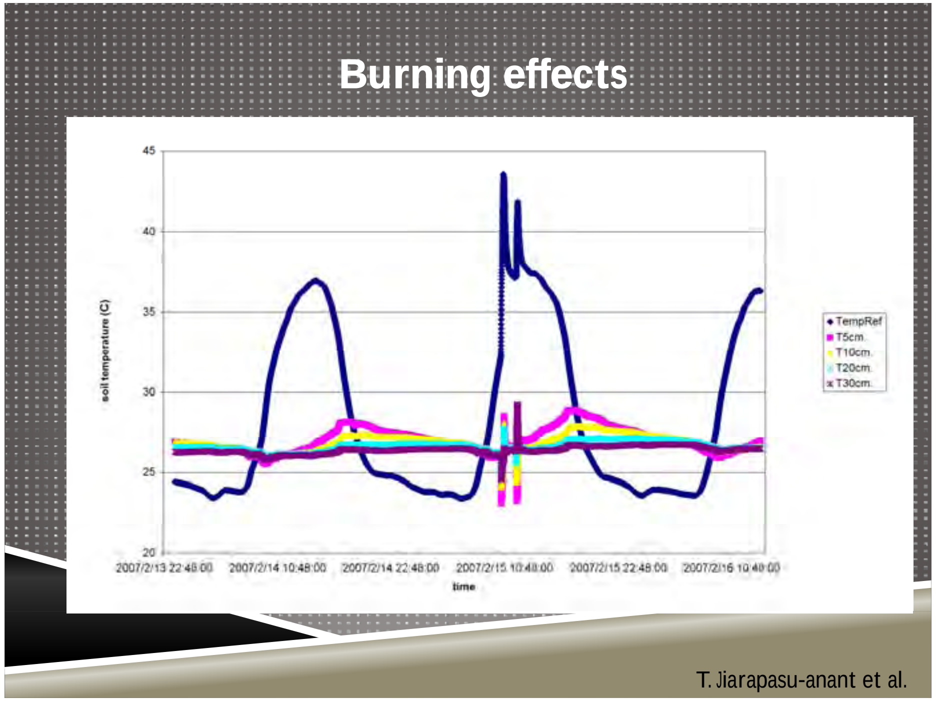
CARBON SEQUESTRATION IN RELATION TO CLIMATE

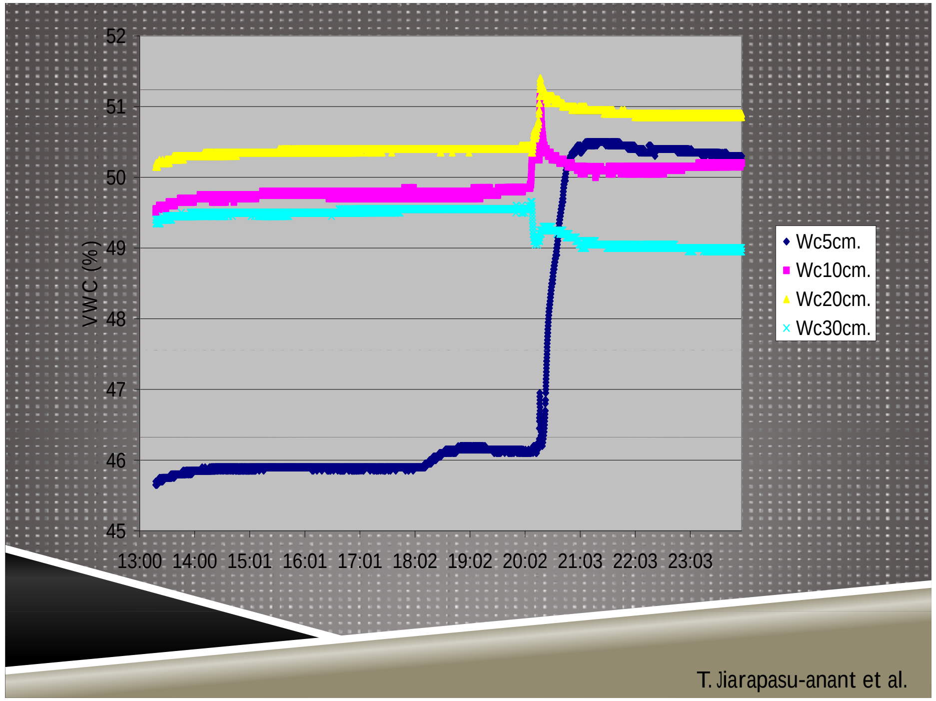


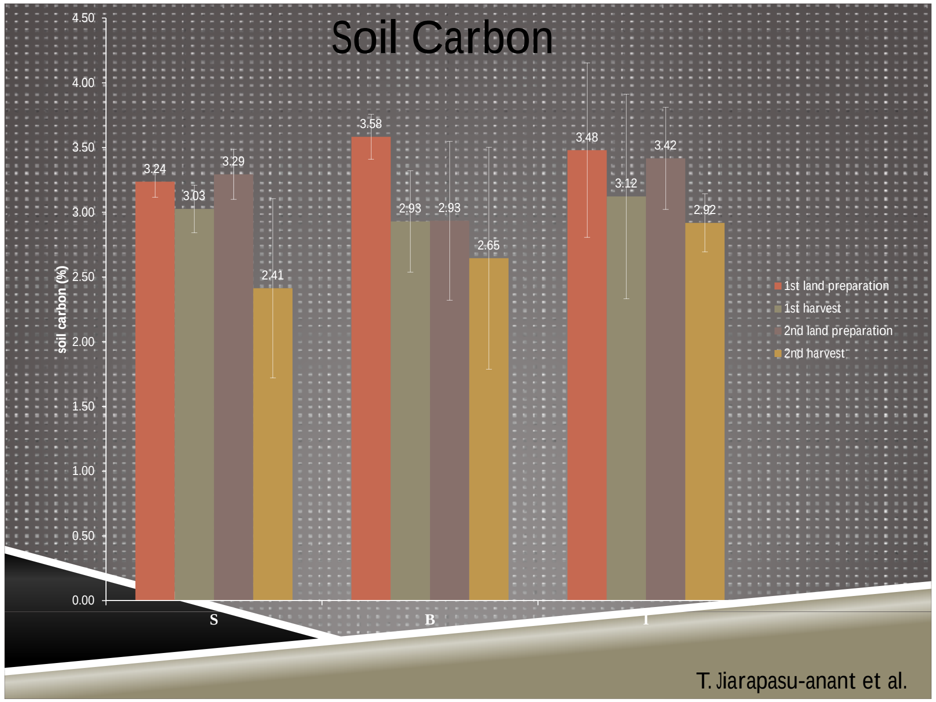
Lal, 2009

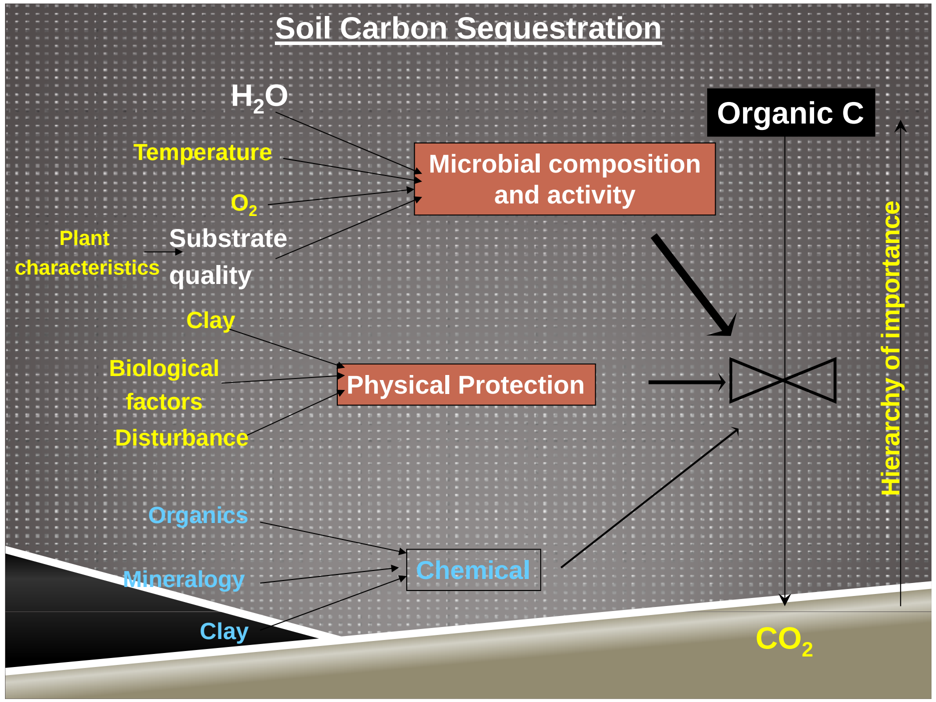
- SOC vs. Cultivation practice in SEA;
  - We know in general but lack accurate number, with detailed information about the relationship between cultivation practice and potentials

- Agricultural soil C sequestration
- keeps land in production in some cases
- in many cases increases profitability for the farmer
- provides other environmental benefits to society
- soil and Water quality (less runoff, less erosion)
- may help adapt to climate change as well as mitigate


Burning effects
soil temperature (C)
45
40
35
30
25
20
2007/2/13 22:48:00
2007/2/14 10:48:00
2007/2/14 22:48:00
2007/2/15 10:48:00
2007/2/15 22:48:00
2007/2/16 10:48:00
time
TempRef
T5cm.
T10cm.
T20cm.
T30cm.
T. Jiarapasu-anant et al.


52
51
50
49
48
47
46
45
VWC (%)
13:00 14:00 15:01 16:01 17:01 18:02 19:02 20:02 21:03 22:03 23:03
Wc5cm.
Wc10cm.
Wc20cm.
Wc30cm.
T. Jiarapasu-anant et al.


Soil Carbon
soil carbon (%)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
3.24
3.03
3.29
2.41
3.58
2.93
2.93
2.65
3.48
3.12
3.42
2.92
S
B
T
1st land preparation
1st harvest
2nd land preparation
2nd harvest
T. Jiarapasu-anant et al.


Soil Carbon Sequestration
H_2O
Temperature
O_2
Plant characteristics
Substrate quality
Microbial composition and activity
Organic C
Clay
Biological factors
Disturbance
Physical Protection
Organics
Mineralogy
Clay
Chemical
Hierarchy of importance
CO_2

Thank you

Appendix 4

Report on “Long monitoring of GHG emissions and soil carbon dynamics of rice cultivation and rotation with energy crops”

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 INTRODUCTION

1.1 Background

Rice is one of the world's major staple foods and in Asia where 94% of the world's rice produced (Salas et al., 2007). Southeast Asia produces the 25 % of global rice and recently the rice production has been increased about 18 % from the period of 2000 – 2010 (Baldwin et al., 2012). Flooded rice fields are the third largest source of agricultural emissions, It is estimated that 19 Mt CO_2 eq/yr CH_4, 20 Mt CO_2 eq/yr N_2O in year 2000 and 20 Mt CO_2 eq/yr CH_4 and 15 Mt CO_2 eq/yr N_2O in the year 2010 were emitted from rice field in Southeast Asian region (USEPA, 2006).

In the past decades, a number of reviews and meta-analysis have been published addressing greenhouse gases (GHG) emissions and mitigation from rice fields. Agricultural activities such as crop and soil management, Land preparation, seed preparation, rice verities, fertilizer, water management practices are responsible for approximately 50 % of global atmospheric input of CH_4 and over 10% of the atmospheric CH_4 emitted from the rice paddies which were identified as a major source of atmospheric CH_4 emissions (USEPA, 2006 & Zhang et al., 2011). From the GHG mitigation point of view, it also becomes a potential opportunity through reducing CH_4 emissions from paddy field. The sustainable agricultural practices has to be maintained to reduce GHG emission with maintaining the rice production (Epule et al., 2011). Therefore, accurate estimation of CH_4 emissions from rice paddies and impact of different agricultural cultivation practices on GHG emissions are very important for GHG inventory or mitigation at country or regional levels.

The GHG emissions are complex and heterogeneous, but the active management of agricultural systems offers the possibility for mitigation. Many agricultural mitigation activities show the synergy with the goal of sustainability and many explicitly influence on the constituents of sustainable development which includes social, economic and environmental indicators. Also there is interaction between mitigation and adoption sector which can occurs simultaneously but different in geographical and spatial character (Smith et al. 2008).

The rice and energy crop rotation is one option not only for GHGs mitigation but also improving soil organic carbon stock. This report provides field experiments conducted for a selected site in Thailand for crop rotation system with corn and sweet sorghum and analyzed utilization of energy crops for rotation with rice and its impact on GHG emissions.

1.2 Objective of study

The major objective to investigate

1. The specific rice-energy crops cultivation practices for monitoring GHG emissions and soil carbon dynamics
2. Comparative evaluation of selected crop rotation practices in terms of carbon cycle, economic and social benefits, barriers and best practices issues

CHAPTER 2 METHODOLOGY

The results presented in this report were obtained from the long term experiment conducted at Ratchaburi campus of King Mongkut's University of Technology Thonburi, Thailand. The experiment were set up for the year 2010-2011 to understand the GHG emissions and soil carbon dynamics from rice crop as well as from the rotation with energy crop using field observations.

2.1 Experimental site

The field experiments established at KMUTT-Ratchaburi campus in Sub-district Rang Bua, Chombung District, Ratchaburi Province, Thailand (13°35′ N, 99°30′ E) (Fig. 1). The rice cropping systems are single rice cropping in rainy season and fallow land in dry season, and double rice cropping in dry and rainy season. The rotation cropping system is rainfed rice (*Pathumthani 1*) with selected energy crop rotation which is corn (*Suwan 5*) and sorghum (*Khonkaen 40*). This experimental site represents the extreme dry area after rain season in the southwestern part of Thailand. The soil in this site is classified as a sandy loam consisting 53% sand, 45% silt and 2% clay with pH 5.8, bulk density 1.75 g/cm^3 and 0.69% total organic carbon content. The daily mean air temperatures and precipitations in 2010 (Dry Dipterocarp Forest at KMUTT-Ratchaburi station) are shown in Fig 2.

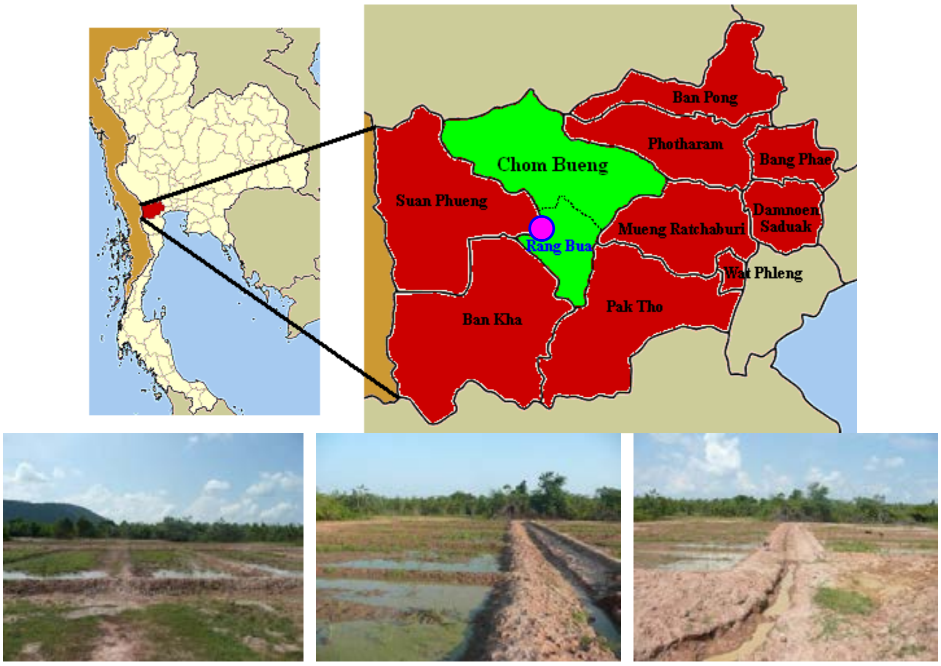


Figure 1 Ratchaburi province map and location of study area

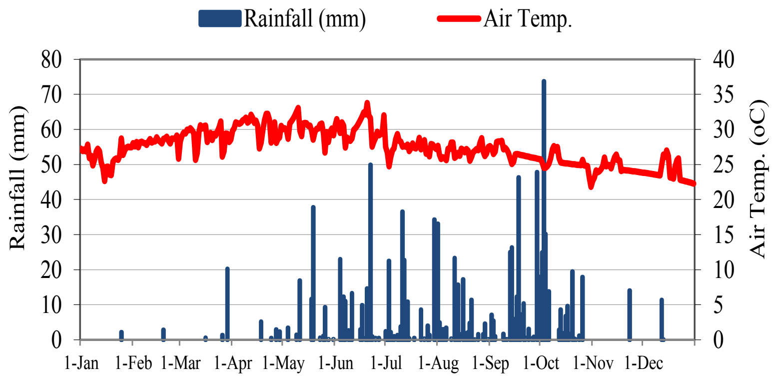


Figure 2 Daily mean air temperature and precipitation in 2010 of cropping season.

2.2 Experimental design

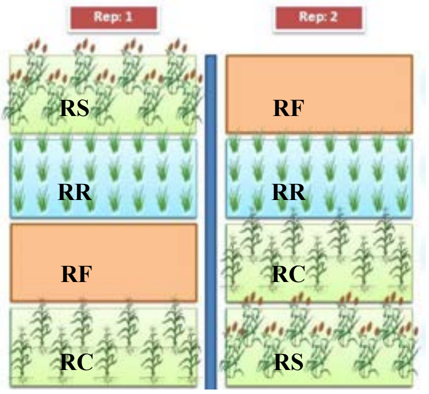
2.2.1 Field plot treatment and management

With local, conventional famers practices as the control, the experiments were laid out in randomized complete block design (RCBD) (Kwanchai, 1972) with in total eight plots with size 75 m^2 (5 m X 15 m) were established for four crop rotation systems (Fig. 3).

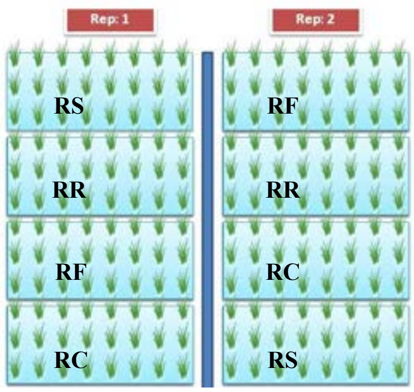
1) Single cropping of fallow land and rain fed rice (RF)
2) Double cropping of corn and rain fed rice (RC)
3) Double cropping of irrigation rice and rain fed rice (RR) and
4) Double cropping of sweet sorghum and rain fed rice (RS)

According Office of Agricultural Economics (OAE) the most of the rice area in Thailand is in lowland, which is classified as a rainfed and irrigated rice ecosystem and occupies 80 % and 19% of the rice area, respectively. So the main crop in rainy season is rice and due to this condition, we have cultivated energy crop in dry season (Feb-Jun 2010 and 2011) and rice field in wet season (Aug-Dec 2010 and 2011). Selected rotation crops for this experiment were short rotation energy crops (corn and sweet sorghum). These both energy crops has very short growing period (~ 4 months) and requires less water (resistant in dry weather condition) than irrigated rice and other energy crop. Also both every crops are useful to produce ethanol (Office of Agricultural Economics, 2008; Suraphong Chareunrat, 2008).

Two replicates were set up for each treatment. The first crop began with the cultivation of corn, rice and sweet sorghum in the related designed plot after that the second cropping followed with rain fed rice in all plot as shown in Fig. 4. All crop cultivations performed with conventional practices (Ministry of Agriculture and Cooperatives, 2008 & 2010).



(a) Energy crop
(February-June, 2010-2011)



(b) Rain-fed rice field
(August-December, 2010-2011)

Figure 3 Diagram of the crop experimental plots
(Rep: 1 and 2 are experiment Replications)

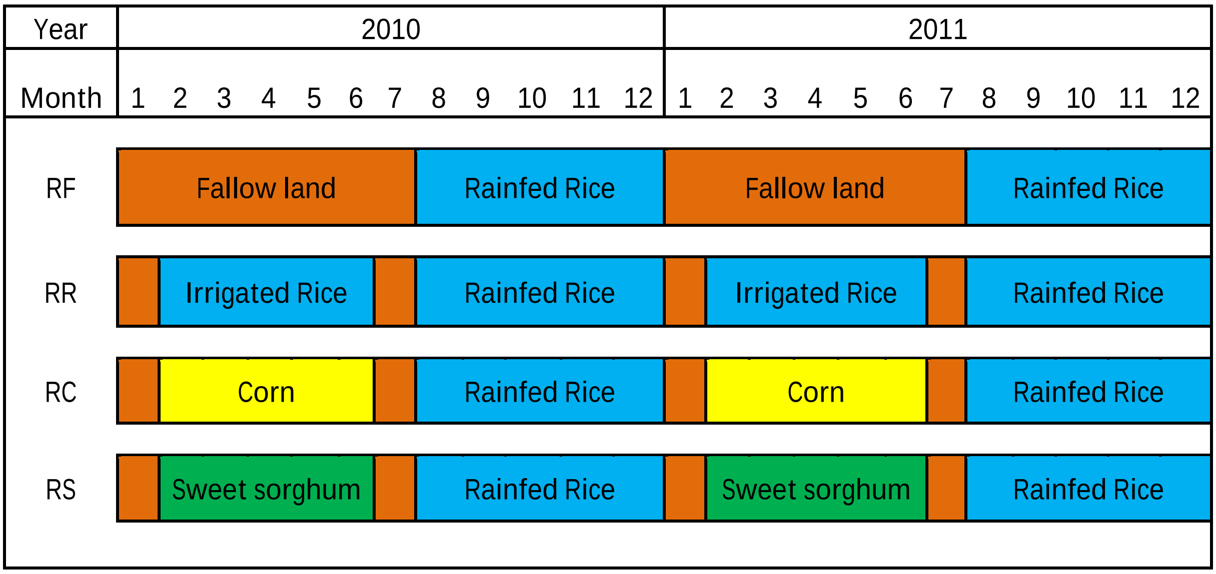


Figure 4 Field experimental designs at KMUTT-Ratchaburi site

2.2.2 Gas sampling and analysis

The black acrylic closed chamber method (Li et al., 1997) was used to trap gas emitted from plant and soil into atmosphere throughout the investigation period. Gas samples were taken once a week between local times 09:00-15:00.Chamber bases are fixed in the field during whole period of experiment. The cross-sectional area of a chamber is 0.09 m^2 (0.3 m x 0.3 m).

The height of the chamber is 15 cm for soil respiration and during the fallow period. While the height of chamber is 1.0-1.2 m for the plants grows. The chamber was wrapped with a foam sheet for minimize temperature changes during the period of sampling. The amount of 20 ml of gas samples are collected with a syringe at 0, 10,20 and 30 minute during fallow period and 0, 5, 10 and 15 minute when plants growing to vegetative stage. Gas samples transferred to evacuated vial bottles and wrapped with parafilm. The temperature inside the chamber was measured by thermometer (0-100 ^{o}C) at the top of the closed chamber and record every time when sampling. The mixing gas samples of CH_4 and CO_2 were analyzed by gas chromatography (Shimadzu, GC-2014) with a flame ionization detector (FID) and $CH_{4,}$ Electron capture detector (ECD) for N_2O.

The gases emission was expressed in terms of mass per unit area per unit of time. Firstly, the concentration obtained from the chamber headspace must be converted to a mass or molecular basis using the ideal gas law. The CO_2, and CH_4 was calculated using the linear portion of the gas concentration inside the chamber change over 15 minute sampling time, step from the following Eq.(1) (Nishimura *et al.,* 2008). CO_2 emission from this research was determined as the total of plant dark respiration and soil heterotrophic respiration, since the chamber covered the plants while taking gas sample.

$$F = \frac{dC_i}{dt} \times \frac{1}{A} \times \frac{M_i PV}{RT} \times t_i \qquad (1)$$

where, F is the cumulative CO_2, CH_4 and N_2O fluxes (mg m^{-2} hr^{-1}), $\frac{dC_i}{dt}$ is the increase/decrease rates of CO_2, CH_4 and N_2O concentrations, respectively (ppm min^{-1}), M_i is the mass number of CO_2 (44 x 10^3), CH_4 (16 x 10^3) and N_2O (44 x 10^3) (mg/mol), A is the area of the chamber (width x length) (m^2), P is the atmospheric pressure (1 atm), V is the chamber volume (width x length x height) (m^3), R is the gas constant (0.082058 x 10^{-3} m^3·atm mol^{-1} K^{-1}), T is the air temperature inside the chamber (K), *and* t_i is time factor for 1 hr (= 60 min), respectively. In biological methane oxidation rate from energy crop field was estimated from the first order rate constant multiplied by initial concentration of methane.

2.2.3 Biomass sampling and analysis

The biomass is biological material from living, or recently living organisms most often is refereeing to plants or plant derived material. In this experiment grain, leaves, stems, straw, stubble and roots of the crops are biomass. All of biomass was sampled at the crop harvesting period and then dried in an oven at 80°C for 48 hr to get dry weight and then ground to pass 0.5 mm sieve. Carbon content is in the form of biomass were analyzed with a nitrogen and carbon analyzer. The amounts of carbon in plant (g C m^{-2}) were calculated by multiplying the C element concentration (g C g^{-1} plant) by plant weight and to the equivalent plant area (m^{-2}).

2.2.4 Soil sampling and analysis

The soil samples were collected from each plot treatment from top layer of soil at depth 0-15 and 15-30 cm at the day after crop harvesting. The samples were air-dried and ground to pass 2 mm sieve. The soil samples were analyzed for organic matter (OM) by wet oxidation method (Walkley and Black method). Soil organic carbon (SOC) is the carbon content of SOM, which is approximately 58%. The factor of 1.724 used to convert SOC to SOM (USDA Natural Resources Conservation Service, 2009).

The bulk density of soil layer was measured at three different random places in each plot. The stainless steel cylinders soil core of 5.0 cm internal diameter and 5.0 cm height were collected at the harvest of plant. The soil cores were dried in an oven at 105°C for 24 hr to get dry weight of the soil. The ratio of dry weight of soil core and internal volume of the stainless cylinder was expressed as bulk density in g cm^{-3}. The soil organic carbon stock of each crop was estimated by equivalent soil mass method (ESM) (Lee *et al*, 2009).

2.2.5 Estimation of soil carbon budget (SCB)

In crop land, carbon is supplied to the soil as root exudates, dead roots and stubble of the crops. Some other additional carbon is also supplied by organic matter incorporation. Carbon in the soil is lost such as by gaseous emissions of CO_2 and CH_4 and by leaching to the underground as dissolved organic and inorganic carbon in the leachate. Soil carbon budget (SCB) can be estimated by integrating the amounts of these net carbon supply and removal (Nishimura *et al.,* 2008).

In this experiment, carbon supplied to the field soil as seed, straw, stubble, manure, chemical fertilizer and root residue. Carbon removed from the soil by gaseous emission of CO_2 and CH_4 and carbon content in grain yield and plant biomass. Therefore, soil carbon budget can be estimated by integrating the amounts of these net carbon supply and removal. The SCB calculations and details parameters are shown in Figure 5 and Table 1, where the positive of SCB is indicated carbon accumulation into the soil, while SCB negative indicated carbon loss from the soil.

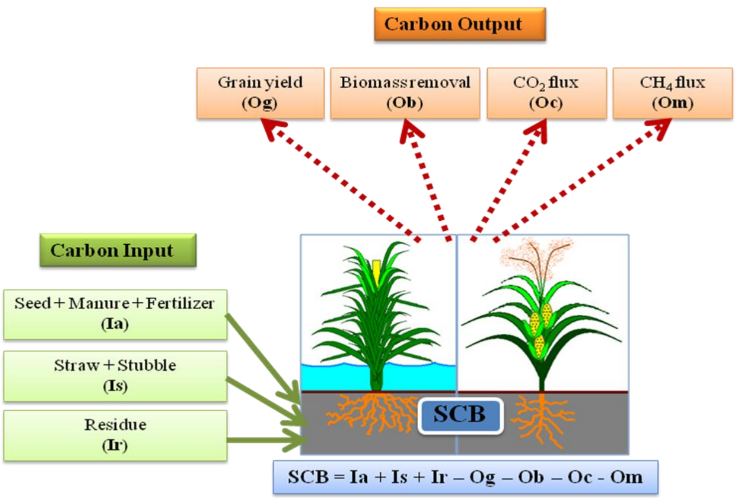


Figure 5 The carbon dynamics in experiment system

Table 1 Terms of carbon calculation

Term	Description	Carbon Calculation (dry mass)
Ia	carbon supplied to the soil by seed, manure and chemical fertilizer	(mass of seed x % C in seed) + (mass of manure x % C in manure) + (mass of fertilizer x % C in fertilizer)
Is	carbon supplied to the soil by straw and stubble incorporation	(mass of stubble x % C in stubble) + (mass of straw x % C in straw)
Ir	carbon supplied to the soil by root residue	(mass of root) x (% C in root)
Og	carbon removed by grain yield	(mass of grain yield) x (% C in grain yield)
Ob	carbon removed by crop biomass	(mass of crop biomass) x (% C in crop biomass)
Oc	carbon emitted from soil to the atmosphere in the form of CO_2 emission	accumulate of CO_2 flux
Om	carbon emitted from soil-plant to the atmosphere in the form of CH_4 emission	(accumulate of CH_4 flux) x (12/16)
SCB	soil carbon budget (g C m^{-2})	Ia + Is + Ir – Og – Ob – Oc - Om

2.3 Statistical Analysis

The one-way analysis of variance (ANOVA) and Duncan's multiple range test ($p = 0.05$) were used to determine the temporal variations of gas fluxes, SOC stock, and SCB between the rotation of cropping systems. Statistical analyses were performed using the statistical software package SPSS (Windows version 17.0) (Xiao *et al*., 2005).

CHAPTER 3 RESULTS AND DISCUSSION

This section includes the field measurement of GHGs emissions from rice in rotation with energy crop followed by cultivation sequence in Figure 4, seasonal variation in GHGs emissions, soil carbon dynamics and total soil carbon budget. Also the comparative evaluation of selected crop rotation practices in terms of carbon cycle, economic and social benefits.

3.1 Methane fluxes

Field observations indicated that the seasonal cumulative of CH_4 fluxes from rice-rice cropping system were 762.26 and 2,960.60 mg CH_4 m^{-2} $crop^{-1}$ in 2010 and 7,043.82 and 2,433.58 mg CH_4 m^{-2} $crop^{-1}$ in 2011, respectively (Table 2). CH_4 fluxes were significant during the rice-growing season but negligible during the fallow land, corn and sweet sorghum growing season (RF, RC, and RS). In all plots of rain-fed rice period (2nd and 4th crop), CH_4 fluxes from continues of rice cropping were significant higher than rice rotated with corn, sweet sorghum and fallow land.
During crop rotation with corn and sweet sorghum the cumulative CH_4 fluxes of corn varies from -0.38 mg CH_4 m^{-2} $crop^{-1}$ in 2010 to 99.19 mg CH_4 m^{-2} $crop^{-1}$ in 2011 and CH_4 fluxes of sorghum varies from 105.74 mg CH_4 m^{-2} $crop^{-1}$ in 2010 to 125.42 mg CH_4 m^{-2} $crop^{-1}$ in 2011. The positive of CH_4 emission was indicated CH_4 emitted into the atmosphere while negative of CH_4 emission was indicated CH_4 absorbed into the soil through microbiological oxidation by methanotrophic bacteria (Cai et al., 1997; Nishimura et al., 2008).
As the results from 2010-2011 showed that the selected of energy crop (corn and sorghum) able to reduced 84 % and 85% of CH_4 emission when compared with continues of rice cropping.

3.2 Nitrous oxide fluxes

Higher N_2O fluxes were observed in fallow period, corn and sweet sorghum growing period possibly because of nitrogen fertilizer application (Table 2). Some lower N_2O fluxes were observed during the rice growing season. The N_2O cumulative fluxes of RF, RC, RR and RS plot in year 2010-2011 were 57.61, 94.78, 37.18 and 105.43 mg N_2O m^{-2}, respectively. For energy crop cultivation, the highest N_2O emissions for corn and sweet sorghum were found to amount to 299-355 µg N_2O m^{-2} day^{-1} and 268-339 µg N_2O m^{-2} day^{-1}. The energy cropping systems without floodwater were produced N_2O emissions through the nitri-denitification process which different from CH_4 emission. The cumulative fluxes of N_2O related to different cropping systems and cropping condition. Consequently, the ratio of cumulative fluxes from 2010-2011 in corn and sorghum were higher 3 times than continuous rice.

3.3 Carbon dioxide fluxes

CO_2 emission from this research was determined as the total of plant dark respiration and soil heterotrophic respiration, since the chamber covered the plants while taking gas sample. The CO2 cumulative fluxes of RF, RC, RR and RS plot in year 2010-2011 were 404.25, 603.30, 733.93 and 694.39 g CO_2 m^{-2}, respectively (Table 2). Fertilizer application induced significant increase in the CO_2 fluxes for all crop. In the 1st and 3rd of energy crop periods in dry season were almost significant crop growing and cumulative CO_2 flux differences with corn, sweet sorghum and rice. In 2nd and 4th of rain-fed rice cropping indicated that the seasonal cumulative CO_2 flux not significant difference among each treatment. Accordingly, the rain-fed rice field cultivated after energy crop, irrigated rice and fallow land were not significant difference of rain-fed rice growing season that related to the rice grain yield.

Table 2 Cumulative flux of CH_4, N_2O and CO_2

Crop/Treatment		CH_4 (mg CH_4 m^{-2} $crop^{-1}$)	N_2O (ug CH_4 m^{-2} $crop^{-1}$)	CO_2 (g CH_4 m^{-2} $crop^{-1}$)
1st crop in 2010				
	RF (*fallow*)	-6.09±4.77	19,513.42±427.26	46.81±2.08
	RC (*Corn*)	-0.38±7.06	26,918.14±419.99	97.14±2.88
	RR (*Rice*)	762.26±32.00	2,753.46±77.98	238.23±6.72
	RS (*Sorghum*)	125.42±8.70	32,166.12±661.70	211.33±4.53
2nd crop in 2010				
	RF (fallow→ *Rice*)	784.90±46.68	14,707.65±321.74	134.78±6.19
	RC (Corn→ *Rice*)	849.66±43.03	19,441.81±329.74	144.98±7.48
	RR (Rice→ *Rice*)	2,960.60±136.50	11,233.00±284.05	130.52±7.61
	RS (Sorghum→ *Rice*)	610.73±48.01	18,945.79±439.96	116.29±6.02
3rd crop in 2011				
	RF (fallow→ Rice→ *fallow*)	6.37±3.60	9,816.33±232.45	80.62±1.78
	RC (Corn→Rice→ *Corn*)	99.19±6.59	32,392.20±847.09	203.37±5.22
	RR (Rice→ Rice→ *Rice*)	7,043.82±125.07	7,421.84±157.41	207.98±4.50
	RS (Sorghum→ Rice→ *Sorghum*)	105.74±6.39	38,680.42±826.67	208.48±6.32
4th crop in 2011				
	RF (fallow→ Rice→ fallow→ *Rice*)	1,003.01±45.85	13,569.14±399.76	142.05±5.23
	RC (Corn→ Rice→Corn→ *Rice*)	1,105.52±50.21	16,030.34±382.06	157.82±5.34
	RR (Rice→ Rice→ Rice→*Rice*)	2,433.58±116.06	15,766.58±367.72	157.16±6.86
	RS (Sorghum→ Rice→ Sorghum→ *Rice*)	1,104.60±53.13	15,637.06±536.38	158.30±5.73

3.4 Soil carbon dynamic

The soil carbon dynamic will be showed in term of soil organic carbon (SOC) stock and soil carbon budget (SCB). Figure 6 shows the soil organic carbon changes for the 2 years (2010-2011).

The SOC stocks decreased from the initial soil through the field preparation by tillage. After cropping, there are generally increased with the land use change by crop rotation that caused by accumulation of root and organic matter into the soil. The lowest SOC stock was observed in fallow land of RF plot (6.32 Mg C ha^{-1}) whereas; highest SOC stock was occurred in corn and sweet sorghum crop rotation as 12.48 and 14.62 Mg C ha^{-1}, respectively. The final of SOC stocks in 4th crop of RR, RC and RS were significant difference (95%) with RF. The double cropping of rice in 1st and 2nd cropping was 33 % increasing of the SOC stock, nevertheless there were not significant differences among crop activities. The different of biochemical process and mechanisms specifically from the water flooding in paddy soil caused the amount of organic carbon stored in paddy soil was greater than in upland soils. Liping and Erda (2001) reported the SOM contents in paddy soil are 12-58 % higher than in upland soil. Moreover, Nishimura et al. (2008) also reported that the significant carbon loss from the soil according to the land use change from paddy rice cultivation to upland crop cultivation with 94-177 g C m^{-2}.

The results of SOC stock able to presented the potential of energy crop rotation in rain-fed rice for maintained carbon into the soil, whereas the fallow land of RF plot unable to maintained the carbon.

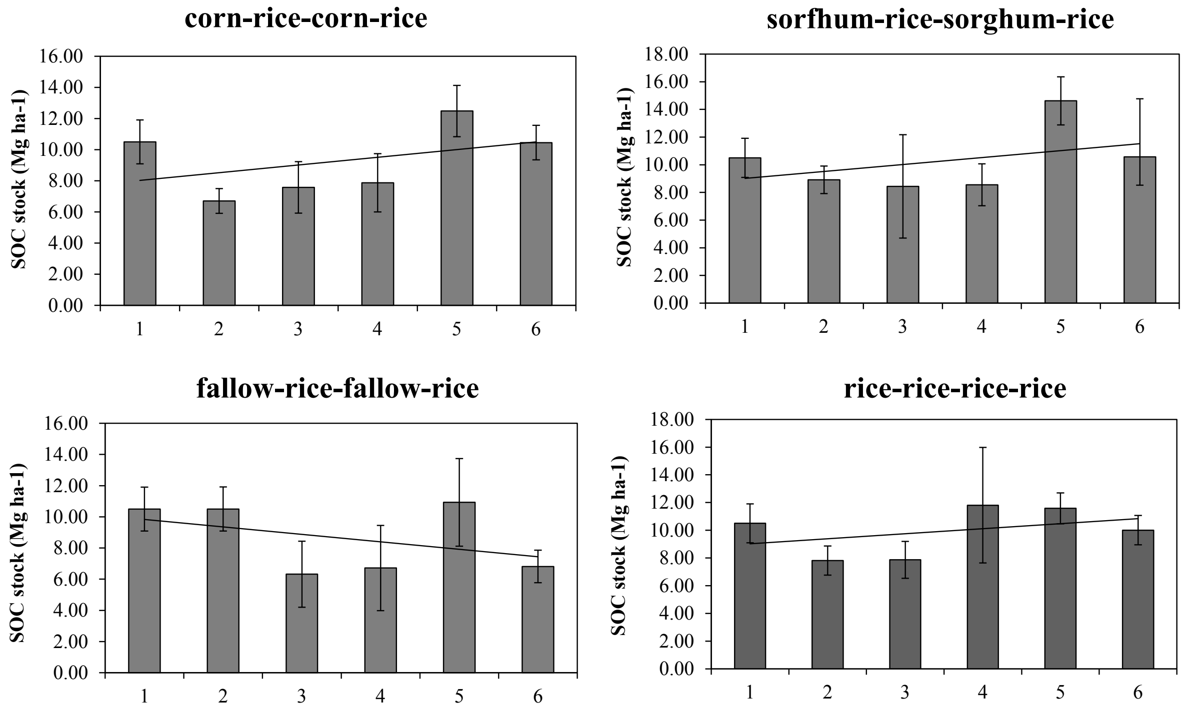


Figure 6 Soil organic carbon (SOC) stock of crop experiment

(* The numbers 1 to 6 of axis "x" are mean 1) initial soil before planting, 2) soil after tillage, 3) soil after 1st cropping, 4) soil after 2nd cropping, 5) soil after 3rd crop and soil 6) after 4th cropping, respectively.)

Figure 7 shows the soil carbon budget (SCB) for the 2 years (2010-2011). The SCB is the balances of carbon supply into the soil and carbon remove from soil. SCB is C input minus C output. C inputs are including seed manure and fertilizer application (Ia), straw/biomass residue incorporation (Is) and root residue incorporation (Ir). C outputs/removal are including grain yield (Og), biomass (Ob), CO_2 equivalent from soil respiration (Oc) and total CH_4 equivalent from soil&plant (Om), respectively.

The SCB after 1st to 4th cropping were -207 to 435 g C m^{-2} (Fig. 8). The negative values of SCB indicated that carbon loss from soil. The most of carbon removal was observed in Ob and Og. There were represented C content in biomass and grain yield. Especially, sweet sorghum in RS plot was highest of C output in form of sorghum stalk and grain. Manure incorporation in 1st and 2nd crop was the most effect for carbon input into the soil. While the most of carbon input in 3rd and 4th crop was crop residue incorporation. The most total SCBs in 2010 to 2011 was 542.28 g C m^{-2} in RR and then 415.11 g C m^{-2} in RC, 150.37 g C m^{-2} in RF and -68.72 g C m^{-2} in RS (Fig. 9).

In this experiment shows that the energy crop rotated by corn-rice was higher benefit for soil carbon budget.

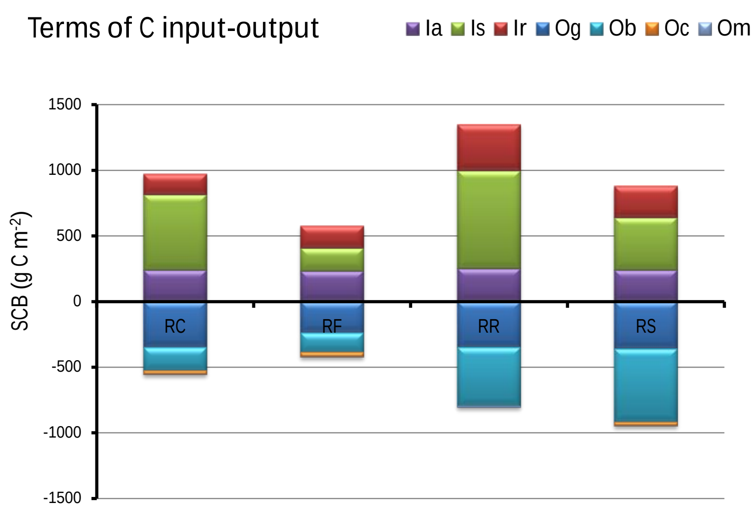
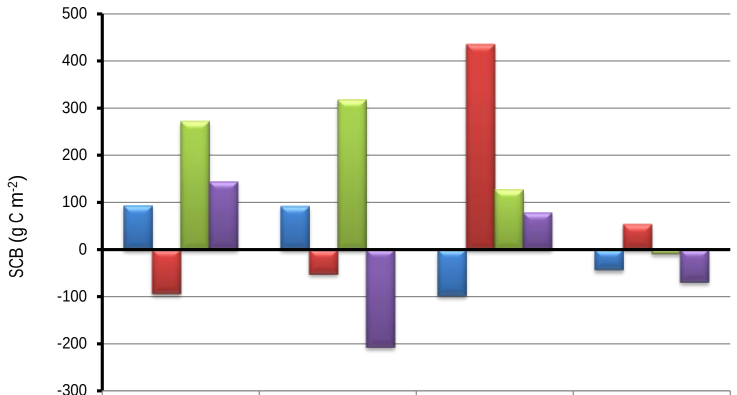


Figure 7 Term of carbon input and output from crop experiment in 2010-2011



	RC	RF	RR	RS
1st crop	93.19	91.37	-98.30	-43.36
2nd crop	-94.28	-51.98	435.46	53.55
3rd crop	272.06	318.36	127.10	-9.29
4th crop	144.14	-207.38	78.02	-69.62

Figure 8 The soil carbon budget after 1st to 4th cropping

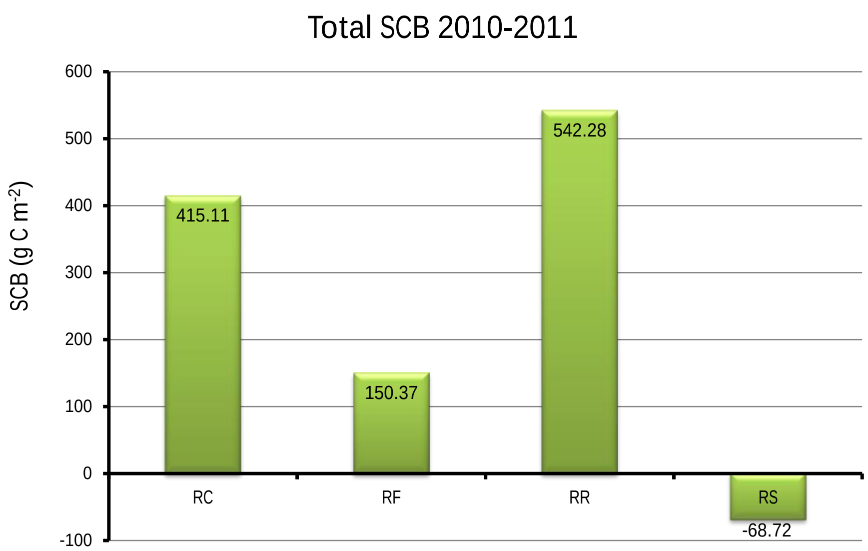


Figure 9 Total of Soil carbon budget in 2010-2011

3.5 Comparative evaluation of energy crop rotation practices

3.5.1 Carbon cycle

The highest of SOC stock presented after 3rd crop of corn and sweet sorghum as 12.48 and 14.62 Mg C ha^{-1}, respectively. The lowest of SOC stock after cropping was observed in fallow land (RF) as 6.32-10.93 Mg C ha^{-1}. The energy crop rotations in rain-fed rice were able to maintained carbon into the soil, whereas the fallow land (RF) was unable to maintain the carbon. Therefore, the systems of energy crops rotation in rain-fed rice field were high carbon sequestration into the soil through organic matter entering in form of manure and crop residue incorporation.

The most of soil carbon budget (SCB) in 2010 to 2011 presented in rice-rice rotation system as 542.28 g C m^{-2}. In energy crop rotation system, the higher of SCB showed in corn-rice which as 415.11 g C m^{-2} and then 150.37 g C m^{-2} in fallow-rice and -68.72 g C m^{-2} in sorghum-rice rotation system. Thus, the energy crop rotated by corn-rice was higher benefit for soil carbon budget.

3.5.2 Economic and Social benefits

Crop rotation has many agronomic, economic, social and environmental benefits as compared with monoculture cropping.

1. Improved soil structure: Appropriate crop rotation increases the soil organic matter in the soil which improves the soil structure, reduces soil degradation, which results in higher yields and greater farm profitability in the long term. Higher organic matter in in soil enhances the water and nutrient retention, and decreases the synthetic fertilizer which is one of the economic benefits to farmers. The regular flood and droughts are the major problem in SEA rice agriculture. The better soil structure improves the drainage, reduces the risk of water logging during floods and boosts the water during droughts. From this experiment we have found that the selected energy crop rotation has significant impact on soil carbon storage.
2. Increase in crop yield and income of farmer: The crop yields from different crop rotation system shown in Table 3-4. The possible income was estimated in only year 2011, there is the good crop yield production than year 2010. Which suggest that if farmer cultivate double crop for each year, they will get more possible income 51,017 Baht/ha/year for corn-rice, 58,581 Baht/ha/year for sweet sorghum-rice, 50,226 Baht/ha/year for rice-rice rotation system. Nevertheless, if farmer will cultivated only rain-fed rice; they will lost opportunity for possible income as 32-41 %.
3. Enhanced pest and disease control: Rotation of crop helps to control weed and pest (reason: weeds and pests are very choosy about the host plant, which they attach when the crop is changed the cycle is broke so they are less effective), as a result significantly reduction in use of pesticides
4. Efficient use of nutrients: Crop rotation creates more balanced nutrient cycle in the field and helps farmer to use less input to maintain nutrient in soil, which results in lower the costs and increase profit of farmer.
5. Reduction in GHGs emission: Crop rotation is one of the climate change mitigation option which is one of serious issue on national as well as on global scale. Better soil nutrient management through crop rotation can decrease the fertilizer use by 100 kg N per ha per year which reduces the emission of related GHGs. Our experiment also suggests that the crop rotation can reduce the GHGs emissions from rice field.
6. Reduced water pollution: The crop rotation reduces the application of synthetic fertilizer which will decrease the water pollution.
7. Increase in employment opportunity: Corn and Sorghum can be used to for the production of ethanol, which can return formers high benefits. The construction and operation of ethanol plants are widely recognized as a catalyst for the job creation, so there will be many small as well as large

job scale opportunity will be available for local people which will lead to less mobilizing and migration of people to biggest cities and can help to restore the local culture.

8. Social impact: Crop and farm enterprises create year round or extended season employment for the farm workers. Workers employed for year round or longer season will have higher incomes, more paid by employer and can help to raise the standard of living of their families. So this whole system can leads to increase in workers availability, increase in productivity, increase in dependability, less need for worker training and personal satisfaction.

Table 3 Crop yield and price of crop yield production in 2010

Treatments/Yield	after 1st crop in 2010		after 2nd crop in 2010		Income (THB/ha)	Total (THB/ha)
	Yield (kg/ha)	*Price (THB/kg)	Yield (kg/ha)	*Price (THB/kg)		
RC						
- Grain corn	31	8.1	-	-	251	
- Grain rice	-	-	2,616	8.6	22,498	22,749
RF						
- Grain rice	-	-	2,076	8.6	17,854	17,854
RR					485	
- Grain rice	63	7.7	2,440	8.6	20,984	21,469
RS						
- Grain sorghum	201	5.8	-	-	1,166	
- Stalk sorghum	4,527	0.6	-	-	2,716	
- Grain rice	-	-	1,645	8.6	14,147	18,029

* Price of yield production data from Office of Agricultural Economics (2010)

Table 4 Crop yield and price of crop yield production in 2011

Treatments/Yield	after 3rd crop in 2011		after 4th crop in 2011		Income (THB/ha)	Total (THB/ha)
	Yield (kg/ha)	*Price (THB/kg)	Yield (kg/ha)	*Price (THB/kg)		
RC						
- Grain corn	1,354	7.6	-	-	10,290	
- Grain rice	-	-	3,954	10.3	40,726	51,017
RF						
- Grain rice	-	-	3,329	10.3	34,289	34,289
RR					23,477	
- Grain rice	2,863	8.2	2,597	10.3	26,749	50,226
RS						
- Grain sorghum	2,550	6	-	-	15,300	
- Stalk sorghum	8,824	0.6	-	-	5,294	
- Grain rice	-	-	3,688	10.3	37,986	58,581

* Price of yield production data from Office of Agricultural Economics (2011)

3.5.3 Barriers

Various factors restrain farmers from adopting more extensive crop rotation in SEA, the barriers exists are at both farm and institutional level. The most of the crop production are based on the precipitation that monitoring and controlling crop rotation at farm level will be very difficult to implement across the whole SEA region.

Still SEA lacks implantation of farm program, research priorities and market outlets from government and local agencies. So need to increase the management skills and information at local level.

SEA rice agriculture suffers from new equipment to match the changed farming practices, also additional storage units are required for wider variety of crops produced.
Application of crop rotation in abandoned field is difficult due to low soil fertility, water availability in the region.

CHAPTER 4 CONCLUSION

The major objective of this study were study the GHGs emissions from crop rotation practices, as a result fluxes has been observed for the period of 2010-2011 at experiment site (Ratchaburi, Thailand). Result of this experiment illustrates the differences in emissions from rice crop in rotation with selected energy crop under traditional cultivation practices. This experiment provides a baseline for comparison of rice and possible energy crops cultivation practices and GHGs emissions across the country also its impact of SOC and SCB.

Due so the special cropping systems and water management practices paddy fields in Thailand are significant source of GHG emission, but the implementation of rice in rotation with energy crop can reduce the CH_4 emissions from rice fields without changing total production which is required to feed population. The experiment result suggest that of rain-fed rice after corn and sweet sorghum cultivation were provided emits less CH_4 as compare to other cultivation practices.
Similarly nitrogen fertilization application has a significant impact on N_2O, after application of synthetic N-fertilizer higher N_2O were observed. Experiment also suggest that crop rotation can also improves the soil fertility and which directly reduces the application of synthetic fertilizer which means less emission of N_2O from rice fields.

Soil organic carbon (SOC) stock and soil carbon budget (SCB) in corn-rice cropping system were significant higher than single rice cropping (Fallow-rice). In addition, the best economic returns can be expected by energy crop rotations.

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Appendix 5

Report on "Assessment of spatio-temporal distribution of GHG emissions and carbon stock of rice paddies in South East Asia using ALU"

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CHAPTER 1 INTRODUCTION TO ALU

1.1 Description of ALU

In this study, the Agriculture and Land Use National Greenhouse Gas Inventory (ALU) Software, version 3.1.1.6, was used to estimate and assess GHG emissions from and soil carbon stock change in rice production. The ALU software can be downloaded from http://www.nrel.colostate.edu/projects/ALUsoftware/

The program can be used to estimate emissions and removals associated with biomass C stocks, soil C stocks, soil nitrous oxide emissions, rice methane emissions, enteric methane emissions, manure methane and nitrous oxide emissions, as well as non-CO_2 GHG emissions from biomass burning. Methods included in the program are based on guidelines provided by the Intergovernmental Panel on Climate Change (IPCC), as documented in the Revised 1996 IPCC National Greenhouse Gas Inventory Guidelines, and further refined in the 2000 IPCC Good Practice Guidance on Uncertainty Management in National Greenhouse Gas Inventories, as well as in 2003 IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry.

The software has several following innovative features:

- It can accommodate Tier 1 and 2 methods as defined by the IPCC
- It allows compilers to integrate GIS spatial data along with national statistics on agriculture and forestry
- It is designed to produce a consistent and complete representation of land use for inventory assessment
- It enables to develop an enhanced characterization for livestock
- It has explicit quality control and quality assurance steps
- It provides a long-term archive of data and results in digital format
- It generates emission reports that can be included in communications with interested parties.

1.2 Equations used for the estimation of GHG emissions and soil carbon stock

1.2.1 Methane emissions from rice cultivation

$$CH_{4\ Rice} = \sum_{i,j,k} (EF_{i,j,k} * t_{i,j,k} * A_{i,j,k} * 10^{-6})$$

Where:

$CH_{4\ Rice}$ = annual methane emissions from rice cultivation, Gg CH_4 yr^{-1}.

$EF_{i,j,k}$ = a daily emission factor for *i*, *j* and *k* conditions, kg CH_4 ha^{-1} day^{-1}.

$t_{i,j,k}$ = cultivation period of rice for *i*, *j* and *k* conditions, day.

$A_{i,j,k}$ = annual harvested area of rice for *i*, *j* and *k* conditions, ha yr^{-1}.

i, *j* and *k* = represent different ecosystems, water regimes, type and amount of organic amendments, and other conditions under which CH_4 emissions from rice may vary.

$$EF_i = EF_c * SF_w * SF_p * SF_o * SF_{s,r}$$

Where:

EF_i = adjusted daily emission factor for a particular harvested area
EF_c = baseline emission factor for continuously flooded fields without organic amendments
SF_W = scaling factor to account for the differences in water regime during the cultivation period
SF_O = scaling factor should vary for both type and amount of organic amendment applied
$SF_{s,r}$ = scaling factor for soil type, rice cultivar, etc., if available

1.2.2 Direct N_2O emissions from managed soils

$$N_2O_{Direct} - N = \sum_i (F_{SN} + F_{ON})_i * EF_{1i} + (F_{CR} + F_{SOM}) * EF_1 + N_2O - N_{OS} + N_2O - N_{PRP}$$

Where:

EF_{1i} = emission factors developed for N_2O emissions from synthetic fertilizer and organic N application under conditions *i* (kg N_2O–N (kg N input)$^{-1}$); i = 1, …n.

N from organic N additions applied to soils

$$F_{ON} = F_{AM} + F_{SEW} + F_{COMP} + F_{OOA}$$

Where:

F_{ON} = total annual amount of organic N fertilizer applied to soils other than by grazing animals, kg N yr^{-1}.
F_{AM} = annual amount of animal manure N applied to soils, kg N yr^{-1}.
F_{SEW} = annual amount of total sewage N (coordinate with Waste Sector to ensure that sewage N is not double-counted) that is applied to soils, kg N yr^{-1}.
F_{COMP} = annual amount of total compost N applied to soils (ensure that manure N in compost is not double-counted), kg N yr^{-1}.
F_{OOA} = annual amount of other organic amendments used as fertilizer (e.g., rendering waste, guano, brewery waste, etc.), kg N yr^{-1}.

N from crop residues and forage/pasture renewal

$$F_{CR} = \sum_T \left\{ Crop_T * \frac{(Area_T - Areaburnt_T * C_f) * Frac_{Renew(T)} *}{[R_{AG(T)} * N_{AG(T)} * (1 - Frac_{Remove(T)}) + R_{BG(T)} * N_{BG(T)}]} \right\}$$

Where:

F_{CR} = annual amount of N in crop residues (above and below ground), including N-fixing crops, and from forage/pasture renewal, returned to soils annually, kg N yr^{-1}.
$Crop_{(T)}$ = harvested annual dry matter yield for crop T, kg d.m. ha^{-1}.
$Area_{(T)}$ = total annual area harvested of crop T, ha yr^{-1}.
$Area\ burnt_{(T)}$ = annual area of crop T burnt, ha yr^{-1}.
C_f = combustion factor (dimensionless).
$Frac_{Renew\,(T)}$ = fraction of total area under crop T that is renewed annually.
$R_{AG\,(T)}$ = ratio of above-ground residues dry matter to harvested yield for crop T (Crop (T)), kg d.m. $(kg\ d.m.)^{-1}$.
$N_{AG\,(T)}$ = N content of above-ground residues for crop T, kg N $(kg\ d.m.)^{-1}$.
$Frac_{Remove\,(T)}$ = fraction of above-ground residues of crop T removed annually for purposes such as feed, bedding and construction, kg N $(kg\ crop\text{-}N)^{-1}$.
$R_{BG\,(T)}$ = ratio of below-ground residues to harvested yield for crop T, kg d.m. $(kg\ d.m.)^{-1}$.
$N_{BG\,(T)}$ = N content of below-ground residues for crop T, kg N $(kg\ d.m.)^{-1}$.
T = crop or forage type

1.2.3 Soils organic carbon stock of rice fields

$$\Delta C_{Mineral} = \frac{(SOC_0 - SOC_{0-T})}{D}$$

$$SOC = \sum_{c,s,i} (SOC_{REF_{c,s,i}} * F_{LU_{c,s,i}} * F_{MG_{c,s,i}} * F_{I_{c,s,i}} * A_{c,s,i})$$

Note: T is used in place of D in this equation if T is ≥ 20 years.
Where:

$\Delta C_{Mineral}$ = annual change in carbon stocks in mineral soils, tonnes C yr^{-1}
SOC_0 = soil organic carbon stock in the last year of an inventory time period, tonnes C
SOC_{0-T} = soil organic carbon stock at the beginning of the inventory time period, tonnes C
T = number of years over a single inventory time period, yr
D = Time dependence of stock change factors which is the default time period for transition between equilibrium SOC values, yr. Commonly 20 years, but depends on assumptions made in computing the factors F_{LU}, F_{MG} and F_I. If T exceeds D, use the value for T to obtain an annual rate of change over the inventory time period (0-T years).
c = represents the climate zones, s the soil types, and i the set of management systems that are present in a country.
SOC_{REF} = the reference carbon stock, tonnes C ha^{-1}
F_{LU} = stock change factor for land-use systems or sub-system for a particular land-use, dimensionless
F_{MG} = stock change factor for management regime, dimensionless
F_I = stock change factor for input of organic matter, dimensionless
A = land area of the stratum being estimated, ha. All land in the stratum should have common biophysical conditions (i.e., climate and soil type) and management history over the inventory time period to be treated together for analytical purposes.

CHAPTER 2 INPUT DATA TO ALU

2.1 Climate data

The climate classification of the IPCC 2006 Guidelines was used to define the climate inputs to ALU software for all the countries in SEA (Table 1).

Table 1 IPCC climate classification

Climate Name	Description
Boreal Dry	Mean annual temperature (MAT) of < 0°C and annual precipitation < evapotranspiration.
Boreal Moist	Mean annual temperature (MAT) of < 0°C and annual precipitation >= evapotranspiration
Cool Temperate Dry	Mean annual temperature (MAT) of < 10°C and annual precipitation less than evapotranspiration.
Cool Temperate Moist	Mean annual temperature (MAT) of < 10°C and annual precipitation similar to or higher than evapotranspiration.
Polar Dry	Polar Regions, little precipitation
Polar Moist	Polar Regions, significant precipitation
Tropical Dry	Tropical Region, Elevation < 1000m, Precip < 1000mm
Tropical Moist, Long Dry Season	Tropical Region, Elevation < 1000m, Annual precipitation >= 1000mm and Annual precipitation < 2000mm, dry season > 5 months
Tropical Moist, Short Dry Season	Tropical Region, Elevation < 1000m, Annual precipitation >= 1000mm and Annual precipitation < 2000mm, dry season <= 5 months
Tropical Montane Dry	Tropical Region, Elevation >= 1000m, Annual precipitation < 1000mm
Tropical Montane Moist	Tropical Region, Elevation >= 1000m, Annual precipitation >= 1000mm
Tropical Wet	Tropical Region, Elevation < 1000m, Annual precipitaiton >= 2000mm
Warm Temperate Dry	Mean annual growing season temperatures in this zone usually range from 10 to 20°C with annual precipitation usually < 600 mm.
Warm Temperate Moist	Mean annual growing season temperatures range from 10-20°C and with annual precipitation >= potential evapotranspiration.

2.2 Soil data

The soil type defaults from the IPCC 2006 Guidelines were used to define the soil type inputs to ALU software for all the countries in SEA (Table 2).

Table 2 IPCC soil type (defaults)

Soil Name	Description
High Activity Clay Mineral	Lightly to moderately weathered soils dominated by 2:1 silicate clay minerals (IPCC 2003)
Low Activity Clay Mineral	Highly weathered soils dominated by 1:1 clay minerals, amorphous iron and/or aluminum oxides (IPCC 2003)
Organic	Soils classified as histosols. See glossary of IPCC GPG 2003 for additional details.
Sandy Mineral	Soils with >70% sand and <8% clay (IPCC 2003)
Spodic Mineral	Soils with strong podzolization (IPCC 2003)
Volcanic Mineral	Soils derived from volcanic ash with allopohanic minerals (IPCC 2003)
Wetland Mineral	Soils with restricted drainage leading to periodic flooding and anaerobic conditions (IPCC 2003), but not organic soils

2.3 Summary of climate and soil data for SEA countries

The climate and soil data used in this study are summarized in Table 3

Table 3 Climate and soil data input to ALU

Country	Climate	Soil types classified by rice ecosystems			
		Irrigated rice	Rainfed lowland rice	Upland rice	Flood prone
Cambodia	Tropical Moist	High Activity Clay	Low Activity Clay	Low Activity Clay	Wetland Mineral
Indonesia	Tropical Wet	High Activity Clay	Low Activity Clay	Low Activity Clay	Wetland Mineral
Laos	Tropical Moist	High Activity Clay	Low Activity Clay	Low Activity Clay	Wetland Mineral
Malaysia	Tropical Wet	High Activity Clay	Low Activity Clay	Low Activity Clay	Wetland Mineral
Myanmar	Tropical Moist	High Activity Clay	Low Activity Clay	Low Activity Clay	Wetland Mineral
Philippines	Tropical Wet	High Activity Clay	Low Activity Clay	Low Activity Clay	Wetland Mineral
Thailand	Tropical Moist	High Activity Clay	Low Activity Clay	Low Activity Clay	Wetland Mineral
Vietnam	Tropical Moist	High Activity Clay	Low Activity Clay	Low Activity Clay	Wetland Mineral

2.4 Rice cultivation area

The rice cultivation areas in SEA classified by rice ecosystem from the International Rice Research Institute were used as inputs to ALU software in this study. The rice ecosystem is divided into 4 classes: (1) Irrigated rice, (2) Rain-fed lowland rice, (3) Upland rice, and (4) Flood prone rice. The inputs are summarized in Table 4.

Table 4 Rice cultivation area in SEA classified by rice ecosystem

Country	Rice cultivation Area in SEA (1000 ha)				
	Irrigated rice	Rain-fed lowland rice	Upland rice	Flood prone	Total
Cambodia	154	1,124	33	614	1,925
Indonesia	6,154	4,015	1,247	23	11,439
Laos	40	319	201	-	560
Malaysia	445	152	84	-	681
Myanmar	1,124	4,166	252	602	6,144
Philippines	2,334	1,304	120	-	3,758
Thailand	2,075	6,792	36	117	9,020
Vietnam	3,687	1,955	345	778	6,765
Total	16,015	19,827	2,318	2,134	40,294

(IRRI Rice Facts, 2002)

2.5 Rice productivity

The inputs related to rice productivity used in this study are from the International Rice Research Institute, and are summarized in Table 5.

Table 5 Productivity of four different rice systems

System	Yield (t/ha)	Crop/Year	Fallow period (yr)	Productivity (t/ha/yr)
Irrigated rice	5.0	2.5	0	12.5
Rainfed rice	2.5	1	0	2.5
Deep water rice	1.0	1	0	1.0
Upland rice	1.0	1	8	0.12

(IRRI Rice Facts, 2002)

2.6 Fertilizer N use by rice

The inputs related to N fertilizer used for rice cultivation in SEA are from the Potash Phosphate Institute-Potash Phosphate Institute of Canada East and Southeast Asia Programs (PPI-PPIC ESAP, 2001), and are reported in Table 6.

Table 6 N fertilizer used for rice cultivation in SEA

Country	Area (1,000 ha)	Fertilizer N		Consumption N (1,000 ton)
		Fertilized (%)	Rate (kg/ha)	
Cambodia	1,873	30	15	8.4
Indonesia	11,523	90	105	1,192.6
Laos	690	30	55	11.4
Malaysia	692	90	95	59.2
Myanmar	6,000	60	35	126.0
Philippines	4,037	85	51	175.0
Thailand	10,048	90	62	560.7
Vietnam	7,655	90	108	744.1
Total	42,518	-	-	2,877.4

(PPI-PPIC ESEAP estimates, 2002)

CHAPTER 3 DEVELOPMENT OF GHG AND SOIL CARBON STOCK MAPS

3.1 Development of spatio-temporal maps of GHG emissions and soil carbon stock of existing and sustainable cultivation practices

The maps of rice cultivation areas were obtained by overlaying SEA countries land cover maps from Land Cover Product of GLOB COVER by ESA/UNEP/FAO/JRC/IGBP/GOFC-GOLD, with spatial distribution of paddy rice derived from analysis of MODIS 8-day surface reflectance data in 2002 (spatial resolution of 500m) (Xiao, 2006).

In order to visualize the change in GHG emissions and soil carbon stock in two different years, e.g. in 2010 and 2030, gridded-maps were developed, with a grid resolution of 10-km x 10-km.

Examples of land cover maps and paddy rice areas derived from MODIS are provided as follows.

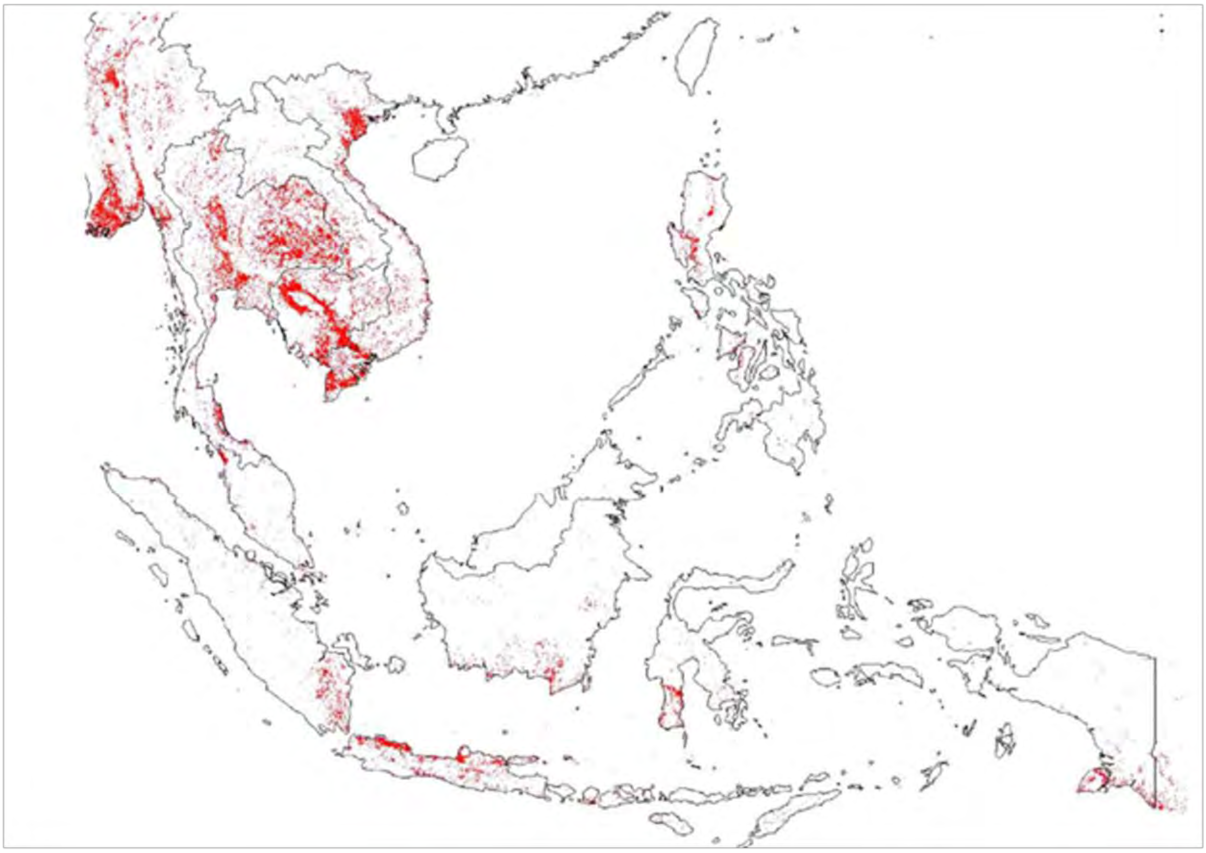

Figure 1 Spatial distribution of paddy rice derived from analysis of MODIS 8-day surface reflectance data in 2002 (Spatial resolution 500m).

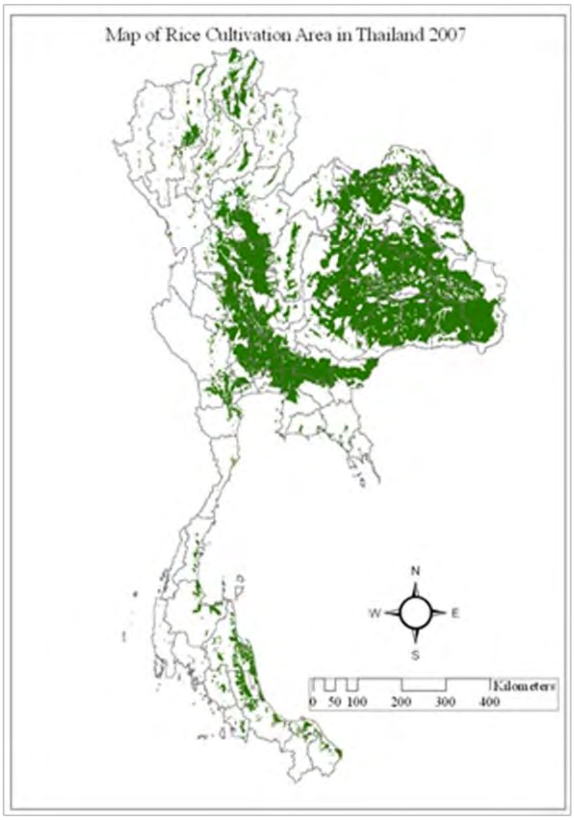

Figure 2 Maps of rice cultivation area of Thailand in 2007.

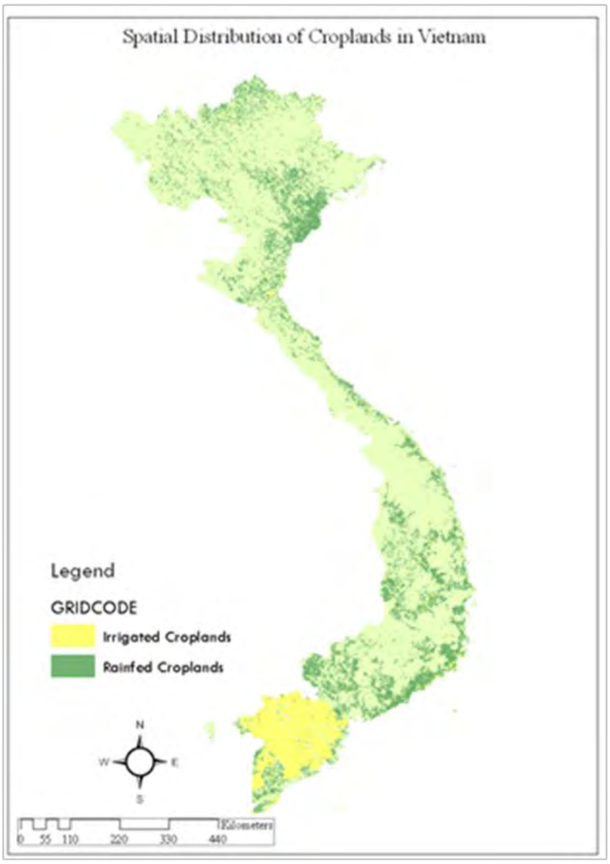

Figure 3 Spatial distribution of cropland in Vietnam in 2002.

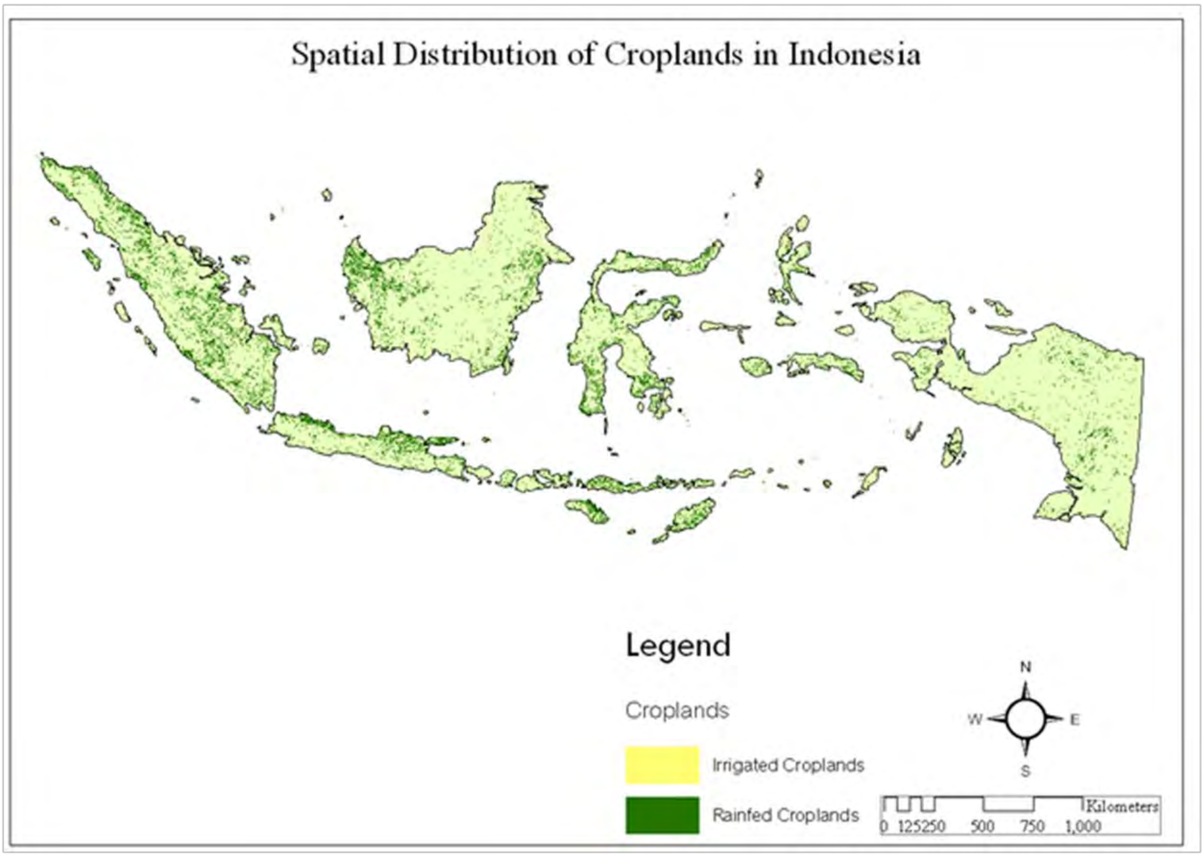

Figure 4 Spatial distribution of cropland in Indonesia in 2002.

3.2 Assessment of potential mitigation options based on different scenarios

Potential mitigation options based on different scenarios resulted from long term field measurement experiments were assessed using ALU software. These scenarios are summarized as follows in Figure 5.

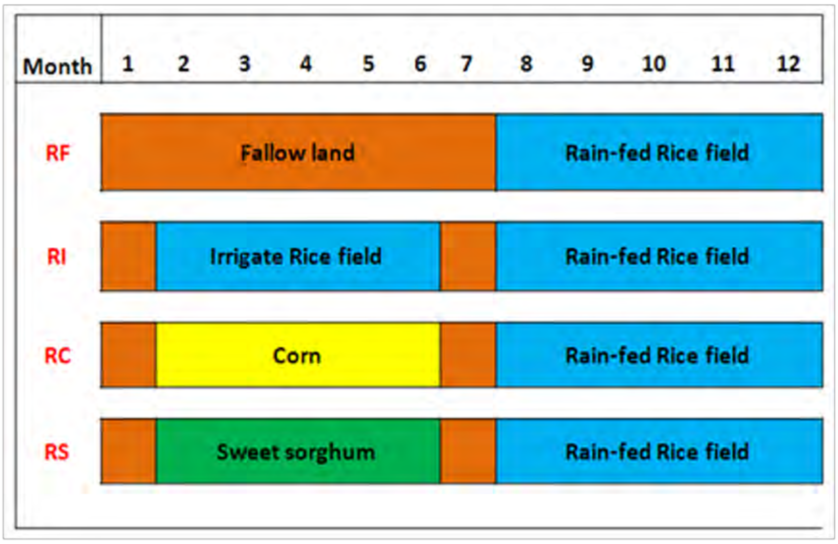

Figure 5 Scenarios of rice cultivation and rotation with energy crop.

Note: Fallow land-Rainfed rice is referred to as RF, Irrigated rice-Rainfed rice is referred to as RI, Corn- Rainfed rice is referred to as RC and Sorghum-Rainfed rice is referred to as RS.

CHAPTER 4 SPATIO-TEMPORAL DISTRIBUTION OF GHG EMISSIONS AND CARBON STOCK OF RICE PADDIES IN SEA

4.1 Spatial distribution of annual GHG emissions from rice cultivation in SEA

4.1.1 Methane emissions

The estimation of annual methane emission from rice cultivation in SEA using ALU software and input data provided in the section 2.4 is detailed in Table 7 and Figure 6. The results indicate that Indonesia is the first emitter of methane from rice cultivation followed by Vietnam, Thailand, Philippines, and Myanmar with emissions of more than 30,000 Gg $CO_{2\text{-eq}}$. Cambodia, Malaysia and Laos' annual methane emission from rice cultivation are less than 10,000 Gg $CO_{2\text{-eq}}$. For all high emitter countries, the main emission of methane from rice cultivation is from the irrigated rice ecosystem. Upland rice ecosystem shows no emission of methane since there is no flooded period.

Table 7 Annual methane emission from rice cultivation in SEA classified by ecosystem

Country	Rice Methane in SEA (Gg CO_2-eq/yr)				
	Irrigated rice	Rainfed lowland rice	Upland rice	Flood prone	Total
Cambodia	1,931	3,660	-	1,999	7,589
Indonesia	77,156	13,072	-	75	90,303
Laos	502	1,039	-	-	1,540
Malaysia	5,579	495	-	-	6,074
Myanmar	14,092	13,564	-	1,960	29,616
Philippines	29,263	4,246	-	-	33,508
Thailand	26,015	22,114	-	381	48,510
Vietnam	46,226	6,365	-	2,533	55,124
Total	200,763	64,554	-	6,948	272,265

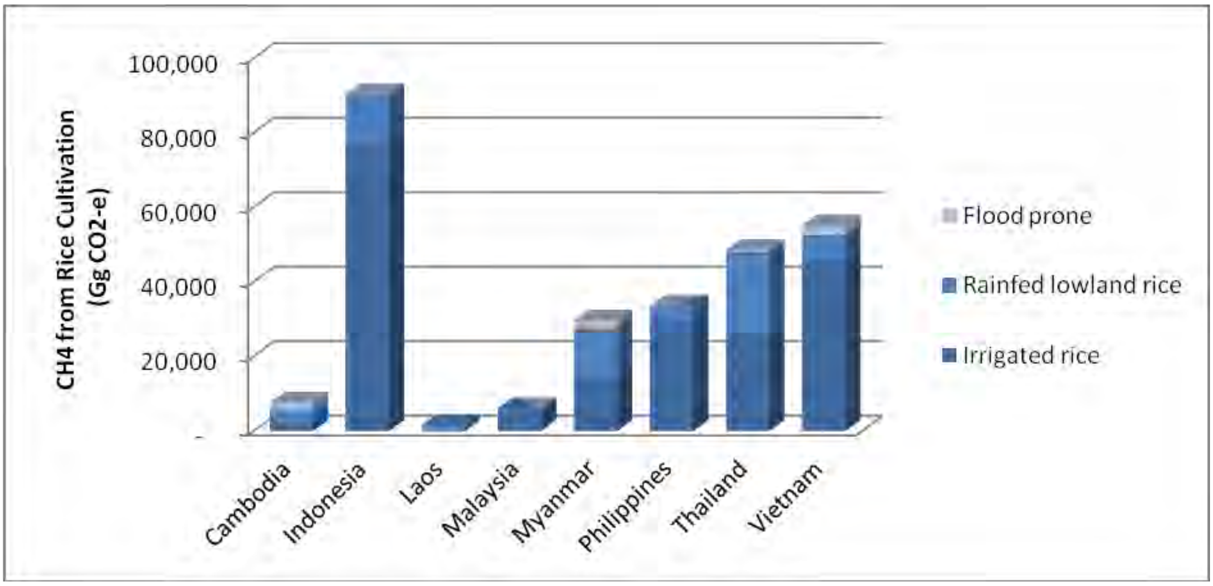

Figure 6 Rice methane from rice fields vs. cultivation practices in SEA.

The spatial distribution of methane emission from rice cultivation in SEA is illustrated in Figure 7 Individual emission maps of Indonesia, Thailand, Vietnam, Laos and Cambodia are also reported (Figure 8-9).

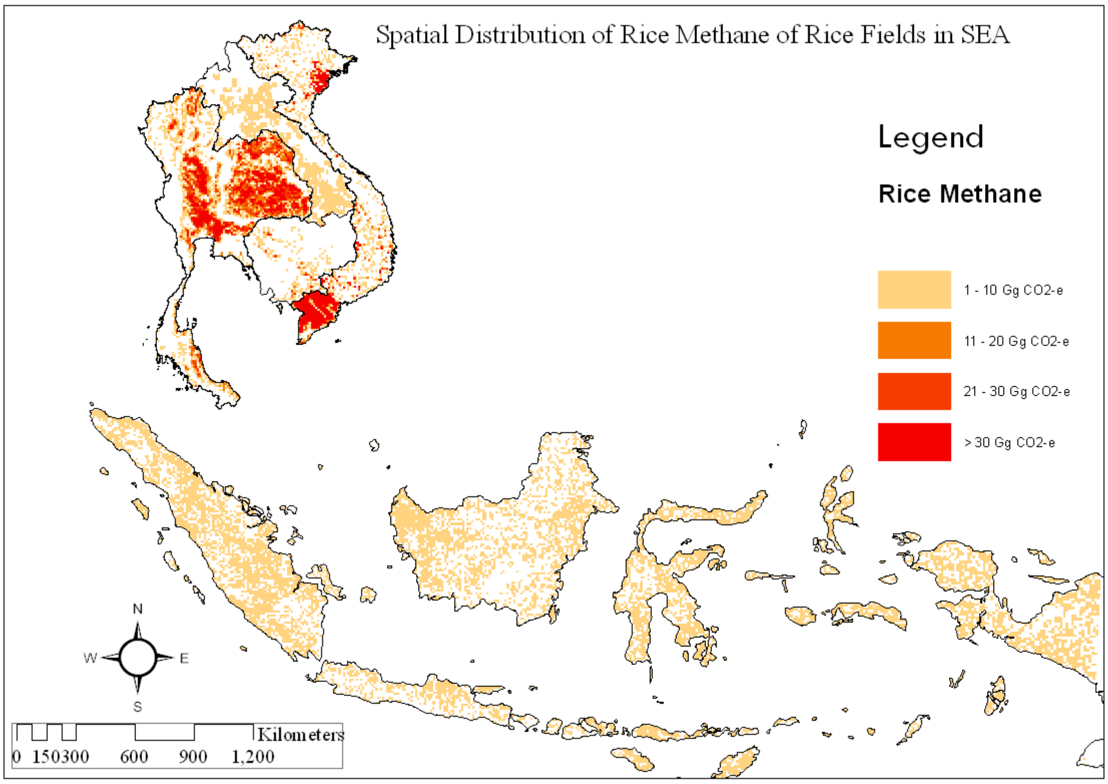

Figure 7 Spatial distribution of methane emission from rice cultivation in SEA.

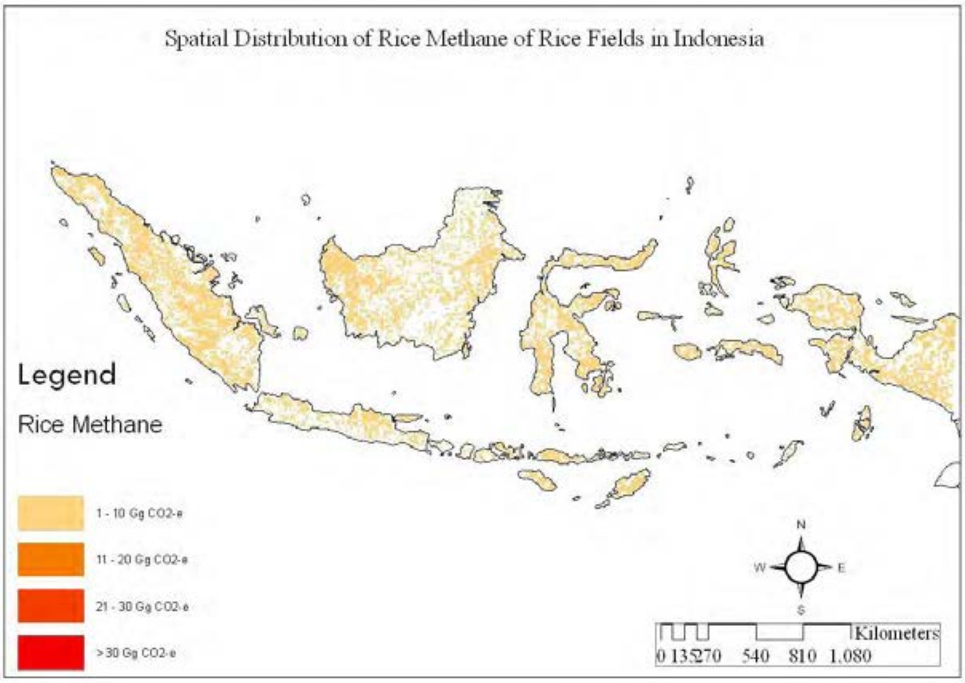

Figure 8 Spatial distribution of methane emission from rice cultivation in Indonesia.

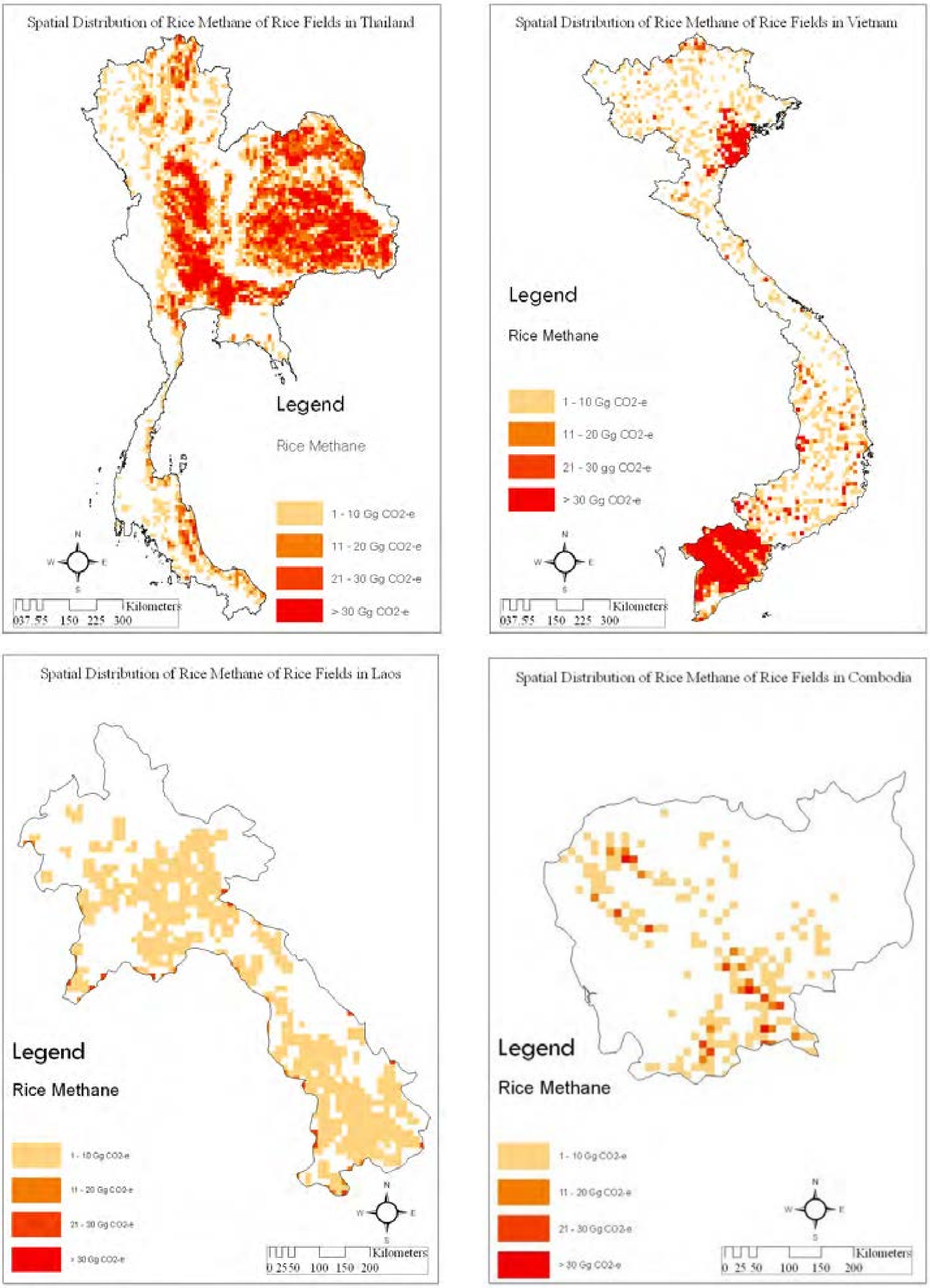

Figure 9 Spatial distribution of methane emission from rice cultivation in (a) Thailand, (b) Vietnam, (c) Laos, and (d) Cambodia.

The results show that Thailand and Vietnam possess high number of highest emission grids (>30 Gg $CO_{2\text{-}eq}$ per grid) or "hot spot". In Thailand, the areas of "hot spot" cover the central and northeastern regions of the country, while in Vietnam they are observed close to the Red Delta and

Mekong Delta. In Cambodia, some "hot spots" appear in the region of Tonle Sap. In case of Indonesia, emission intensity is quite stable throughout the country.

4.1.2 Nitrous oxide emissions

Regarding nitrous oxide, the emissions may come from two pathways: (1) from N contained in crop residues incorporated into the soil, and (2) from N fertilizer. The results from calculation using ALU software are reported in Table 8-9. As for methane emission, irrigated rice ecosystem constitutes the main source of N_2O emission.

Table 8 N_2O direct from N in Crop residue in SEA

Country	N_2O from N in Crop residue in SEA (Gg CO_2-eq/yr)				
	Irrigated rice	Rainfed lowland rice	Upland rice	Flood prone	Total
Cambodia	3,141.0	4,585.0	53.8	1,001.9	8,782
Indonesia	125,517.4	16,378.0	2,034.7	37.5	143,968
Laos	815.8	1,301.3	328.0	-	2,445
Malaysia	9,076.2	620.0	137.1	-	9,833
Myanmar	22,925.2	16,994.0	411.2	982.3	41,313
Philippines	47,604.4	5,319.3	195.8	-	53,120
Thailand	42,321.8	27,706.0	58.7	190.9	70,277
Vietnam	75,200.3	7,974.9	562.9	1,269.5	85,008
Total	326,602.1	80,878.5	3,782.2	3,482.0	414,745

Table 9 N_2O direct from synthetic fertilizer N from rice fields vs. cultivation practices in SEA

Country	N_2O direct from synthetic fertilizer N in SEA (Gg CO_2-e/yr)
Cambodia	41
Indonesia	5,810
Laos	56
Malaysia	288
Myanmar	614
Philippines	853
Thailand	2,731
Vietnam	3,625
Total	14,017

4.1.3 Summary of GHG Emissions from rice cultivation in SEA

GHG emissions from rice cultivation composed of CH_4, N2O direct from N in Crop residue, and N_2O direct from synthetic N fertilizer are summarized in Table 10 and Figure 10. Indonesia is the first emitting country because of largest area of cultivation, followed by Vietnam where intensification of crop rotation is practiced with up to three crops per year, and Thailand where double cropping is a common practice, especially in the central region and irrigated areas. In each country, the major source of GHG is N_2O direct from N in Crop residue followed by rice CH_4.

Table 10 GHG Emissions from rice fields vs. cultivation practices in SEA

Country	GHG Emissions from rice fields vs. cultivation practices in SEA (Gg CO_2-e/yr)			
	Rice CH_4	N_2O direct from N in Crop residue	N_2O direct from synthetic N fertilizer	Total GHG Emissions
Cambodia	7,589	8,782	41	16,412
Indonesia	90,303	143,968	5,810	240,080
Laos	1,540	2,445	56	4,041
Malaysia	6,074	9,833	288	16,196
Myanmar	29,616	41,313	614	71,542
Philippines	33,508	53,120	853	87,480
Thailand	48,510	70,277	2,731	121,519
Vietnam	55,124	85,008	3,625	143,756
Total	272,265	414,745	14,017	701,027

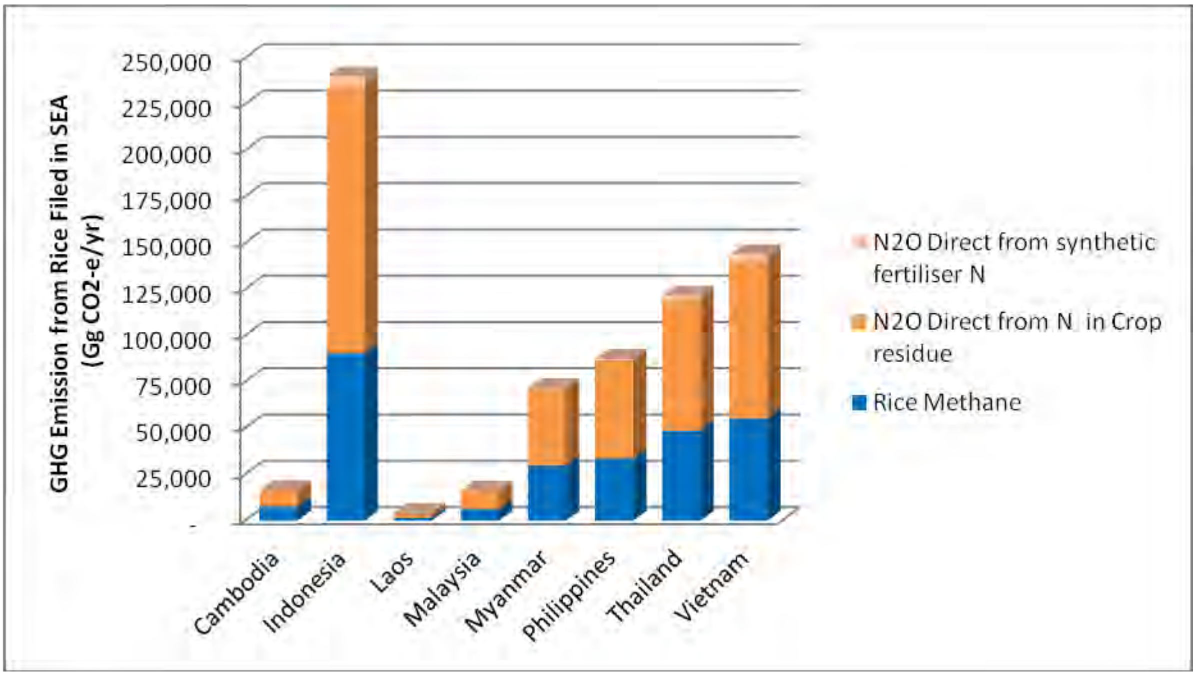

Figure 10 GHG Emissions from rice fields vs. cultivation practices in SEA.

The spatial distribution of GHG emission from rice cultivation in SEA is illustrated in Figure 11. Individual emission maps of Indonesia, Thailand, Vietnam, Laos and Cambodia are also reported (Figure 12-13).

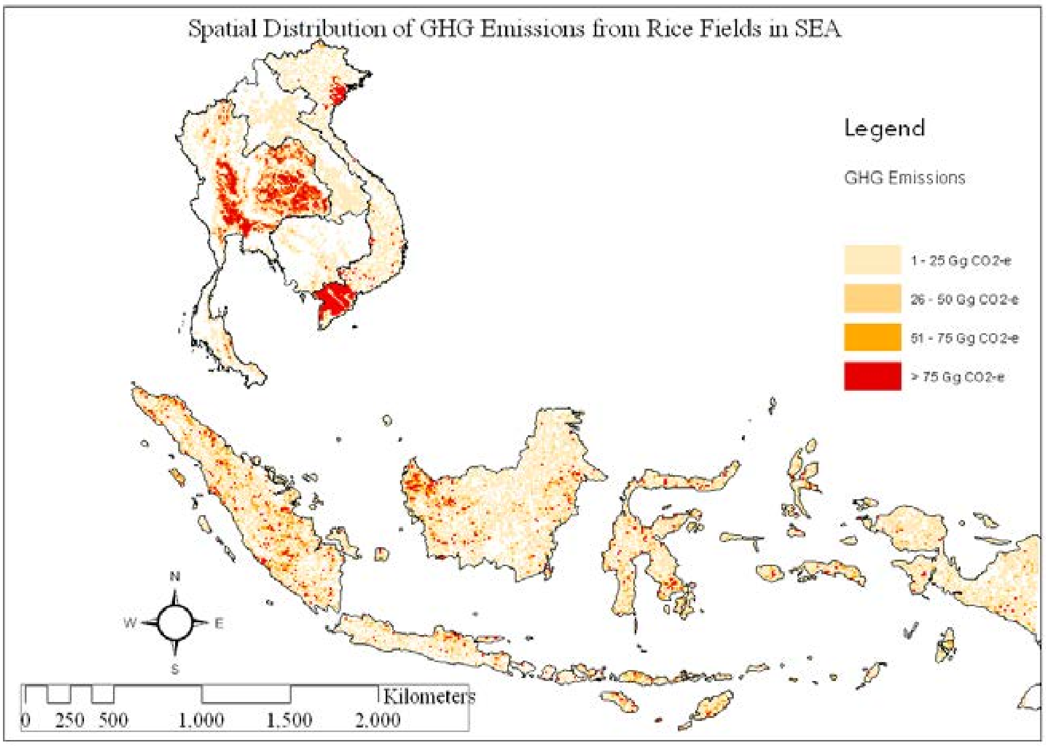

Figure 11 Spatial distribution of GHG emissions from rice cultivation in SEA.

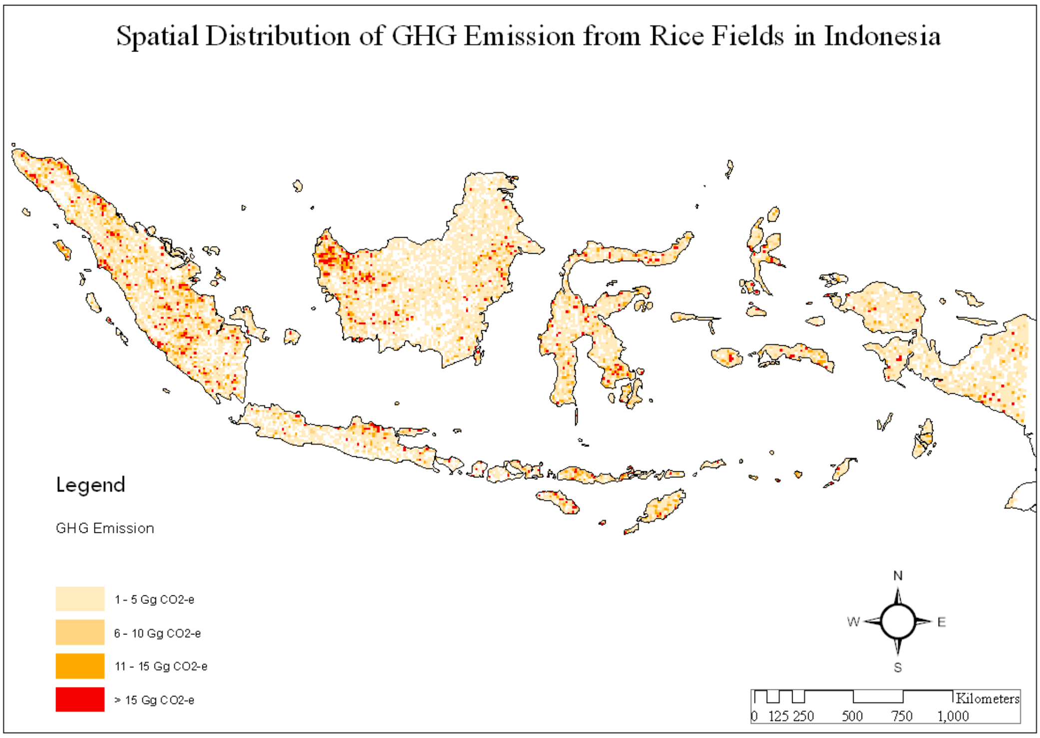

Figure 12 Spatial distribution of GHG emissions from rice cultivation in Indonesia

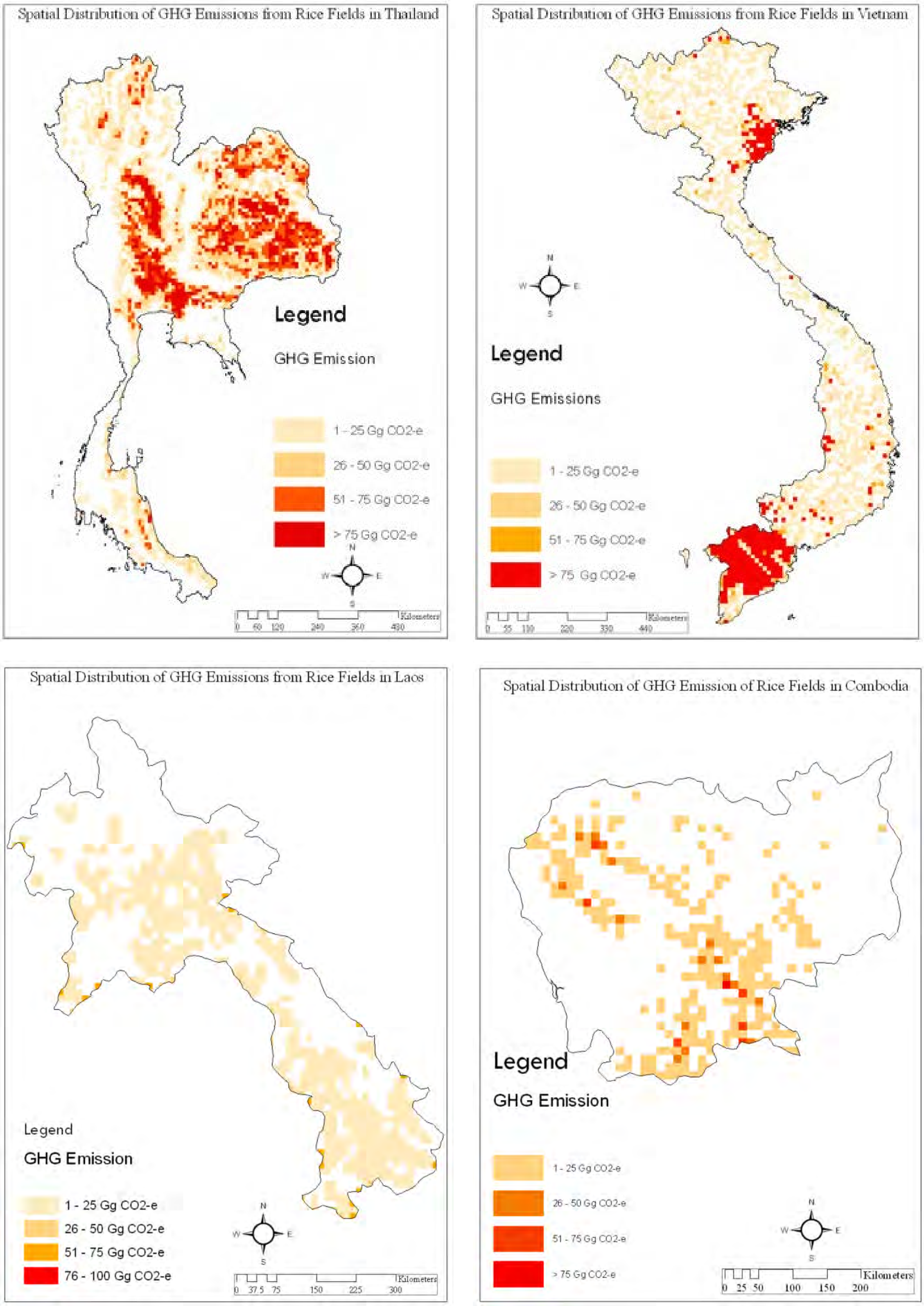

Figure 13 Spatial distribution of GHG emissions from rice cultivation in (a) Thailand, (b) Vietnam, (c) Laos, and (d) Cambodia

The results show that Thailand and Vietnam possess high number of highest GHG emission grids (>75 Gg $CO_{2\text{-}eq}$ per grid) or “hot spot”. In Thailand, the areas of “hot spot” cover the central and northeastern regions of the country, while in Vietnam they are observed close to the Red Delta and

Mekong Delta. In Cambodia, some "hot spots" appear in the region of Tonle Sap. In case of Indonesia, emission intensity is quite stable throughout the country.

4.2 Spatio-temporal distribution of soil organic carbon stock and soil organic carbon stock change in rice ecosystems in SEA

4.2.1 Soil organic carbon stock

The soil organic carbon stock of the four rice ecosystems in SEA was estimated for the year 2010 and 2030. The results are reported in Table 11-12. The highest soil organic carbon ecosystem in Indonesia and Vietnam is irrigated rice, and rain-fed rice in the case of Thailand, whether for 2010 or 2030, since it depends only on the land use type. The gain is around 10% in 20 years for irrigated rice, while it is much lower for rain-fed rice.

Table 11 Soil organic carbon stocks in SEA in 2010

Country	Soil Organic C Stocks in SEA in 2010 (Gg CO_2-e/yr)				
	Irrigated rice	Rain-fed lowland rice	Upland rice	Flood prone	Total
Cambodia	36,703	193,703	5,687	193,615	429,708
Indonesia	992,845	883,300	274,340	7,253	2,157,738
Laos	9,533	54,974	34,639	-	99,147
Malaysia	71,793	33,440	18,480	-	123,713
Myanmar	267,887	717,941	43,428	189,831	1,219,086
Philippines	376,552	286,880	26,400	-	689,832
Thailand	494,542	1,170,488	6,204	36,894	1,708,128
Vietnam	878,735	336,912	59,455	245,329	1,520,431
Total	3,128,591	3,677,637	468,633	672,921	7,947,782

Table 12 Soil organic carbon stocks in SEA in 2030

Country	Soil Organic C Stocks in SEA in 2030 (Gg CO_2-e/yr)				
	Irrigated rice	Rainfed lowland rice	Upland rice	Flood prone	Total
Cambodia	40,374	213,073	2,730	212,976	469,152
Indonesia	1,092,130	971,630	103,152	7,978	2,174,890
Laos	10,487	60,472	16,627	-	87,585
Malaysia	78,973	36,784	6,948	-	122,705
Myanmar	294,675	789,735	20,845	208,814	1,314,069
Philippines	414,207	315,568	9,926	-	739,702
Thailand	543,996	1,287,537	2,978	40,583	1,875,094
Vietnam	966,609	370,603	28,538	269,862	1,635,612
Total	3,441,450	4,045,401	191,745	740,213	8,418,809

4.2.2 Soil organic carbon stocks change

The soil organic carbon stock change of rice cultivation in SEA was estimated between 2010 and 2030. The results are reported in Table 13 and FigURE 14. Thailand has the highest gain followed by Vietnam and Myanmar.

Table 13 Soil Organic C Stocks Change in SEA between 2010 and 2030

Country	Soil Organic C Stocks Change in SEA (Gg CO_2-e/yr)		
	Soil Organic C Stocks in 2030	Soil Organic C Stocks in 2010	Soil Organic C Stocks Change (2010-2030)
Cambodia	469,152	429,708	- 1,972
Indonesia	2,174,890	2,157,738	- 858
Laos	87,585	99,147	578
Malaysia	122,705	123,713	50
Myanmar	1,314,069	1,219,086	- 4,749
Philippines	739,702	689,832	- 2,493
Thailand	1,875,094	1,708,128	- 8,348
Vietnam	1,635,612	1,520,431	- 5,759
Total	8,418,809	7,947,782	- 23,551

(-)=Gain and (+)=Loss

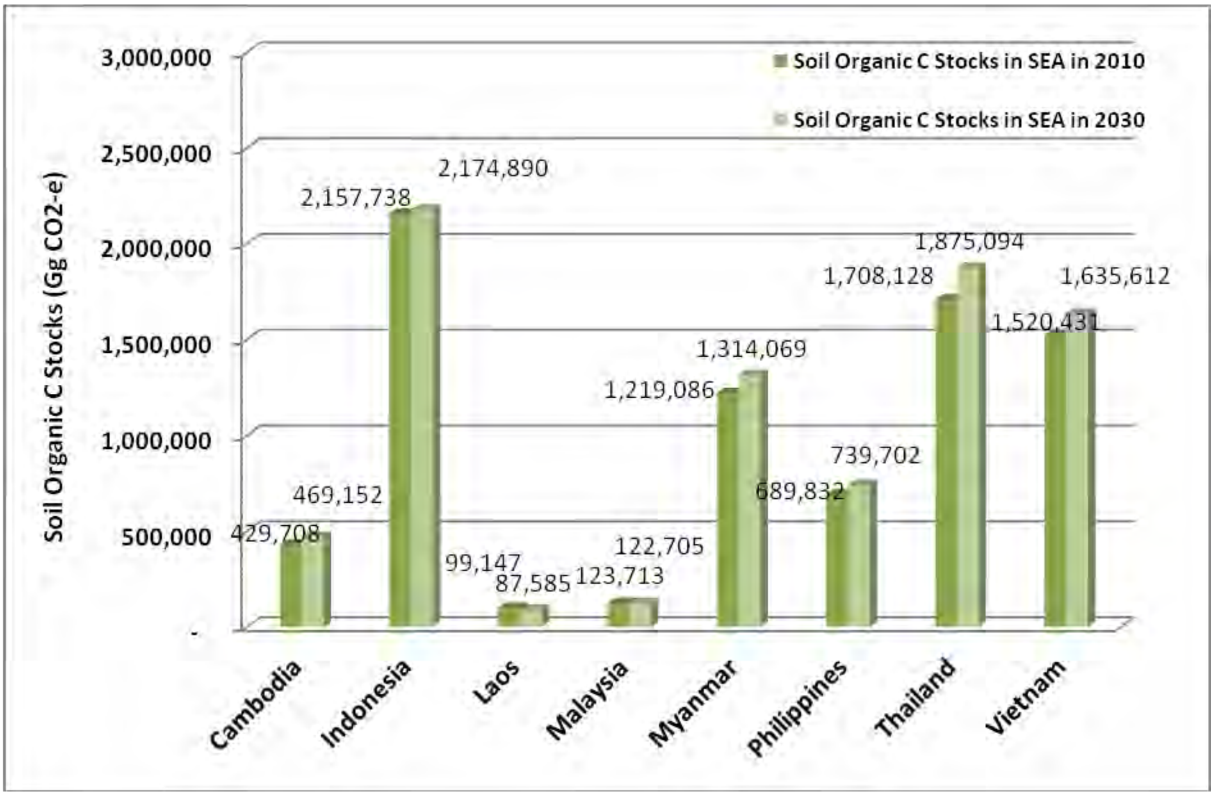

Figure 14 Soil organic carbon stocks in SEA in 2010 and 2030.

The spatial distribution of soil organic carbon of rice cultivation in SEA is illustrated in Figure 15. Individual emission maps of Indonesia, Thailand, Vietnam, Laos and Cambodia are also reported (Figure 16-17).

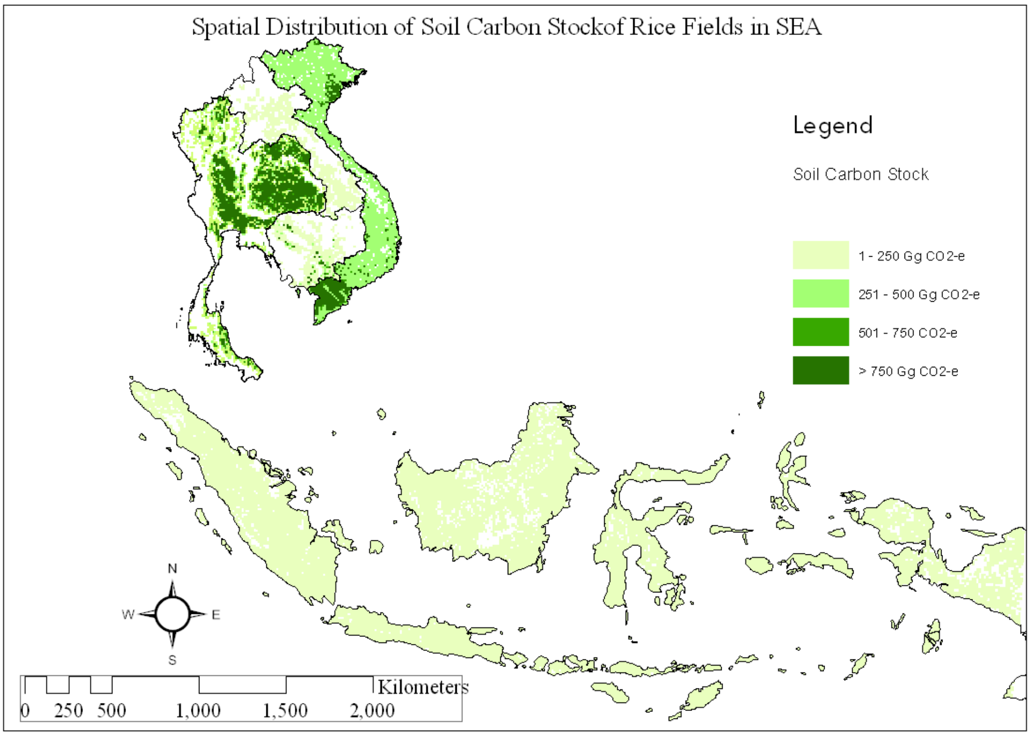

Figure 15 Spatial distribution of soil organic carbon stock of rice cultivation in SEA.

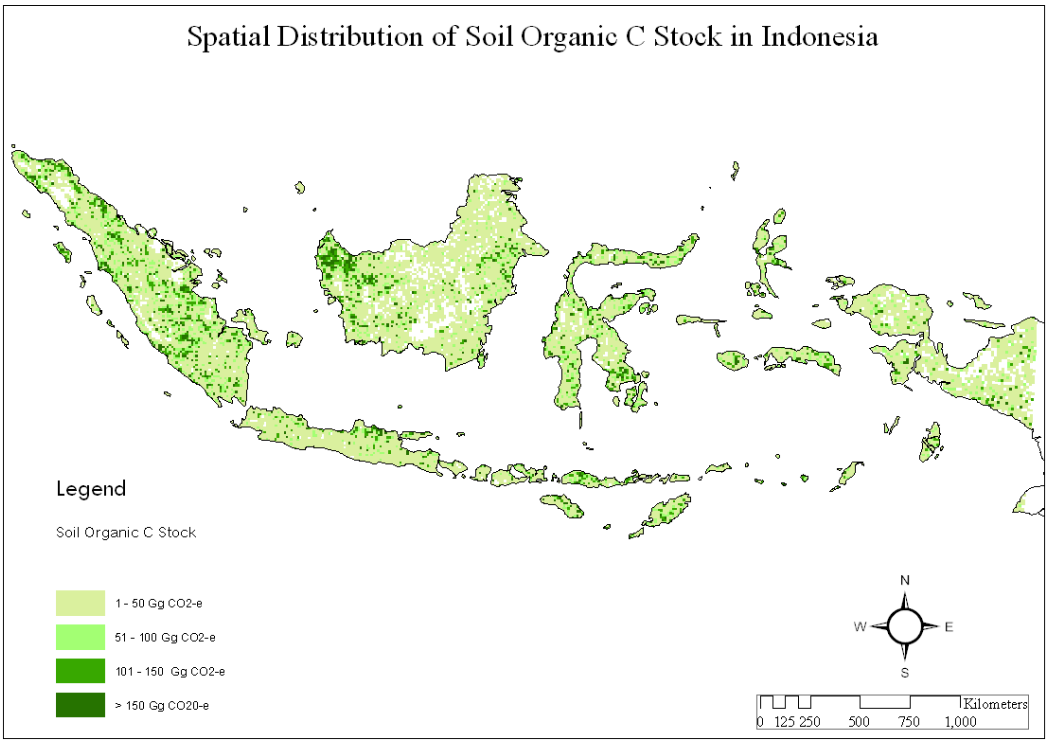

Figure 16 Spatial distribution of soil organic carbon stock of rice cultivation in Indonesia.

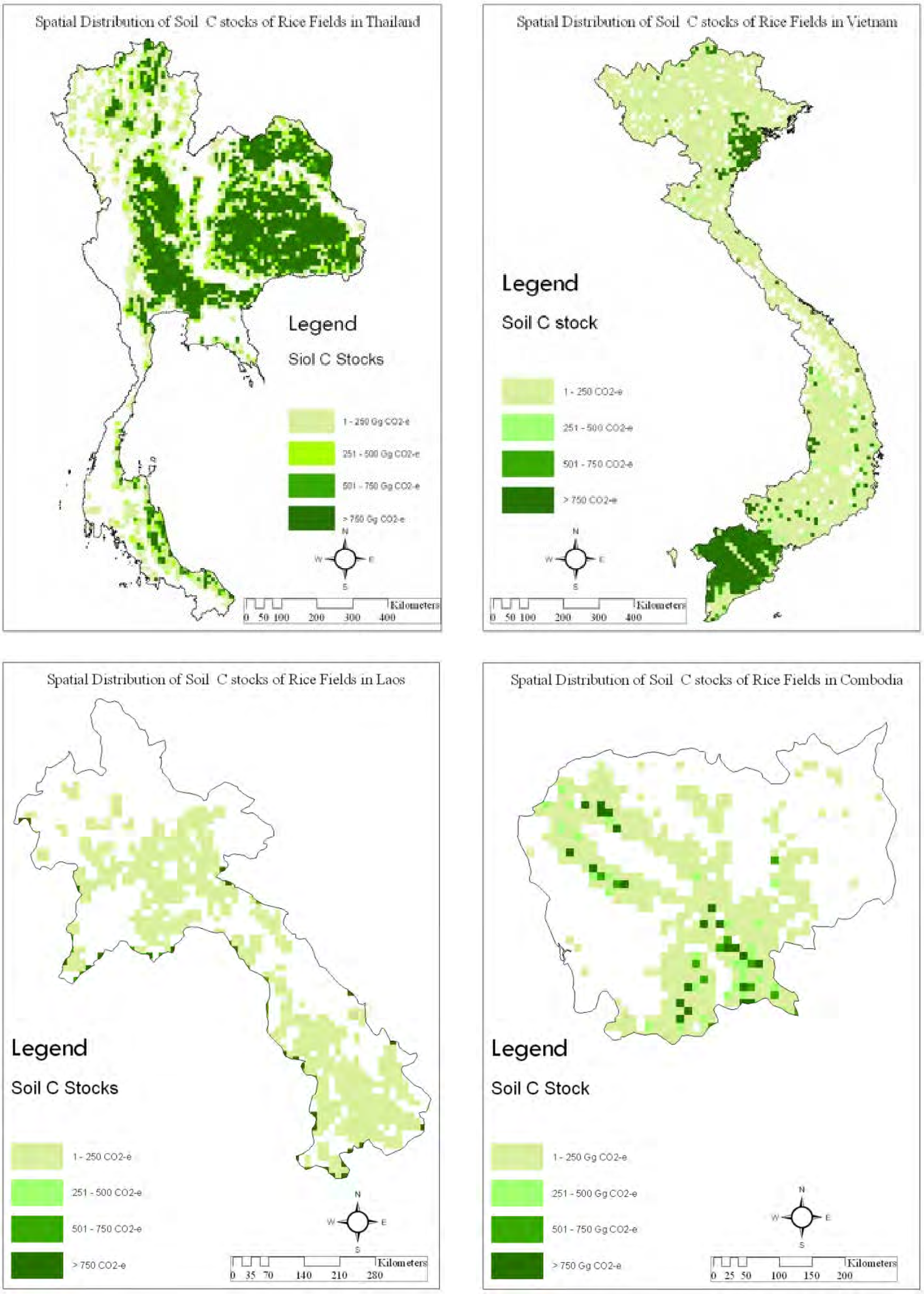

Figure 17 Spatial distribution of GHG emissions from rice cultivation in (a) Thailand, (b) Vietnam, (c) Laos, and (d) Cambodia.

4.2.3 Carbon Budget of the Rice Cultivation Systems

The summary of carbon budget of rice cultivation in SEA in 2030 is shown in Figure 18.

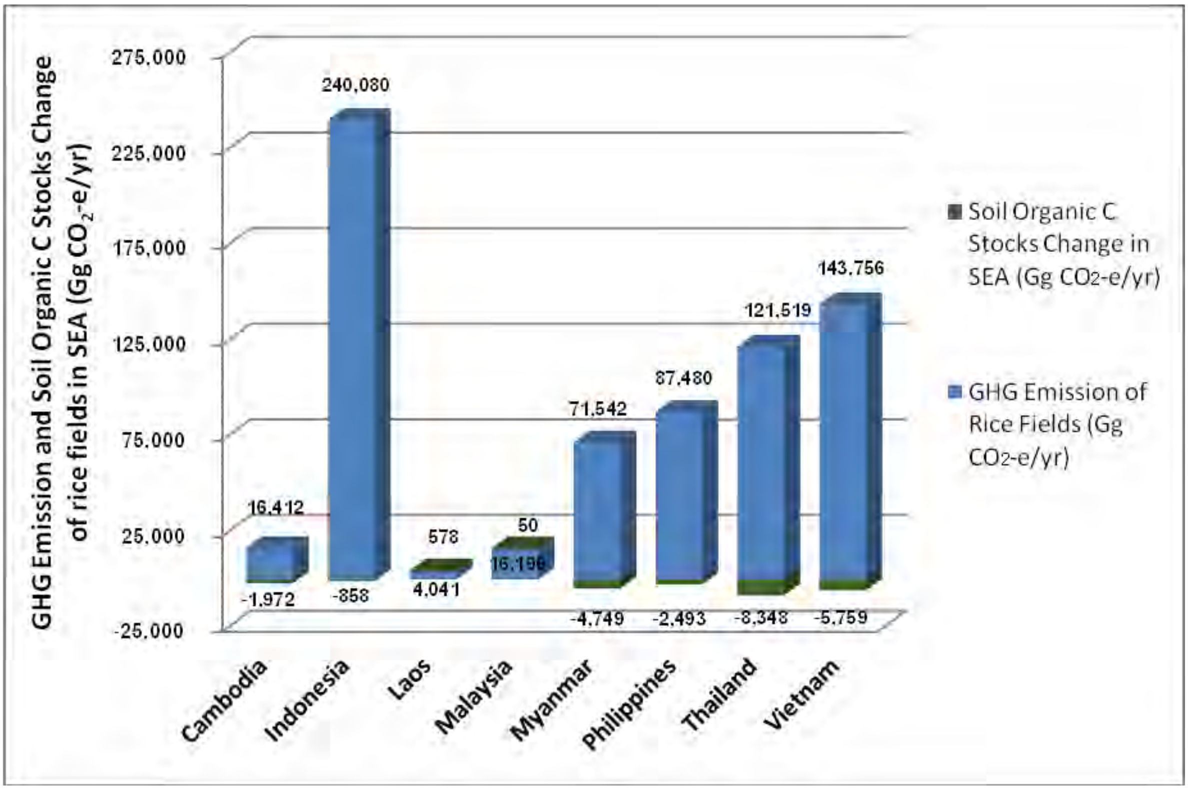

Figure 18 Carbon budget of the rice cultivation systems in SEA in 2030.

4.3 Assessment of the carbon budget of rice cultivation under existing and sustainable practices in Thailand

The assessment results for the four scenarios are summarized in Table 14 and Figure 19.

Table 14 Carbon budget of rice cultivation under existing and sustainable practices in Thailand in 2030

Scenarios	CH_4 Rice cultivation (Gg CO_2-e)	Soil N_2O Emission from synthetic fertilizer N (Gg CO_2-e)	Soil N_2O Emission from N in Crop Residue (Gg CO_2-e)	Soil Organic C Stocks Change (Gg CO_2)
RF	42,559	1,116	51,838	- 8,103
RI	64,268	1,949	91,917	- 8,103
RC	42,559	2,747	132,527	- 8,103
RS	42,559	2,095	145,975	- 8,103

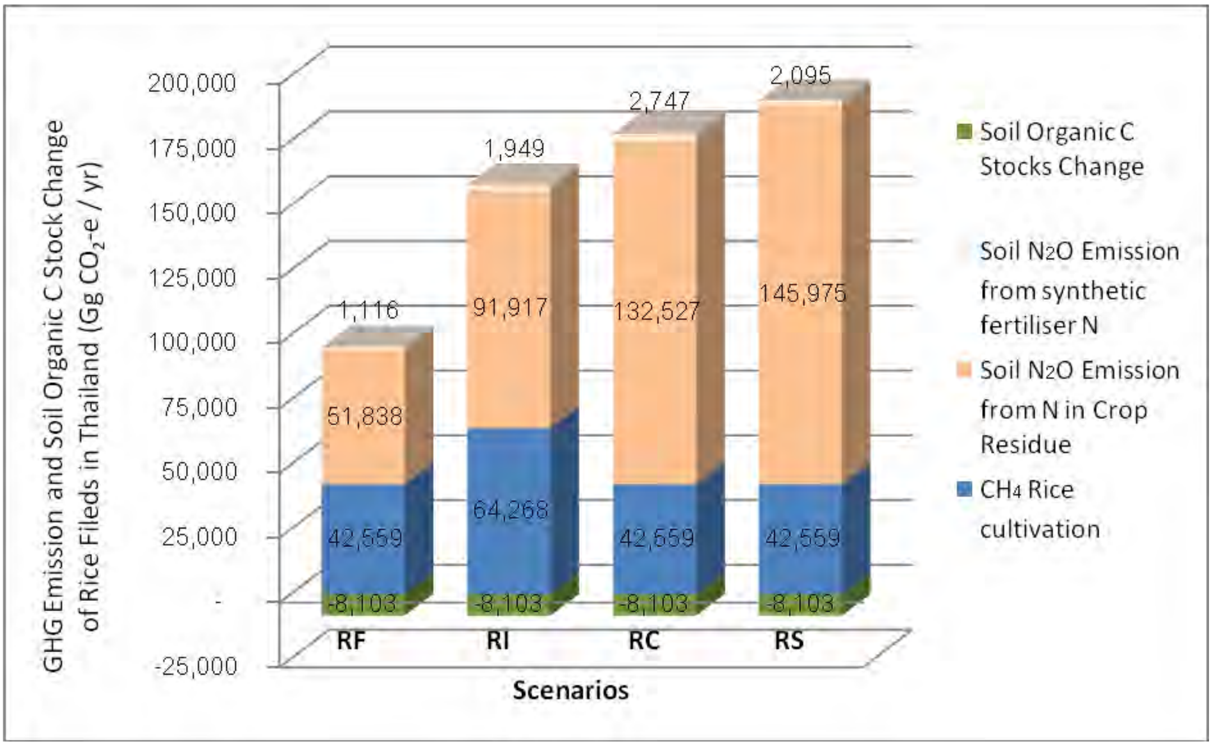

Figure 19 Carbon budget of rice cultivation under existing and sustainable practices in Thailand

From the results, scenarios RI, RC and RS contribute to enhance GHG emissions, especially from soil N_2O emission from N in crop residues. The soil organic carbon stock change remains the same for the four scenarios because the principal land use is considered in ALU to be rice field whether the case.

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Appendix 6

Report on “Assessment of long term GHG emissions and soil carbon dynamics of various rice paddy cultivation systems using DNDC model”

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CHAPTER 1 INTRODUCTION

1.1 Background

Climate change has received significant attention from scientists and government's from all over the world. The GHGs, of which the CO_2 ranks topmost have been recognized as a key player in global climate change (Davidson et al., 2001). The global carbon cycle describes the transfer of carbon in to the earth's atmosphere, vegetation, soils and oceans. The two most important anthropogenic processes are the responsible for emitting CO_2 are the burning of fossil fuels and land use. Rapidly growing GHG emissions are outpacing the growth of the natural sinks. The efficiency of major sinks (ocean and lands) has been decline significantly over time. The ocean and land sinks use to remove 60% of all anthropogenic CO_2 fifty years before presently its decline to 55% (World Bank (ARD), 2012).

Soils plays key role in determining global carbon dynamics because they serves the link between the atmosphere, vegetation and ocean. Globally the soil carbon pool is estimated at 2500Gt up to 2m depth, where soil organic pool is 1550 Gt and soil inorganic and elemental pool is 950 Gt (World Bank (ARD)., 2012). The soil organic carbon pool is main indicator of a dynamic balance between gain and losses. Presently the main reason of carbon loss is due to the land use change (deforestation) and related land change processes (erosion, tillage practices, burning of biomass, fertilizer applications, residue removal and drainage)is between 0.7 and 2.1 Gt carbon per year.

Compared with the natural ecosystem, C in agricultural soil shows great sensitivity in the global C cycling. Various agricultural practices such as residue retention, tillage, fertilization and irrigation influences the agricultural soil pool, which affect not only soil fertility but also global and regional C cycling (Wen et al., 2007).

According to FAO statistics, rice plantation covers 12.5% of total crop plantation area in the world. South-East Asia (SEA) is the region with the major rice plantation area covering 30% of the world plantation area. Recognizing the role of rice paddies in the regional carbon budget, an evolution of soil organic carbon change in SEA rice paddies is grate important to understand the future contribution of rice paddies to the carbon sequestration and mitigation options. Also while understand the soil organic carbon in rice paddies it is also important to understand other GHGs emissions from rice field (such as CH_4 and N_2O), which has significant impact on climate change.

It is estimated that rice paddies are responsible for GHGs emissions, so balancing food production to feed population and environmental protection, and predicting the impact of climate change or alternative management on both environment safety and food production are drawing great attention in the global scientific community (Zhang et al. 2002). Agricultural ecosystem include complex climatic components and soil processes, the atmosphere and farming and cropping practices, so this complex structure limits the measurement and monitoring of GHGs and soil organic carbon. But these days dynamic modeling is an effective approach to characterize whole system by integrating various processes and model can be used for understanding mechanism, estimation and prediction of GHGs and soil organic carbon, also to determine strategies to reduce GHGs emission of one gas and whether there may be other adverse consequences.

In this study we have used DeNitrification - DeComposition (DNDC) model developed by Li, C.S. and his colleagues to simulate the GHGs emission and soil organic carbon in SEA region from rice paddies and selected rotation crops and cultivation practices, validate these simulations against the field observation, sensitivity analysis and scenario assessment. The major objectives of this research were to collect informative data on long term GHGs emission and soil carbon storage from rice field and selected energy crop (Activity II) and assessment of appropriate cultivation practices as mitigation options for low/ reduced carbon emission in the agriculture sector in SEA region.

1.2 Objective of study

The major objective of this report is long term soil carbon dynamics assessment of suitable low carbon cultivation using DNDC biogeochemistry process based model. Also to understand the soil carbon storage and sequestration of the feasible rice-energy crop system using modeling framework and comparison between observed and modeled data. This study also focuses on GHGs emissions with crop cultivation practices and there validations with observed data from field experiment conducted at experiment site in Thailand.

CHAPTER 2 METHODOLOGY

2.1 DNDC model Description

The DNDC 9.3 version was used in this study for to simulate the field measurement of CH_4, N_2O and CO_2. The DNDC model under development at the University of New Hampshire since 1992, which is process based simulation model for soil carbon and nitrogen biogeochemistry cycle's (Li et al., 1992a, 1992b, 1994, 1996). The DNDC is integration of six sub models which describes the generation, decomposition, transformation of organic matter and outputs the dynamics of components of SOC and GHGs (Zhang et al., 2009).

The six sub models in DNDC are

1. Soil climate sub model: This uses soil physical properties, air temperature and precipitation to calculate the soil temperature, moisture and redox potential profiles and soil water fluxes through the time. Results from soil climate sub model were used by other sub models.
2. A nitrification sub model
3. A denitrification sub-model, which calculates hourly denitrification rates and N_2O, NO and N_2 production during periods when the soil Eh decreases due to rainfall, irrigation, flooding or soil freezing;
4. A sub-model simulating the decomposition of SOC pools and CO_2 production through soil microbial respiration;
5. Plant growth sub-model, which calculates daily root respiration, water and N uptake by plants, and plant growth; and
6 .A fermentation sub-model, which calculates daily methane (CH_4) production and oxidation

Figure 1 shows the structure of the DNDC model, where it uses the Soil properties, crop parameter, climate data and farming practices as input then model considers the dynamics of crop growth and its responses to climate conditions and farming practices, interactions soil biogeochemical processes and finally it simulates crop yield, GHGs emissions responding to climate conditions and management practices.

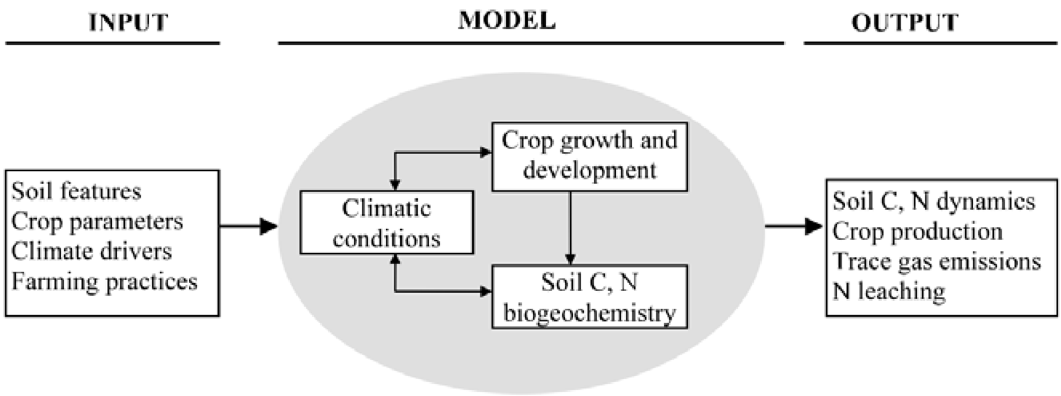

Figure 1 DNDC model structure and working flow
[Source (Zhang *et al*., 2002)]

2.2 Study area

The field experiment was conducted at Ratchaburi campus of King Mongkut's University of Technology Thonburi, Thailand for the year 2010-2011 to understand the GHG emissions and soil carbon dynamics from rice crop as well as from the rotation with energy crop using field observations. The further details of site can be found in Activity II.

2.3 Data input

The site mode of DNDC model (version 9.3) used to estimate the soil organic carbon storage and GHGs emission in rice-energy crop rotation. The major ecological factors to drive model for simulating the GHGs emissions from paddy field in rotation with energy crop included three major input parameters which includes climate (maximum and minimum temperature and precipitation), soil properties and farm management practices. There all input parameters were used to run DNDC model on site mode for the experiment site. The climate data were collected from Thai Meteorological Department; TMD-Ratchaburi station, soil physical and chemical properties were collected from laboratory analyses, and farm management data were collected from literature review and personal interview with farmers (more details can be found in Activity I). Detailed information on climate data and soil properties in 2010 and 2011 were presented in Table 1. The long term simulation from 2011-2030 was conducted the climate data from PRECIS Climate model ECAM4 SRES B2 and used the crop management practices form the second year (2011) of field experiment.

Table 1 Climate data and Soil properties of KMUTT's experimental site

Items	2010	2011
Location	Latitude: 13^{o}35' N	Longitude: 99^{o}30' E
Climate data		
Average annual temperature (^{o}C)	29.01	27.87
Annual rainfall (mm)	1,205	910
Soil properties (0-15 cm of soil depth)		
Land-use type	Rice paddy field	
Soil texture	Sandy loam	
Sand (%)	53.00	
Silt (%)	45.00	
Clay (%)	2.00	
Bulk density (g/cm^3)	1.75	
Soil pH	5.80	
SOM (0-15 cm) (%)	0.69	
SOC (0-15 cm) (%)	0.40	
Phosphorus (P) (mg/kg)	4.00	
Potassium (K) (mg/kg)	20.00	
Total N (%)	0.04	
C:N ratio	10.00	

The information of crop management practices in KMUTT's experimental site for the DNDC model runs are following:

1. (1) Manure application: incorporated cow manure C=1041 kg C/ha, N= 80 kg N/ha and C=1236 kg C/ha, N= 95 kg N/ha in only year 2010;
2. (2) Tillage: plow depth of 20 cm after harvest; and 5-10 cm depth on planting day;
3. (3) Fertilizer application: NH_4NO_3+Urea (40 kg N/ha) and Urea (57.5 kg N/ha) for corn and sweet sorghum, NH_4NO_3 (23 kg N/ha) and Urea (57.5 kg N/ha) for rice;
4. (4) Flooding: continuously flooding at 10 cm (one week after rice sowing until two weeks before harvesting).

2.4 Model validation

Validation against experimental data is an essential part of model development. If experimental measurements agree well with model predictions, there is increased confidence that the model is correctly simulating the underlying processes. In contrast, in case where the model fails to predict the measurements this can help identify processes that the model simulates poorly (Giltrap *et al*., 2010).

To validate applicability of DNDC model in Thailand, field experiment were conducted at the crop experimental site at Ratchaburi campus of King Mongkut's University of Technology Thonburi, Thailand. The observed GHGs fluxes were conducted once per week with the black acrylic closed chamber method (see methodology in activity II) and then simulated GHGs fluxes were compared with observed fluxes. The model was evaluated using correlation (R^2) and root mean square error (RMSE) coefficients. RMSE is considered as best overall measure of model performance as it summarizes the mean difference in the units of observed and predicted values (Willmott, 1982; Babu *et al.,* 2006).

2.5 Sensitivity analyses and uncertainty

Sensitivity analysis involves testing the model performance as various inputs are changed. This helps determine which inputs are having the greatest effect on the predicted emissions and whether the model has captured observed differences in emissions under different management strategies. Sensitivity analysis differs from validation as it does not compare the model out field data (Giltrap *et al*., 2010). For the sensitivity analyses, the parameter being evaluated was set to several values within a predefined range in agricultural soil, while all other model parameters and inputs were held constant at standard values. Simulated seasonal CH_4 and N_2O fluxes sensitivities were evaluated for air temperature, clay fraction, initial SOC and amount of N-fertilizer, while SOC storages were evaluated for air temperature and clay fraction.

Sensitivity analyses can be used to estimate the degree of uncertainty in the model predictions resulting from imperfect knowledge of the input parameters. These uncertainties can be estimated using Monte Carlo simulation, in which a large number of possible scenarios are generated using random values (within a specified range) for each input parameter (Giltrap *et al*., 2010).

3.1 Simulation of methane and nitrous oxide emissions

Seasonal CH_4 emission from the rotated of energy crop and rice system were simulated practically by site mode of DNDC (version 93). There were some differences in the daily average CH_4 emission values. DNDC simulation showed that the seasonal variations of CH_4 emission (Fig. 2) were significant higher during the rice-growing season but fewer during the fallow, corn and sorghum growing season. Simulated daily average CH_4 emission values ranged from zero before and after flooding to a maximum of 10.52 kg C/ha/day.

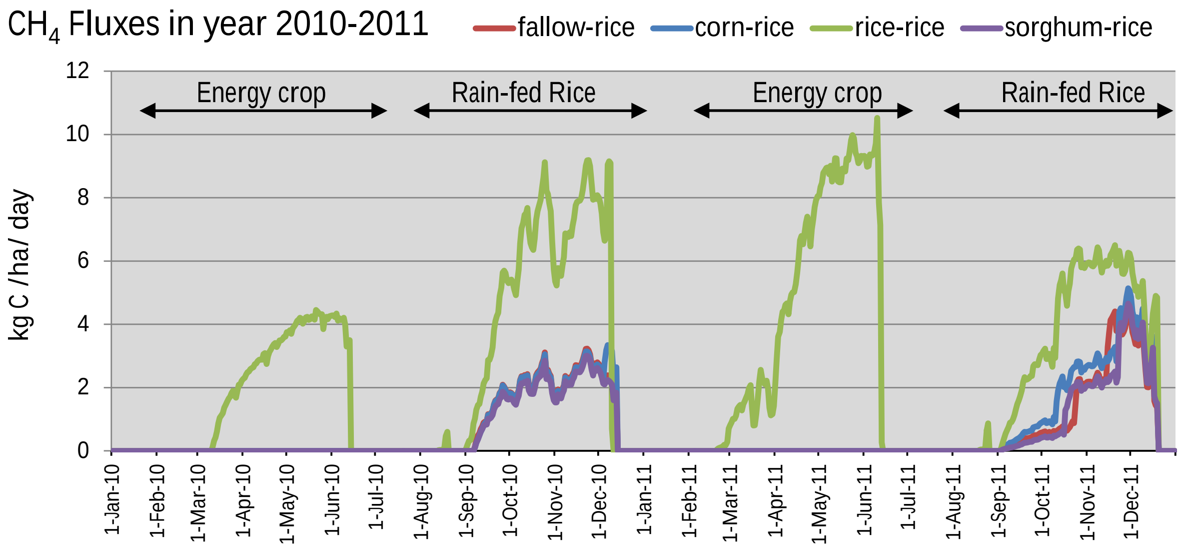

Figure 2 Seasonal variation for methane emissions in 2010-2011 using site mode of DNDC model

DNDC simulation showed that the seasonal variations of N_2O emission (Fig. 3) were significant higher during fallow, corn and sorghum growing season. In during the rice-growing season, the small N_2O emissions peaks were observed at the beginning without flooding and harvesting period. In year 2010, N_2O emissions were extreme peak by tillage and cow manure incorporation. Some peaks of N_2O were presented during nitrogen fertilizer application. Simulated daily average N_2O emission values ranged from zero to 0.211 kg N/ha/day.

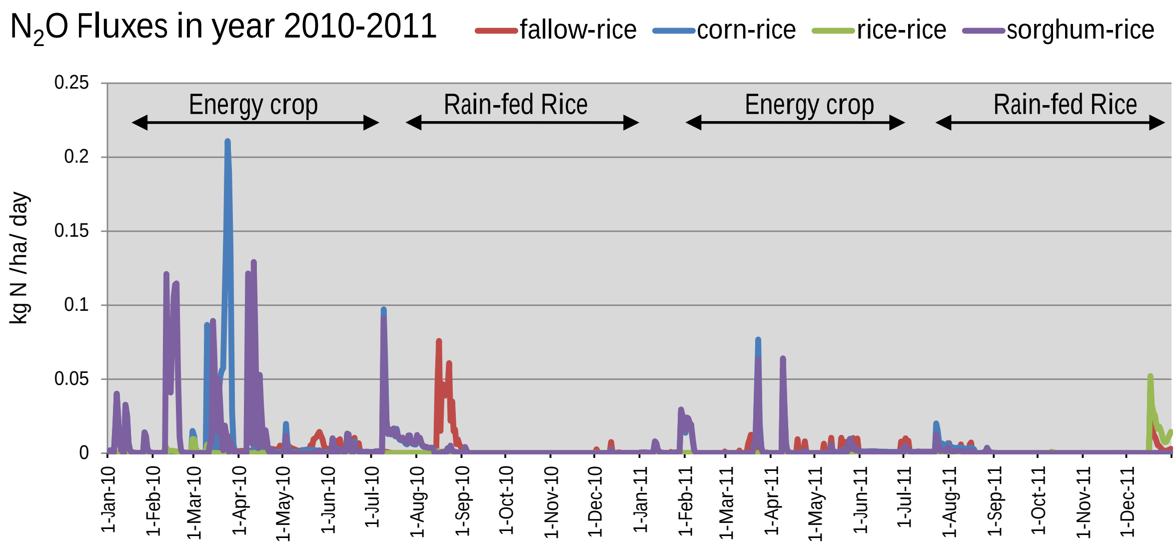

Figure 3 Seasonal variation for nitrous oxide emissions in 2010-2011 using site mode of DNDC model

Root means square error (RMSE), correlation (R^2), sample number (N), cumulative flux and % difference of daily simulated and observed values were shown in Table 2. DNDC model could able to capture the overall trend of the daily CH_4 emissions. The RMSE and correlations between observed and simulated seasonal fluxes for RF, RC and RS cropping system were in the range of RMSE 0.4508-0.5807 and R^2 0.7841-0.8732, while RR cropping system was 3.1761 of RMSE and 0.2445 of R^2. There were indicated the model could able to capture CH_4 fluxes in plot of RF, RC and RS. Most differences between simulated and observed seasonal CH_4 fluxes were less than 20%. In RR cropping system, the model failed to capture the pattern of daily average CH_4 emission (RMSE= 3.1761, R^2=0.2445), but total seasonal CH_4 emission were in good agreement between observed and simulated values (5.59% different). The observed data in RR cropping system found higher CH_4 flux peak after two weeks of rice sowing, it is probably attributed to the organic residues incorporation from the previous crop, whereas the data from model could not showed higher peak in this period.

The total seasonal N_2O emissions of observed and simulated values were not well correlated with the ranges of R^2 0.0023-0.0569. DNDC simulated higher N_2O emission during tillage and after fertilizer application during crop growing season, while simulated zero N_2O emission a few days after flooding the rice field. The RMSE and R^2 show that the model has a relatively high error. Field cumulative N_2O fluxes during crop growing season ranged from 3.133 to 9.686 kg N ha^{-1} while the simulated emissions were in the range of 0.109 to 3.329 kg N ha^{-1}. The difference between observed and simulated cumulative N_2O emissions ranged from 63-96%. The model was completely failed to capture the trend as well as magnitude of daily N_2O emissions.

Table 2 Observed and modeled seasonal methane and nitrous oxide fluxes in year 2010-2011

Treatment	CH_4 (kg C ha^{-1})		N_2O (kg N ha^{-1})	
RF (fallow-rice)	RMSE	0.4508	RMSE	0.0110
	R^2	0.8732	R^2	0.0364
	N	69	N	51
	Observed	348.10	Observed	5.228
	Simulated	410.10	Simulated	1.272
	% different	15.12	% different	75.68
RC (corn-rice)	RMSE	0.5807	RMSE	0.0329
	R^2	0.8327	R^2	0.0102
	N	69	N	52
	Observed	396.54	Observed	9.160
	Simulated	468.60	Simulated	3.329
	% different	15.38	% different	63.65
RS (sorghum-rice)	RMSE	0.5298	RMSE	0.0248
	R^2	0.7841	R^2	0.0023
	N	69	N	53
	Observed	369.90	Observed	9.686
	Simulated	386.95	Simulated	2.230
	% different	4.41	% different	76.97
RR (rice-rice)	RMSE	3.1761	RMSE	0.0103
	R^2	0.2445	R^2	0.0569
	N	69	N	56
	Observed	2,136.40	Observed	3.133
	Simulated	2,017.03	Simulated	0.109
	% different	5.59	% different	96.54

3.2 Long term simulation of annual methane and nitrous oxide emissions over 20 years

The general of rice cultivation practices in non-irrigation area of Thailand is fallow land in dry season and cultivated rain-fed rice in wet season, therefore RF (fallow-rice) is the baseline for this research. The 20-years simulation for predicted annual CH_4 and N_2O emission in the future within each cropping system showed in figure 4. Annual CH_4 emission values ranged from 153.43 to 1,328.49 kg C ha^{-1} $year^{-1}$. In the long term of 20-years average annual n, the selected energy crop with corn and sweet sorghum could able to reduce CH_4 emission as 72% and 80% when compared with continues of rice cultivation (RR). In addition, the sweet sorghum rotated in rain-fed rice was not significant difference of CH_4 emission with baseline (fallow-rice).

Annual N_2O emissions were dissimilar patterns with CH_4 emission. There were mainly caused by difference of cropping condition between paddy rice and upland crop. Annual N_2O emission values ranged from 0.18 to 3.43 kg N ha^{-1} $year^{-1}$. In double cropping of rice (RR) was significant lowest of N_2O emission decided by flooding condition of rice cultivation. While the N_2O emission from energy crops of corn and sweet sorghum was higher 4 and 2 time than double cropping of rice, respectively.

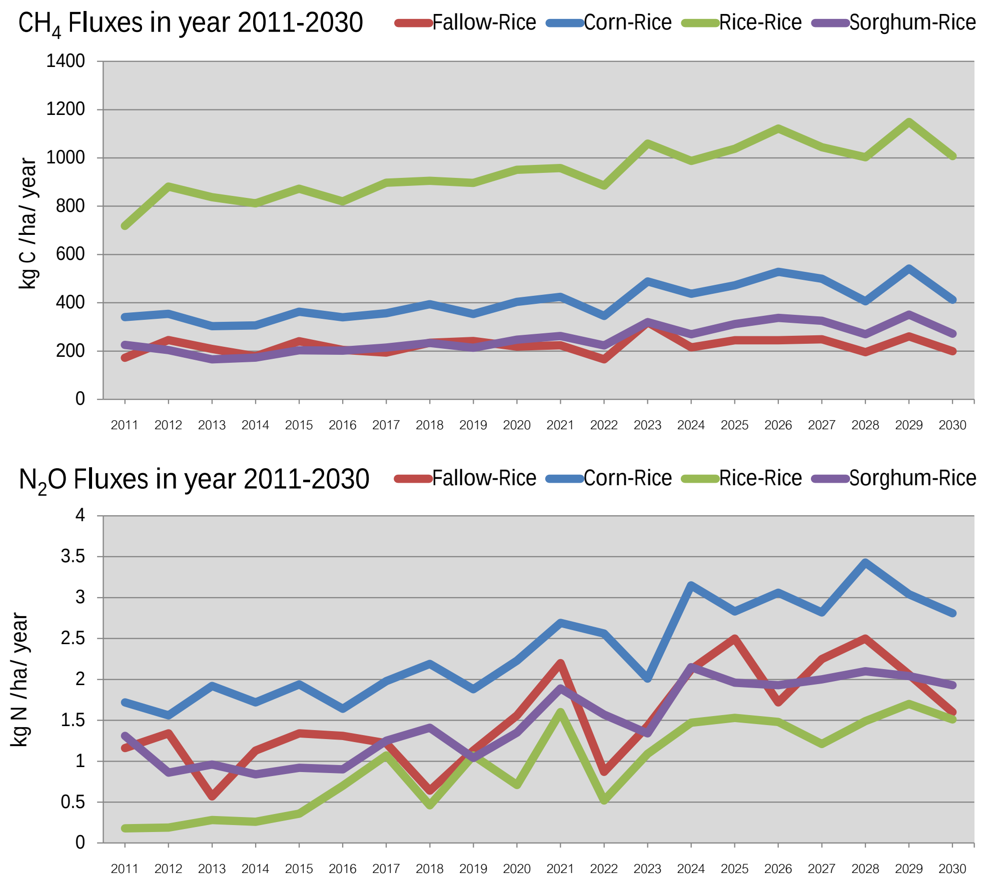

Figure 4 Long term simulation of annual methane and nitrous oxide emissions over 20 years

3.3 Long term simulation of annual soil organic carbon dynamics over 20 years

Figure 5 presented the modeled SOC dynamics, there were showed similar trends across the crop rotation system. The SOC contents in the crop rotation of rice-rice, corn-rice and sorghum-rice more continuously increased during the simulated 20 years, although fallow-rice gradually increased. The annual SOC values ranged from 20,168 to 60,723 kg C ha^{-1} $year^{-1}$. The highest increasing rate of SOC was observed in rice-rice rotated field as 1,957 kg C ha^{-1} $year^{-1}$ through more incorporated crop residue into the field. SOC storage in crop rotation of rice-rice, corn-rice and sweet sorghum-rice was higher 42%, 33% and 25% than baseline of fallow-rice crop system, respectively.

The modeled data showed the change of SOC (dSOC). The dSOC data was calculated by change of the end SOC from initial SOC of each year. All crop rotation system, the soil lost SOC at relatively low rates during the simulated 20 years. The near equilibrium status for all crop rotation system was indicated by the special water management practice for paddy soil reduced SOC decomposition rate, and relatively high crop productivities introduced more litter into the soils (Wang, et al. 2008).

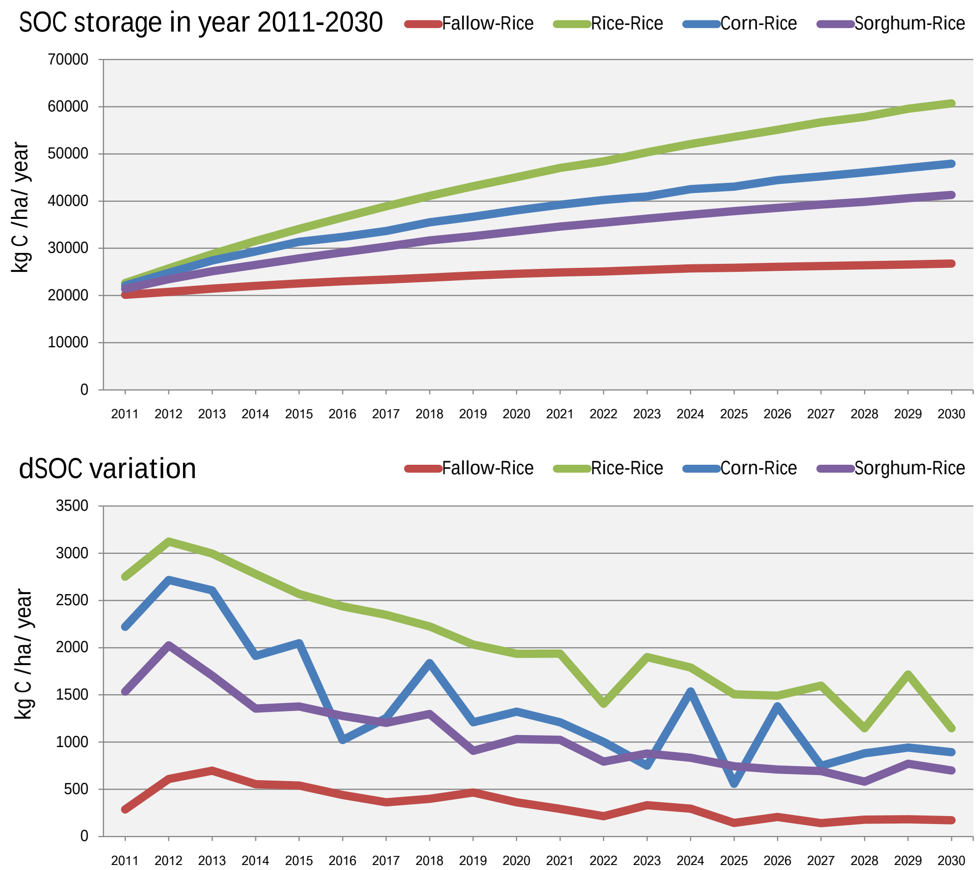

Figure 5 Long term simulation of annual soil organic carbon dynamics over 20 years

3.4 Sensitivity analysis

CH_4 and N_2O emission was most sensitive to soil texture with emission decreasing with an increase of clay content. The emission of CH_4 and N_2O decreased 8.2-38 % when increased clay content to 60% of baseline in initial soil. Moreover, CH_4 and N_2O emission were positive increasing with high air temperature and amount of nitrogen fertilizer application.

CHAPTER 4 CONCLUSION

In activity 4, the data generated from Activity 2 was used as input data into existing DNDC model, for analyzing the carbon storage and GHGs emissions from the various cultivation practices. The results indicated that the DNDC model was capable of capturing quantitatively the major aspects of CH_4 emission. There were some disagreements between observed and simulated daily N_2O fluxes and unable to capture daily CH_4 fluxes at the beginning of the rice growing season, indicating that DNDC does not capture all processes occurring in the field.

During the simulated 20 years, the modeled results indicated that the SOC storage in rice-rice, corn-rice and sorghum-rice could able to remained carbon into the soil than fallow land-rice. There are in agreement with the long term projection of soil carbon storage change using DNDC model which confirmed that rotated of energy crop cultivation with rain-fed rice can increase soil carbon in the long run.

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Appendix 7

Training Workshop on “Capacity building on estimation of GHG emissions from rice fields: The application of DNDC model”

Training Workshop on

"Capacity Building on Estimation of GHG Emissions from Rice Fields: The Application of DNDC Model"

11-13 February 2013

Phuttaraksa Room (3rd floor), Seminar Building, Continuing Education Center

King Mongkut's University of Technology Thonburi, Bangkok, Thailand

Organized by

The Joint Graduate School of Energy and Environment (JGSEE)

Purpose of the workshop

This training workshop aims at providing participants with an improved understanding of carbon and nitrogen biogeochemistry in agro-ecosystem and enhanced knowledge of spatio-temporal dynamics of GHGs from rice fields.

Date and venue

The event will be held during 11- 13 February 2013, Phuttaraksa Room (3rd floor), Seminar Building, Continuing Education Center, King Mongkut's University of Technology Thonburi, Bangkok, Thailand

Participants

Researchers in ACRP-APN project and JGSEE students (invited participants only)

Registration

Free of change

Language

The workshop will be held in English

Programme of the training workshop

11 February 2013:

8.30 – 9.00	Registration	
9.00 – 9.10	Opening ceremony	Dr Sirintornthep Towprayoon Director, JGSEE, Thailand
9.10 – 9.30	Introduction to APN project	Dr Sebastien Bonnet Lecturer, JGSEE, Thailand
9.30 – 10.00	Challenges to mitigate soil greenhouse gases - linking field scientists and modellers	Dr Yoshitaka Uchida Assistant Professor, Hokkaido University, Japan
10.00 – 10.30	Group Photo and Coffee Break	
10.30 – 11.00	Introduction to DNDC model	Dr Kruamas Smakgahn Lecturer, KU, Thailand
11.00 – 11.45	DNDC Model: Site mode	Dr Kruamas Smakgahn Lecturer, KU, Thailand

11.45 – 12.30	DNDC Model: Regional mode	Dr Michiko Hayano Researcher, NIAES, Japan Dr Yoshitaka Uchida Assistant Professor, Hokkaido University, Japan
12.30 – 13.30		Lunch Break
13.30 – 15.00	Demonstration of Regional mode: Japan case	Dr Michiko Hayano Researcher, NIAES, Japan Dr Yoshitaka Uchida Assistant Professor, Hokkaido University, Japan
15.00 – 15.30		Lunch Break
15.30 – 17.00	Practice on input data preparation	Dr Michiko Hayano Researcher, NIAES, Japan Dr Yoshitaka Uchida Assistant Professor, Hokkaido University, Japan Dr Kruamas Smakgahn Lecturer, KU, Thailand

12 February 2013:

9.00-12.30	Hands on training on site mode	Dr Michiko Hayano Researcher, NIAES, Japan Dr Yoshitaka Uchida Assistant Professor, Hokkaido University, Japan
12.30-13.30		Lunch Break
13.30-16.30	Hands on training on regional mode	Dr Michiko Hayano Researcher, NIAES, Japan Dr Yoshitaka Uchida Assistant Professor, Hokkaido University, Japan

13 February 2013:

9.00-12.30	Presentation, discussion and way forward	Participants and APN Team
12.30-13.30		Lunch Break

Newsletter article

The training Workshop on "Capacity Building on Estimation of GHG Emissions from Rice Fields: The Application of DNDC Model" was organized by The Joint Graduate School of Energy and Environment (JGSEE) at Phuttaraksa Room (3rd floor), Seminar Building, Continuing Education Center, King Mongkut's University of Technology Thonburi (KMUTT), Bangkok, Thailand on 11 February 2013.

This event is part of and APN-ARCP funded Project on: Strategic Rice Cultivation for Sustainable Low Carbon Society Development in South East Asia led by JGSEE (Thailand) in collaboration with the National Institute for Agro-Environmental Sciences (Japan) and the Bogor Agricultural University (Indonesia).

This training workshop aimed at providing participants with an improved understanding of carbon and nitrogen biogeochemistry in agro-ecosystem and enhanced knowledge of spatio-temporal dynamics of GHGs from rice fields. Participants of this training workshop consisted of 30 persons: including DNDC experts from Japan, Thailand, and Indonesia, the APN project team, and lecturers/researchers from several universities in Thailand.

A closed training workshop followed up during 12-13 February at JGSEE involving only the APN researchers and DNDC experts. During this 2 day-training, data on rice cultivation collected as part of the project activities for Thailand and Indonesia were used to run the DNDC model and discuss the results obtained from the simulations.

List of participants

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Presentation materials

Strategic Rice Cultivation for Sustainable Low Carbon Society Development in South East Asia

Dr Sebastien Bonnet
The Joint Graduate School of Energy and Environment

Training workshop "Capacity Building on Estimation of GHG Emissions from Rice Fields: The Application of DNDC Model"
11 February 2013, KMUTT, Bangkok

The Asia-Pacific Network for Global Change Research - APN

- APN: The Asia-Pacific Network for Global Change Research
- APN is a network of 22 member countries promoting global change research in the region and strengthening interactions between scientists and policy-makers
- The APN funds its research programmes based on an annual open call for proposals under its regional research and capacity development programmes (ARCP and CAPaBLE).
- ARCP: Asia Pacific Network - Annual Regional Call for Research Proposals
- ARCP is one of the scientific pillars of the APN to encourage and promote global change research in the Asia-Pacific region, establishing a sound scientific basis for policy-making.

APN-ARCP project led by JGSEE

- Project title: Strategic Rice Cultivation for Sustainable Low Carbon Society Development in South East Asia
- Project duration: 2 years
- Budget: 40,000 USD per year
- Organizations involved:
  - The Joint Graduate School of Energy and Environment (JGSEE), Thailand *Lead organization (Assoc. Prof. Dr. Sirintornthep Towprayoon)*
  - The National Institute for Agro-Environmental Sciences (NIAES), Japan
  - Bogor Agricultural University. Indonesia

Background information on rice production

- Annual world production of rice is 678 millions tonnes (2009) with global rice plantation covering 12.5% of total crop plantation area
- The 2 largest world producers of rice are China and India followed by other Asian countries including for SEA: Indonesia, Myanmar, Vietnam, Thailand, Philippines and Cambodia (top 20 world producers of rice).
- Rice plantation in South East Asia (SEA) covers 30% of the world area of rice plantation
- The harvested area of rice in 2008 in SEA was 47 mil. ha dominated for almost half by Indonesia (12 mil. ha) and Thailand (10.5 mil. ha) and closely followed by Myanmar (8 Mil. ha) and Vietnam (7 Mil. Ha)
- In SEA, the yields of rice are in the range 3 – 5 tonnes per ha, the highest found in Vietnam and lowest in Cambodia

Background information on rice production

- In 2010, the three largest exporters of rice, in decreasing order of quantity exported were Thailand and Vietnam followed by India. They accounted for nearly 70% of the world rice exports.
- The primary variety of rice exported by Thailand and Vietnam is Jasmine rice.
- The main species of rice found in SEA are: *Oryza officinalis, O. minuta, O. granulate, O. meyeriana, O. nivara, O. sativa, and O. ridleyi.*
- Major categories of rice in the world are *Oryza sativa, Oryza glaberrima, and wild rice.*

Project objectives

- The overall goal of the project is to identify strategic rice cultivation practices enabling SEA to develop towards a sustainable low carbon society while enhancing the adaptive capacity in the agriculture sector
- The specific objectives are:
  - To develop long-term field studies to measure, monitor and evaluate the impacts of various cultivation practices on climate change and identify potential adaptive measures and mitigation options
  - To identify strategic rice cultivation practices, in rotation with selected energy crops, enabling to fully utilize the rice plantation fallow period and therefore to optimize rice and energy feedstock production
  - To enhance regional capacity of scientists and policy makers in SEA for sustainable low carbon development of their society

Project activities

The project consists of 5 main activities:

Activity I: Review of rice cultivation practices and use of energy crops for rotation in SEA

Activity II: Long-term monitoring of GHG emissions and soil carbon dynamics from rice cultivation and utilization energy crops for rotation

Activity III: Capacity assessment of GHG emissions and soil carbon stock from sustainable cultivation practices in SEA

Activity IV: Long-term soil carbon dynamics assessment of sustainable low carbon cultivation using process model

Activity V: Knowledge dissemination to scientists and policy-makers in SEA

Activity I: Review of rice cultivation practices and use of energy crops for rotation in SEA

Description of Tasks

- Review of information on current rice cultivation practices in SEA and state-of-the-art of regional traditional practices as well as potential for introducing selected energy crops to be cultivated in rotation with rice.
- Involvement of SEA experts in the agricultural sector to contribute information to the review study as part of an expert meeting organised in Thailand by JGSEE

Deliverables

- Report on the state-of-the-art of rice cultivation practices and use of energy crops as the potential rotation crops for SEA countries.
- Database of rice cultivation practices in SEA
- Identification of country specific rice cultivation practices and potentials for energy crop cultivation in SEA countries
- Background data for preparation of Activity II and III

Activity I: Review of rice cultivation practices and use of energy crops for rotation in SEA

- Literature survey to assess current practices of rice cultivation in SEA including land management.
- Review supported with a questionnaire survey (in Thailand and Indonesia) to collect information from farmers regarding their agricultural practices and assessing potentials for rotation with selected energy crops, i.e. maize and sorghum.
- Expert meeting organized by JGSEE in June 2011 gathering selected experts from SEA countries including: Indonesia, Japan, Cambodia, Lao PDR, Myanmar, Vietnam and Thailand to to help evaluate and confirm the results from the surveys.
- Production of a Report on: "state of the art of rice cultivation practices in SEA and rotation with energy crops".
- Presentation on "Rice Cultivation and Potential Areas for Rotation with Energy Crops in South-east Asia" at the 17th Inter-Governmental Meeting (IGM) and Scientific Planning Group (SPG) Meeting in Jakarta (Indonesia), on 14 March 2012.

JGSEE CEE-PERDO APN

Expert Meeting on
"State-of-the-Art of Rice Cultivation Practices in South-East Asia"

2-3 June 2011
JGSEE, Bangkok, Thailand

Under APN-ARCP Funded Project on:
Rice Cultivation for Sustainable Low Carbon Society Development in South-East Asia

Organized by
The Joint Graduate School of Energy and Environment (JGSEE)

Report on "state of the art of rice cultivation practices in SEA and rotation with energy crops"

- The report provides background information on statistic of rice cultivation in SEA including harvested area, production, yield, trade as well as rice varieties and ecosystems
- The report also provides country specific information for : Cambodia, Indonesia, Lao PDR, Myanmar, Thailand and Vietnam
- The information reviewed and reported include:
  - Rice variety
  - Ecosystem
  - Land preparation
  - Rice plantation and cultivation practices (water, fertiliser, pesticide, etc.)
  - Harvesting method
  - Management of rice residues
  - Rotation crops
  - soil organic carbon
  - Socio-economic status of farmers

Activity II: Long-term monitoring of GHG emissions and soil carbon dynamics from rice cultivation and rotation with selected energy crops

Description of Tasks

- Assessment of GHG emissions and soil carbon dynamics associated to rice cultivation and rotation with selected energy crops (corn and sorghum) during fallow period at KMUTT - Ratchaburi campus experimental site (Thailand)
- Continuous monitoring of trace gas emissions, soil carbon stock, biological and physical parameters associated to above-ground and below-ground biomass

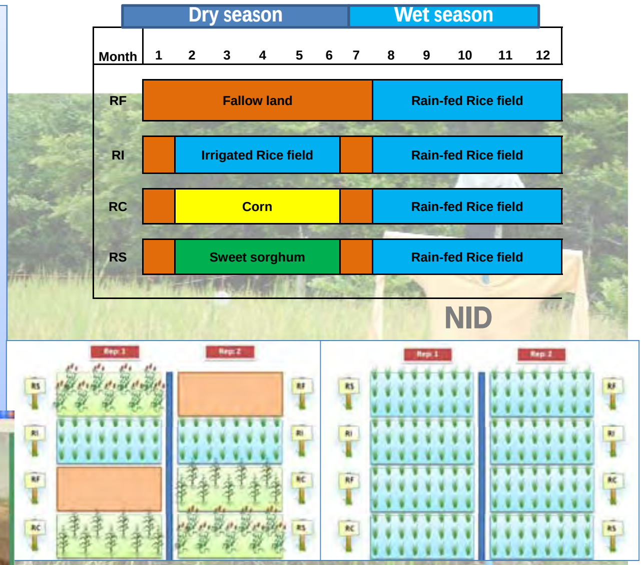
Deliverables

- long-term monitoring data on GHG emissions and soil carbon dynamics associate to rice cultivation and rotation with corn and sorghum.
- Comparative evaluation of specific crop rotation practices in terms of carbon cycle, economics, social benefits, potential barriers, etc.
- Identification of potentially sustainable rice-energy crop cultivation practices under well-defined conditions

Field experiments in Ratchaburi (Thailand)

Cultivation Practices

- ❑Dry season
  - ❑Normal practice (non-irrigated): fallow land
  - ❑Normal practice (Irrigated): rice
  - ❑ Rotation with Energy crops: corn and sweet sorghum
- ❑Wet season
  - ❑Normal practice (rain-fed)
- ❑ Experimental results: input data for Site mode of DNDC model to Estimate Soil Organic Carbon stock, CH_4 and N_2O emissions



(February-June) (August-December)

Activity III: Capacity assessment of GHG emissions and soil carbon stock from sustainable cultivation practices in SEA

Description of Tasks

– Assessment of the capacity of C budget in terms of emissions and soil carbon stock of rice fields in SEA
– Development of GIS maps of GHG emissions from existing and sustainable cultivation practices
– Assessment of potential mitigation options based on different scenarios

Deliverables

– GIS maps of GHG emissions from rice fields for selected cultivation practices in SEA
– GIS maps of carbon stock of rice fields in SEA
– Database of GHG emissions inventory using ALU software
– Assessment of C budget of the rice cultivation systems investigated under existing and sustainable practices in SEA

Activity IV: Long-term soil carbon dynamics assessment of sustainable low carbon cultivation using process model

Description of Tasks

– Assessment of long-term soil carbon dynamics of sustainable low carbon cultivation using DNDC model
– Assessment of long-term soil carbon storage and sequestration of specific rice-energy crop systems based on monitoring and modeling data.
– Use of Relevant data generated from activity II as input to DNDC for analyzing the time-series change in carbon storage vs. the corresponding GHGs emissions.

Deliverables

– Informative data on long-term soil carbon storage incl. rotation with selected energy crops and cultivation practices
– Comparative assessment of soil carbon sequestration for selected rice-energy crop rotation systems
– Assessment of appropriate cultivation practices as mitigation options for low/reduced carbon emissions in the agricultural sector

Training Workshop: Capacity Building on Estimation of GHG Emissions from Rice Fields: The Application of DNDC Model

- **Objective:** Providing participants with an improved understanding of carbon and nitrogen biogeochemistry in agro-ecosystem and enhanced knowledge of spatio-temporal dynamics of GHGs from rice fields
- **Participants:** Researchers involved in ARCP-APN project and JGSEE students

Activity V: Knowledge dissemination to scientists and policy-makers in SEA

Description of Tasks

- Knowledge transfer to scientists and policy-makers in SEA regarding the strategic approach to follow for sustainable rice cultivation i.e. reducing GHG emissions while increasing energy crop production.
- The project closing workshop is to be conducted in Thailand in May 2013 with invited participants from selected SEA countries.

Deliverables

- Capacity building of scientists on inventories of GHG emissions and carbon stock as well as process modeling tools (ALU and DNDC).
- Capacity building of scientists and policy-makers on mitigation options in the agricultural sector for a low carbon society.

THANK YOU

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Challenges to mitigate soil greenhouse gases – linking field scientists and modelers

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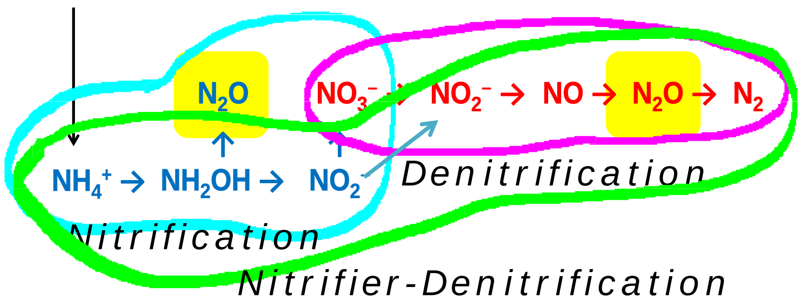
Greenhouse gases – How are they related to agriculture?

- CO_2
  - Respiration / photosynthesis.
- CH_4
  - Paddy fields, ruminants (e.g. cows and goats), from animal effluent.
- N_2O
  - The use of nitrogen fertilizers, the decomposition of crop residues.

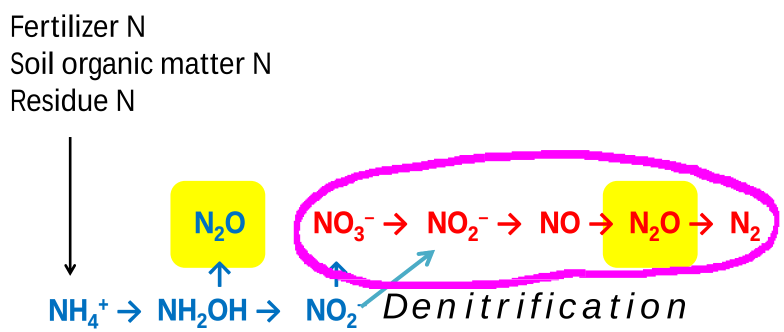
Mitigation of soil N_2O emissions - why is it so difficult?

Fertilizer N
Soil organic matter N
Residue N

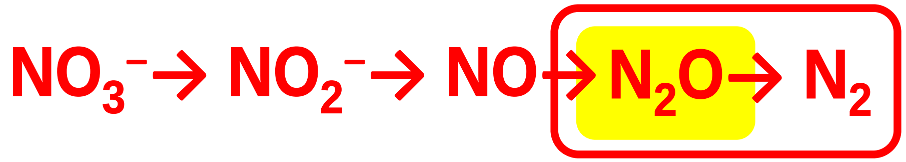


Mitigation of soil N_2O emissions - why is it so difficult?

- Emissions are controlled by microbes.
  - Complicated processes (nitrification, denitrification, nitrifier-denitrification)
  - Limited knowledge in soil microbiology (fungi? Bacteria? carbon sources?)
- Microbial knowledge plus soil physics!
  - N_2O production ≠ N_2O emissions
- Nobody wants to reduce N inputs.
  - N_2O reduction = loss of productivity?



N₂O emissions can be reduced by reducing N_2O into N_2.



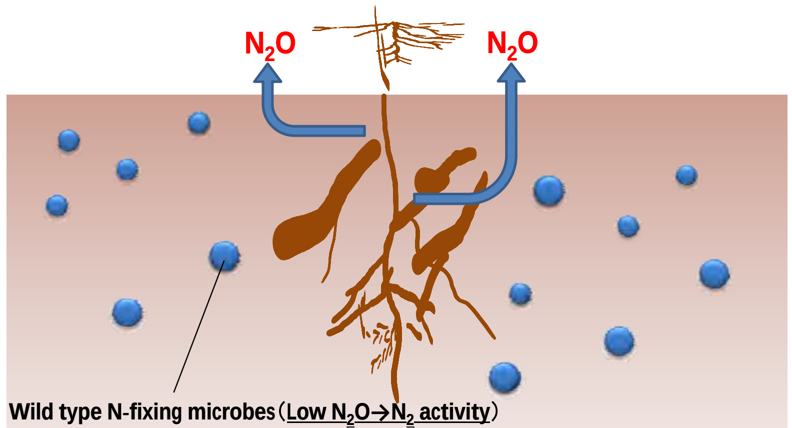
Field experiment (soybean field)

Increasing the $N_2O \rightarrow N_2$ activity in soybean root systems

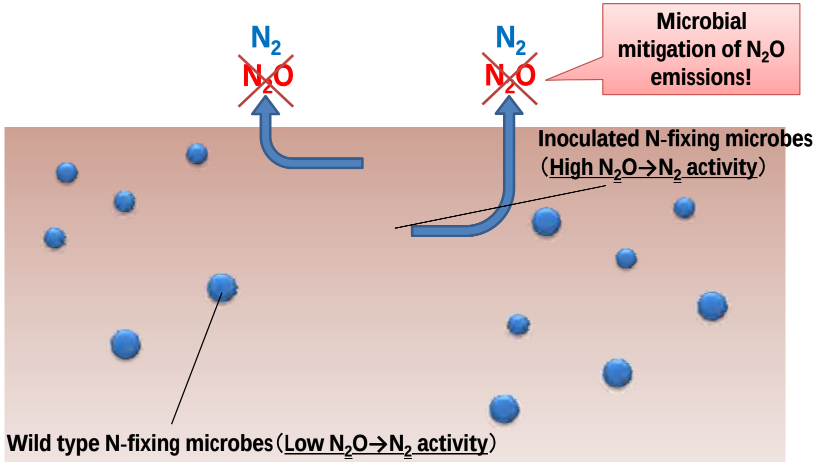
- N_2O emissions in soybean systems are high before/after the harvest.
- Soybeans obtain N from 'nodules' made by N-fixing microbes.
- Nodules decompose before/after the harvest and N-fixing microbes denitrify and produce N_2O (Inaba et al. 2009).

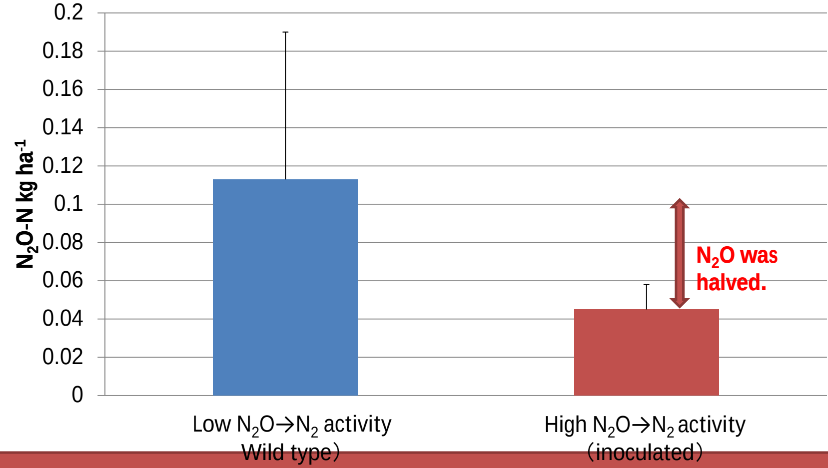
N_2O may be mitigated when the $N_2O \rightarrow N_2$ activity of N-fixing microbes is increased.

The inoculation of the high $N_2O \rightarrow N_2$ activity N-fixing microbes.



The inoculation of the high $N_2O \rightarrow N_2$ activity N-fixing microbes.





New N_2O mitigation option using N-fixing microbes!!!

nature climate change

LETTERS

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Mitigation of nitrous oxide emissions from soils by *Bradyrhizobium japonicum* inoculation

Manabu Itakura[1†], Yoshitaka Uchida[2†], Hiroko Akiyama[2†], Yuko Takada Hoshino[2], Yumi Shimomura[2], Sho Morimoto[2‡], Kanako Tago[2], Yong Wang[2], Chihiro Hayakawa[2], Yusuke Uetake[1], Cristina Sánchez[1], Shima Eda[1], Masahito Hayatsu[2*] and Kiwamu Minamisawa[1*]

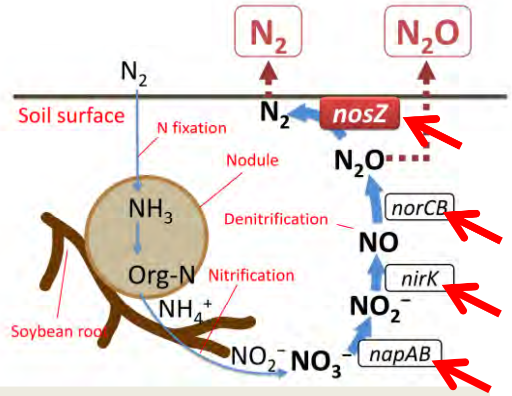
Nitrous oxide (N_2O) is a greenhouse gas that is also capable of destroying the ozone layer[1]. Agricultural soil is the largest source of N_2O (ref. 2). Soybean is a globally important leguminous crop, and hosts symbiotic nitrogen-fixing soil bacteria (rhizobia) that can also produce N_2O (ref. 3). In agricultural soil, N_2O is emitted from fertilizer and soil nitrogen. In soybean ecosystems, N_2O is also emitted from the degradation of the root nodules[4]. Organic nitrogen inside the nodules is mineralized to NH_4^+, followed by nitrification and denitrification that produce N_2O. N_2O is then emitted into the atmosphere or is further reduced to N_2 by N_2O reductase (N_2OR), which is encoded by the *nosZ* gene. Pure culture and vermiculite pot experiments showed lower N_2O emission by *nosZ*+ strains[5] and *nosZ*++ strains (mutants with increased N_2OR activity)[6] of *Bradyrhizobium japonicum* than by *nosZ*– strains. A pot experiment using soil confirmed these results[7].

expression analysis (*nosZ*++; Supplementary Fig. S1 and Table 1). The N_2OR activity of the two *nosZ*++ strains (5M09 and PRNOS) was significantly higher in free-living and bacteroid (symbiotic) cells than in the wild-type *nosZ*+ strain USDA110. N_2OR activities of 5M09 (non-GMO) were approximately 5 and 2.5 times the USDA110 values in free-living and bacteroid cells, respectively. The increased N_2OR activity probably resulted from higher *nosZ* expression, although the 5M09 expression levels were less than those of PRNOS (Table 1). This suggests that the non-GMO strain 5M09 could efficiently mitigate N_2O emission from the soybean (*Glycine max* [L.] Merr.) rhizosphere under both conditions.

We also examined whether *nosZ*++ strains reduced N_2O emission from soybean root systems with degrading nodules in vermiculite pots, after shoot decapitation and the addition of soil containing *nosZ*++ strains as previously investigated[16] (Supplementary Fig. S2A). With ambient air (0.32 μl N_2O l^{-1}),

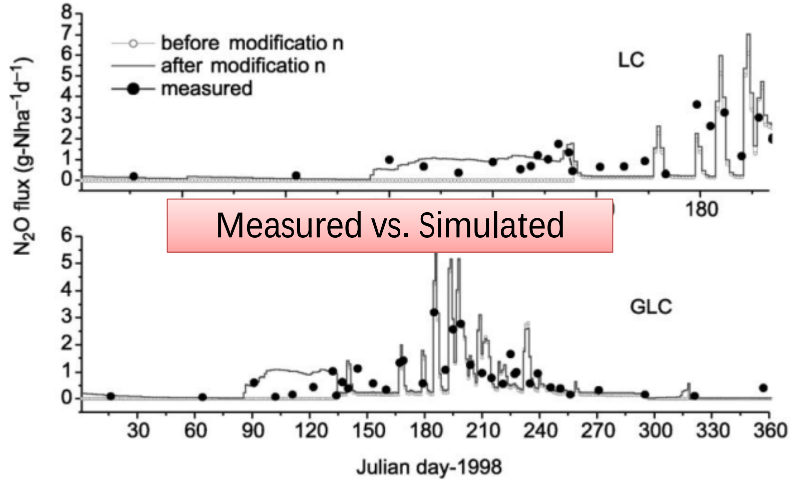
Recent advances in field sciences (and expectations for DNDC)

- Microbiology and greenhouse gas mitigation
  - $N_2O \rightarrow N_2$ activity
- Soil physics and greenhouse gas
  - Dry-wet cycles (heavy rain event)



Evaluation of short term changes in greenhouse gases (hourly to daily)

What is DNDC for field scientists?

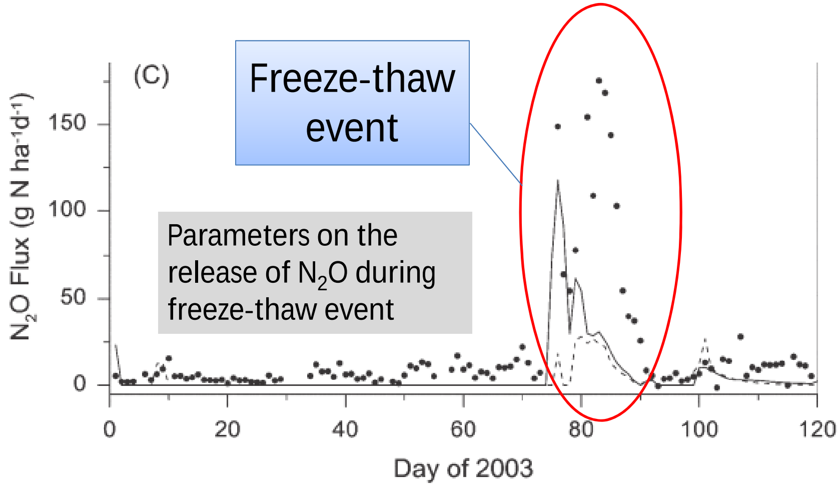


Ri et al. Soil Biol. Biochem. 2003.

What are we going to learn for the next few days?

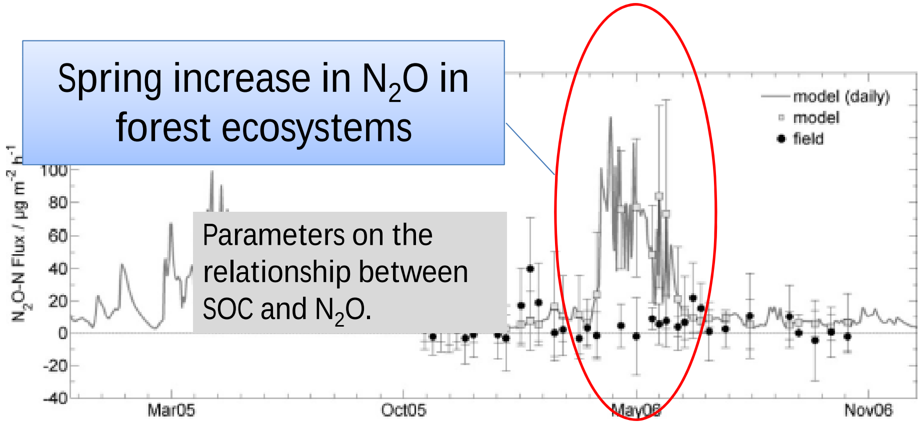
- Dr Hayano and I – try to teach you the basic of the DNDC-rice model.
- First – <u>'SITE' mode</u>
  - Look closely at changes in moistures, gas, C, N etc…
- Second – <u>'Region' mode</u>
  - Expand the model to a larger scale.

Recent (2011-2012) studies on DNDC.



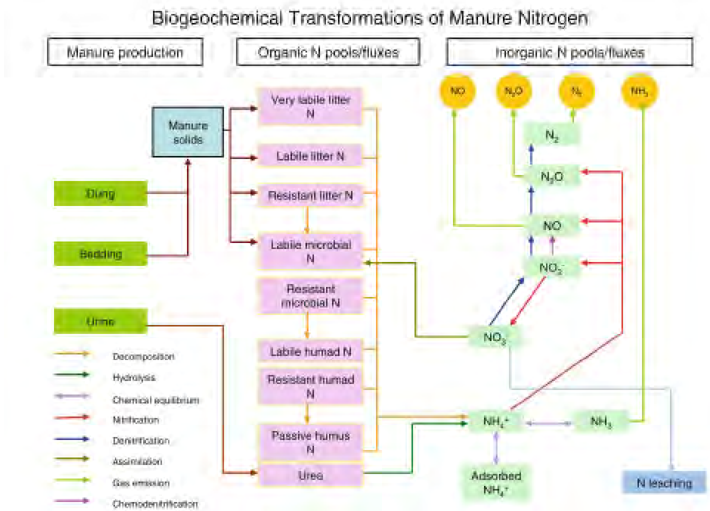
Kriyapperuma et al. SSSAJ 2011. Arable crop farms.

Recent (2011-2012) studies on DNDC.



Jungkunst et al. J Plant Nutr Soil Sci. 2012. Old-growth beach for.

Recent (2011-2012) studies on DNDC.



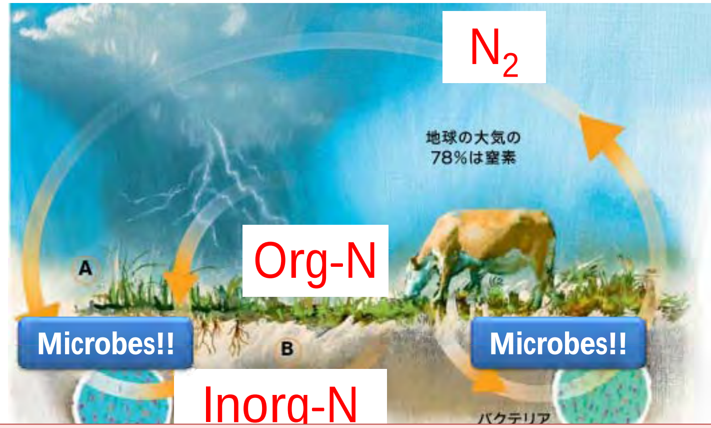
Li et al. Nutr Cycl Agroecosys. 2012. Manure management.

‘measured vs. simulated’ of ‘next generation’

- Why do you use DNDC?
  - Large scale evaluation (scaling up)
  - Sensitivity analysis (influential factors)
  - Comparison of sites, management (e.g. ploughing)

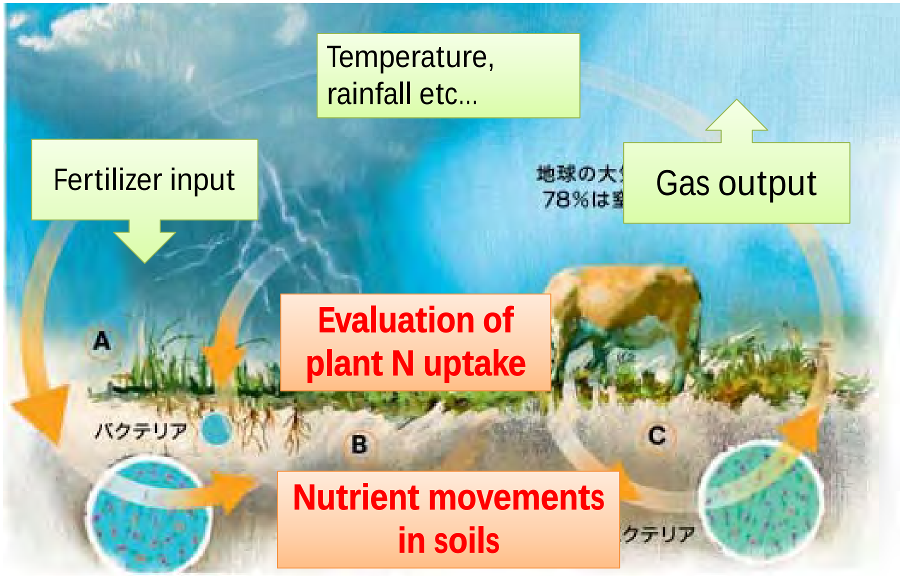
‘measured vs. simulated’ of ‘next generation’

- Think as ‘cycling’.



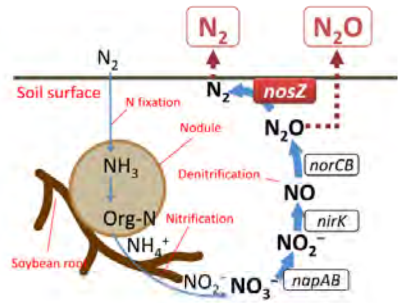
Perfectly & beautifully balanced ‘100% recyclings’ in nature

‘measured vs. simulated’ of ‘next generation’



‘measured vs. simulated’ of ‘next generation’

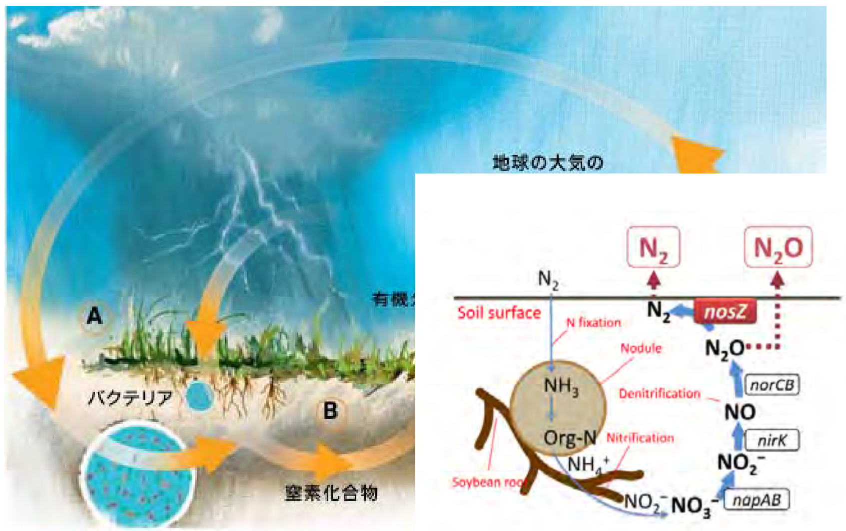
- What are important parameters in DNDC?
  - Be careful in treating ‘estimated’ parameters
    - Gas emissions, Soil moisture, N intake, NH_4^+, NO_3^-
  - Evaluation of the ‘estimated’ parameters (only important ones)



‘measured vs. simulated’ of ‘next generation’

- Modifying DNDC?
  - Maybe DNDC-Thailand?
    - Special climate, rice varieties, soil types etc...
  - Written in C++, learn a new language!
- DNDC-Forest/DNDC-rice/DNDC-manure management
  - Modified DNDC models are already available
  - for future DNDC (e.g. in Japan)
    - Volcanic ash soils (special ratio between C: microbial biomass C??)

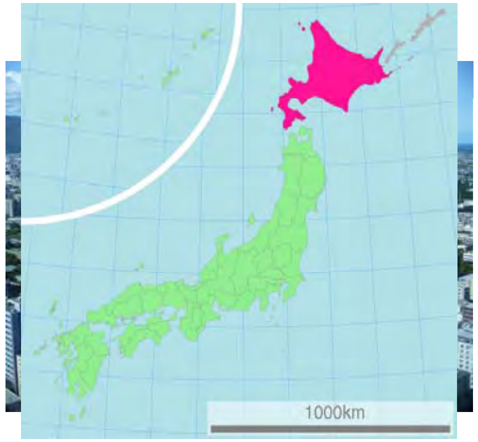
Conclusion



Advertisement (Hokkaido University)

Advertisement (Hokkaido University)

- Located in Hokkaido, established in 1918. Formally 'Sapporo Agricultural College (1875)'.
- Strong promotions on international collaborations.



Advertisement (The Uchida Lab)

- Research in Environmental Biogeochemistry.
- I started this position this January.
- Students/ideas/collaborations – all welcome!

Contact The Uchida Lab
(**uchiday@chem.agr.hokudai.ac.jp**)

Me Japan and Thailand...

Me Japan and Thailand…

Thank you… kob kun mak krab… Arigato

Introduction to DNDC model

Dr. Kruamas Smakgahn
Kasetsart University, Kamphaeng Saen Campus
Nakornprathom province
E-mail: faaskms@ku.ac.th, smakgahn@yahoo.com

DNDC

- **DNDC: DeNitrification DeComposition Model**
- **DNDC is a comprehensive biogeochemistry model that simulates crop growth and soil C and dynamics based on input data on soil properties, climate, and farming practices (e.g. Li et al., 1992, 1994).**
- **The model was expanded to simulate the emission of trace gases such as NO, N_2O, NH_4 , and CH_4 from agricultural ecosystems and natural wetlands (Zhang et al., 2002; Li et al ., 2004).**

De-Nitrification De-Composition model

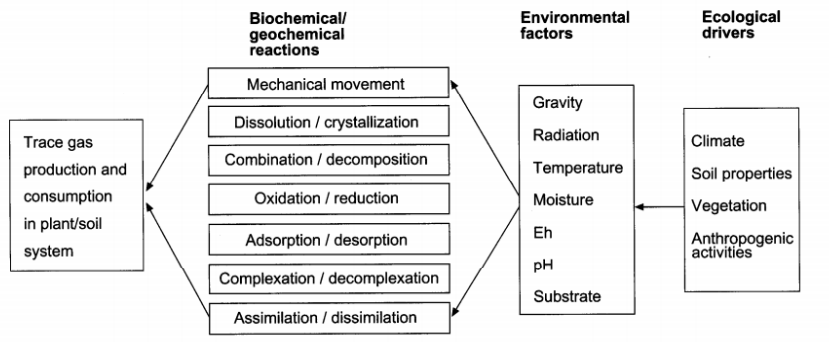


Figure 1. A biogeochemical model is a mathematical expression of biogeochemical field which consists of spatially and temporally differentiated environmental forces driving a series of biogeochemical reactions in ecosystems. Fluxes of NO, N_2O, CH_4, and NH_3 are regulated by directions and rates of the relevant biogeochemical reactions

C.S. Li 2000

DNDC

- **The DNDC model predicts C and N biogeochemistry in agricultural ecosystems at site and regional scales.**
- **The accuracy of prediction depends on the input data on four drivers.**
- **Four major ecological drivers, namely climate, soil physical properties, vegetation, and anthropogenic activities, drive the entire model.**

DNDC

All the impacts in the system can be categorized into 2 groups.

- The first group includes impacts of ecological drivers on soil environmental variables,
- The second groups includes the impacts of the soil environmental variables on trace gas-related geochemical or biochemical reactions.

DNDC components

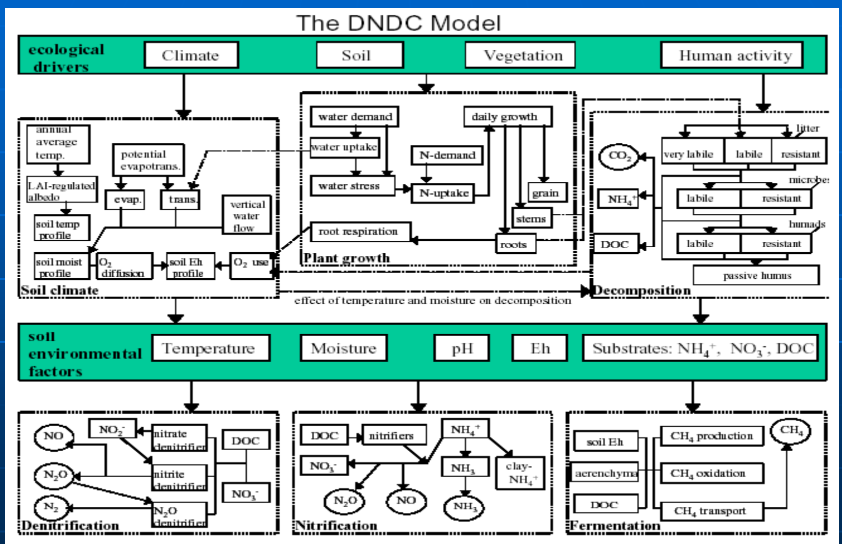
DNDC consisted of 2 components

- The first component consisting of the

Soil climate submodel, crop growth, and decomposition submodes, predicts soil temperature, moisture, pH, Eh, and substrates component,

- The second component consisting of nitrification, denitrification, and fermentation submodels, predicts NH_3, NO, N_2O, CH_4 fluxes

De-Nitrification De-Composition model



Source: University of New Hampshire, 2003

Linking ecological drivers to soil environmental variables

- DNDC needs site-specific input data of climate, soil, vegetation, and farming practices for the simulated agricultureal land.
- DNDC integrates the ecological drivers in the three submodels to generate their collective effects on soil temperature, moisture, pH, Eh, and substrate concentrations.

Linking ecological drivers to soil environmental variables

- The soil climate submodel calculates soil temperature, moisture, pH, Eh profiles by integrating air temperature, precipitation, soil thermal and hydraulic properites, and oxygen status.
- By integrating crop characters, climate, soil properties, and farming practices, the plant growth submodel simulates plant growth and its effects on soil temperature, moisture, pH, Eh, dissolved DOC, and available N concentration.

Linking ecological drivers to soil environmental variables

- The decomposition submodel simulates concentrations of substrates (e.g., DOC, NH_4^+, and NO_3^-) by integrating climate, soil properties, plant effect, and farming practices.
- The three submodels interact with each other to finally determine soil temperature, moisture, pH, Eh, and substrate concentrations in the soil profiles at a daily time step.

Linking ecological drivers to trace gases

- The links were set up based on either the basic physical, chemical, or biological laws, or equations obtained from the experiments under controlled conditions so that effect of each soil variable could be distinguished.

Linking ecological drivers to trace gases

- Biological oxidation/reduction dominates NO and N_2O evolution in soils.
- Nitrification (i.e., microbial oxidation of ammonium) has been observed to be the main source of NO and N_2O under aerobic conditions.

Nitrification: $NH_4^+ \rightarrow H_2NOH \rightarrow NOH \rightarrow NO_2^- \rightarrow NO_3^-$ (1)

(with $H_2NOH \downarrow NO$ and $NOH \downarrow N_2O$)

- The factors controlling nitrification have been determined to be soil temperature, moisture, pH, and NH_4^+ concentration.

Linking ecological drivers to trace gases

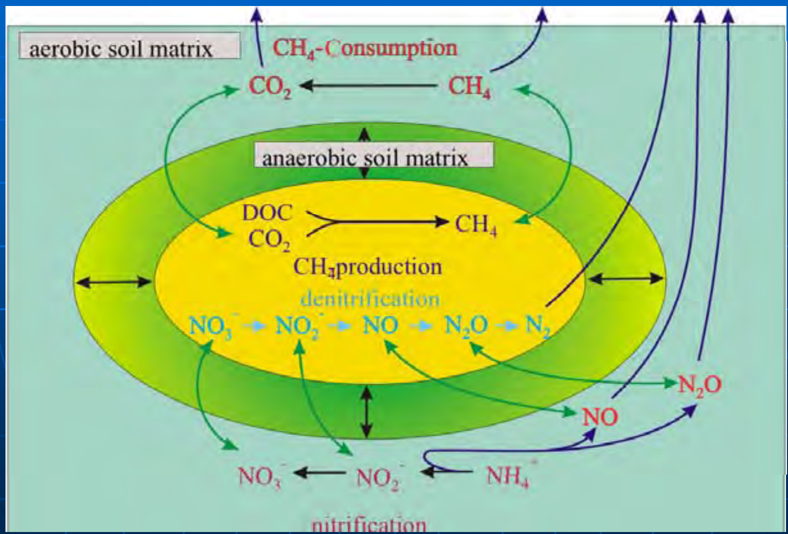
- Denitrification is another main source of N_2O and NO from soil.
- Denitrification includes a sequential reduction of nitrate to dinitrogen (N_2) driven by denitrifying bacteria under anaerobic conditions.

$$\text{Denitrification: } NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 \quad (2)$$

- Denitrification controlled by soil moisture and Eh.

Linking ecological drivers to trace gases

- The DNDC model simulates relative growth rates of nitrate, nitrite, NO, and N_2O denitrifiers based on soi Eh, concentrations of DOC, and nitrogen oxides.
- A simple scheme of anaerobic balloon was developed in the model to divide the soil matrix in to aerobic and anaerobic parts.
- DNDC simulated swelling and shrinking of the anaerobic balloon.
- Only the substrates allocated in the anaerobic part are involved in denitrification.



http://imk-ifu.fzk.de/823.php

Linking ecological drivers to trace gases

- Methane is an end product of the biological reduction of CO_2 or organic carbon under anaerobic conditions.

$$\text{Methane production: } CO_2 + 8\,H^+ \rightarrow CH_4 + 2\,H_2O \quad (3)$$
$$\text{or}$$
$$\text{Organic C} + 4\,H^+ \rightarrow CH_4$$

- Methane fluxes were strongly controlled by soil available carbon (i.e., DOC) content, and soil temperature.
- The reduction of available carbon to methane is mediated by anaerobic microbes (e.g., methanogens) that are only active when the soil Eh is low enough.

Linking ecological drivers to trace gases

- DNDC calculates methane production rate as a function of DOC content and temperature as soon as the predited soil Eh reaches -150 mV or lower.
- Methane is oxidized by aerobic methanotrophs in the soil. A highly simplified scheme was employed in DNDC to model methane diffusion between soil layers based on methane concentration gradients, tempeture, and porosity in the soil.

Function 3.5. CH_4 diffusion rate (kg C/ha/d)

$$Rd = 0.01 * (CH_4[l] - CH_4[l+1]) * T[l] * PORO;$$

AC – Available C concentration, kg C/ha;
T – soil temperature, °C;
l – soil layer number;
AERE – plant aerenchyma;
FloodDay – flooding days;
PORO – soil porosity;
$CH_4[l]$ – CH_4 concentration at layer l, kg C/ha.

Linking ecological drivers to trace gases

- DNDC predicts plant-transported methane flux as a function of methane concentration and plant aerenchyma.

Equation 3.3. CH_4 flux through plant aerenchyma (kg C/ha/d)

$$CH_{4(aere)} = 0.5 * CH_4[l] * AERE;$$

$$AERE = -0.0009*PGI^5+0.0047*PGI^4-0.883*PGI^3+1.9863*PGI^2-0.3795*PGI+0.0251;$$

PGI = (days since planting) / (season days); (plant growth index)

- DNDC assume that ebullition only occurs at the surface layer, and ebullition rate is regulated by soil methane concentration, temperature, porosity, and plant aerenchyma.

Function 3.4. CH_4 flux through ebullition (kg C/ha/d)

$$CH_{4(ebullition)} = 0.025 * CH_4[l] * PORO * Ft * (1 - AERE);$$

$$Ft = -0.1687*(0.1*T[l])^3 +1.167*(0.1*T[l])^2 -2.0303*(0.1*T[l])+1.042;$$

Linking ecological drivers to trace gases

- Soil NH_3 concentration is directly regulated by a chemical reaction occurring in the soil liquid phase:

$$[NH_4^+] + [OH^-] = [NH_{3\ (liquid)}] + H_2O \quad (4)$$

where $[NH_4^+]$ is ammonium concentration, $[OH^-]$ is hydroxide ion concentration, and $[NH_{3\ (liquid)}]$ is ammonia concentration in soil water.

- DNDC calculate $NH_{3(liq)}$ concentration base on NH_4^+ and OH^- concentration, and NH_4^+ concentration in the soil profile is calculated by the decomposition submodel.

Linking ecological drivers to trace gases

- The equations describing the effects of soil environmental factors on NO, N_2O, CH_4, and NH_3 were organized into three submodels.
- 1. The fermentation submodel contains all the methane related equation. This submodel calculates production, oxidation, and transport of methane under submerged conditions.
- 2. The denitrification submodel contains all the denitrification equations. This submodel calculates production, consumption, and diffusion of N_2O and NO during rainfall, irrigation, or flooding events.

Linking ecological drivers to trace gases

- 3. Nitrification related equations are included in the nitrification submodel. As a logical extension of the NH_4^+ / $NH_{3(liq)}$ / $NH_{3(gas)}$ equilibrium, functions for NH_3 production and volatilization are also included in the nitrification submodel.

- The three submodels compose the second component of the DNDC model.

Input and output

- Daily temperature
- Precipitation
- Soil bulk density
- Texture
- Soil organic carbon content
- pH
- Farming (e.g., crop type and rotation, flooding, grazing, and weeding)

Input and output

When the DNC is used for regional estimates of trace gases emissions, the model needs the spatially and temporally differentiated input data stored in geographical information system type database in advance.

Base on the input parameters of the ecological drivers,

DNDC first predicts daily soil temperature, moisture, Eh, pH, and substrate concentration, and then uses the environmental parameters to drive nitrification, denitrification, methane production/oxidations.

Daily emissions of trace gases are finally calculated as their daily net fluxes.

Input and output

Most parts of the model run at a daily time step except the soil climate and denitrification submodels which run at an hourly time step.

Output paratmeters from the model runs are daily soil profiles of temperature, moisture, Eh, pH, and concentrations of total soil orgainic carbon, nitrate, nitrite, ammonium, urea, ammonia, as well as daily fluxed of trace gases emission.

For the regional version of DNDC, the simulated results are recorded as geographically explicit data in a GIS database.

DNDC Site mode

Figure 2. Main menu of DNDC

DNDC Site mode

III Model Operation

1. Site Mode

1.1. Input Parameters

- Page 1: Site and climate
- Page 2: Soil
- Page 3: Farming management
- Page 4: Crop
- Page 5: Tillage
- Page 6: Fertilization
- Page 7: Manure amendment
- Page 8: Weeding
- Page 9: Flooding
- Page 10: Irrigation
- Page 11: Grazing and cutting

1.2. Save and Open Input File
1.3. Run DNDC at Site Scale
1.4. A Quick View of Modeled Results
1.5. Batch Run

DNDC Site mode

Figure 2. Main menu of DNDC

Climate/Soil/Cropping

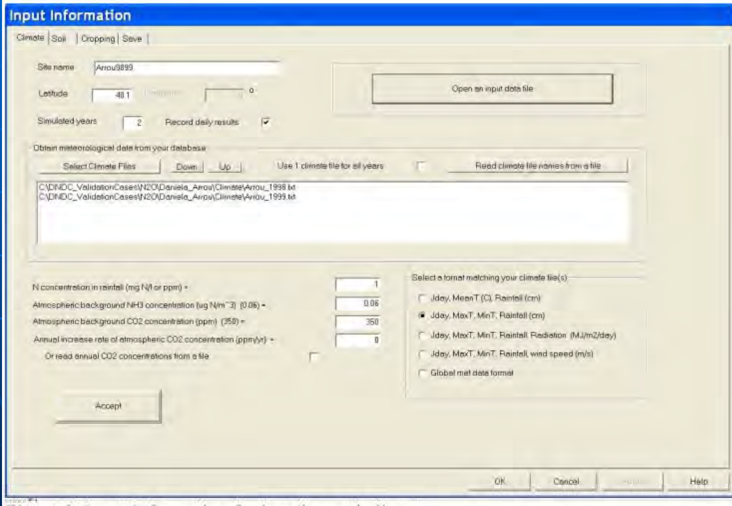


Figure 3. Input information for location and climate

Climate/Soil/Cropping

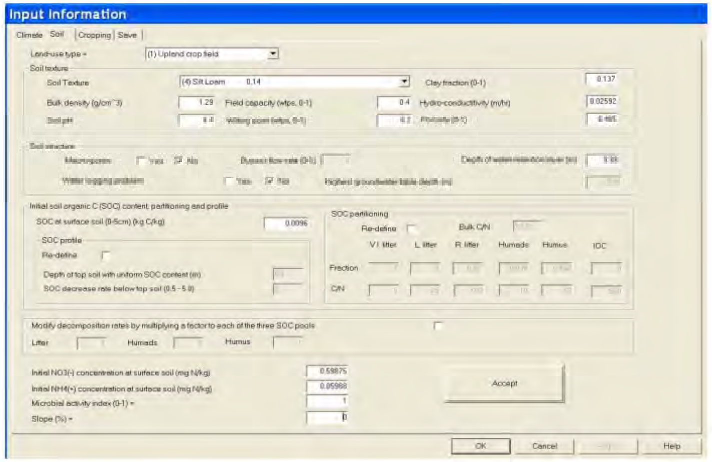


Figure 4. Input information for soil properties

Climate/Soil/Cropping

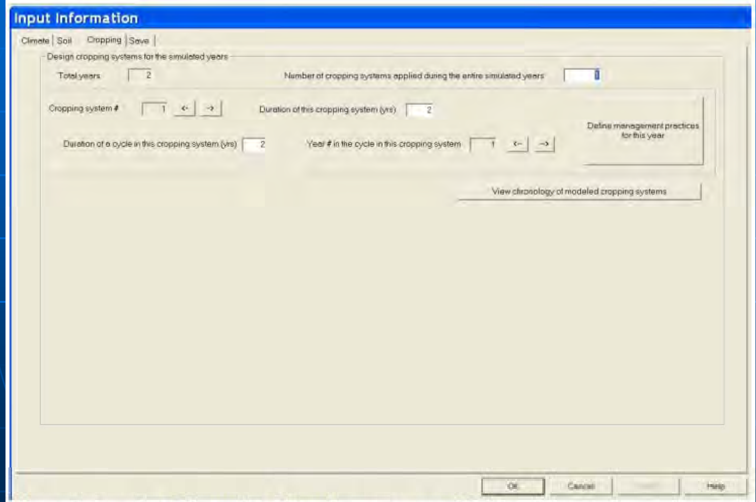


Figure 5. Rotation information: Cropping systems and Cycles

Farming management practices

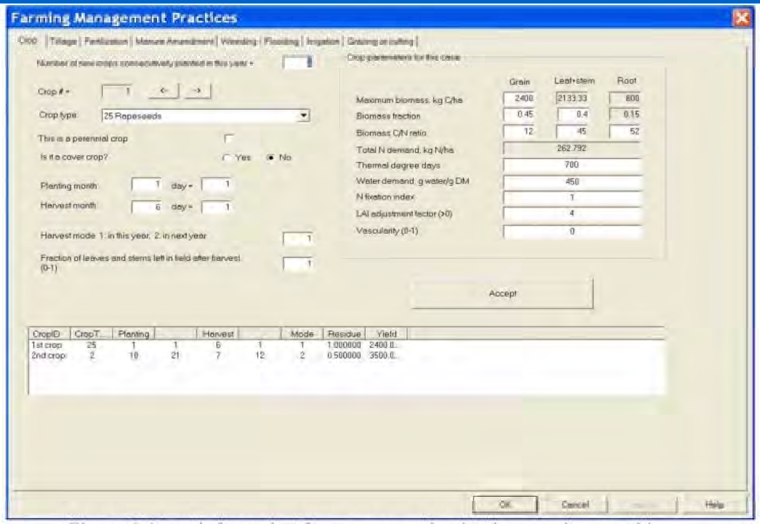


Figure 6. Input information for crop type, planting/harvest dates, residue management and crop physiological/phenology parameters

Farming management practices

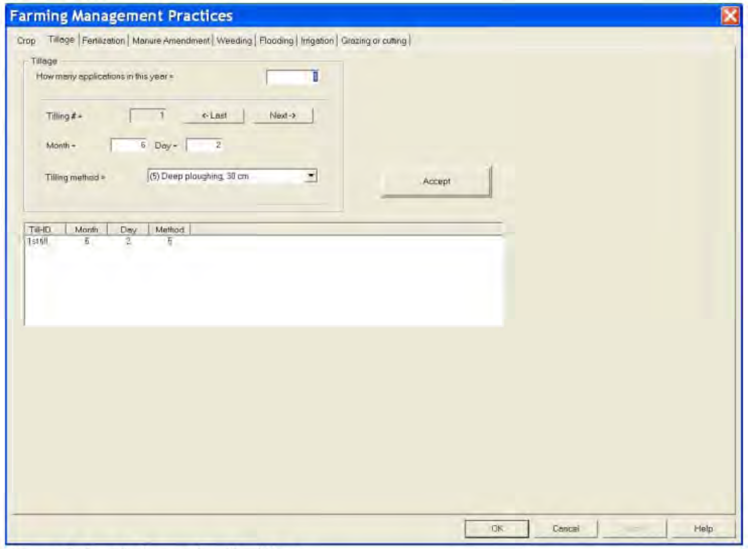


Figure 8. Iput information for tillage

Farming management practices

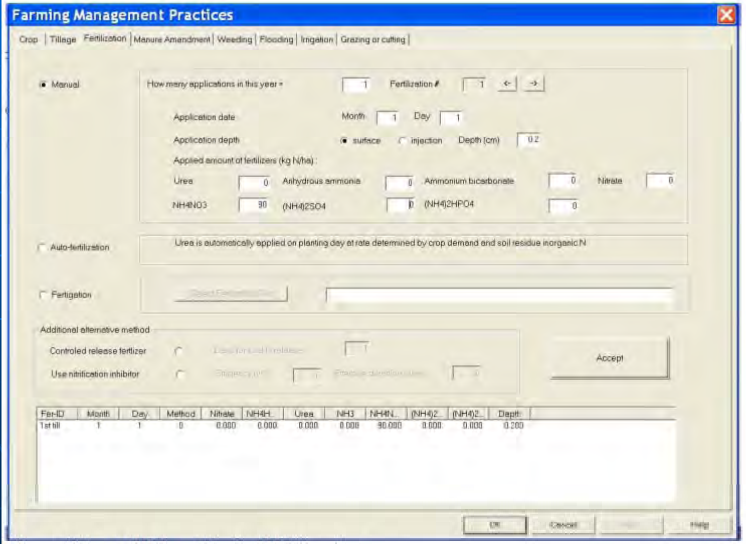


Figure 9. Input information for fertilization

Farming management practices

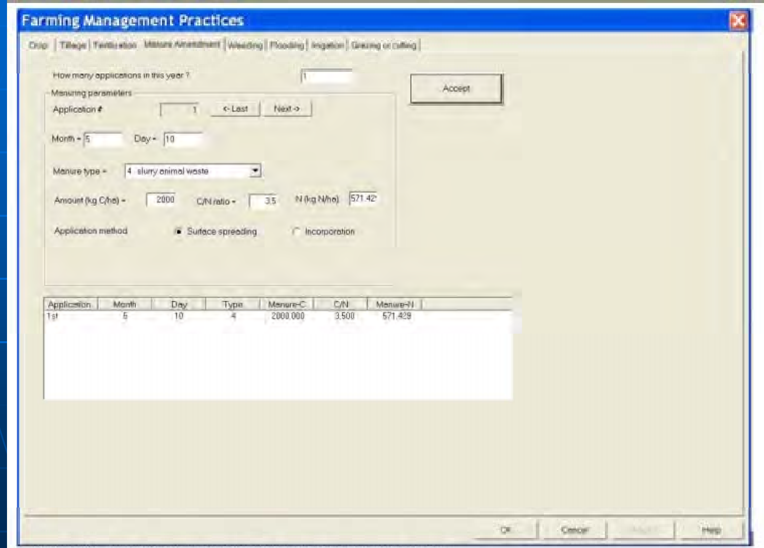


Figure 10. Input information for manure amendment

Farming management practices

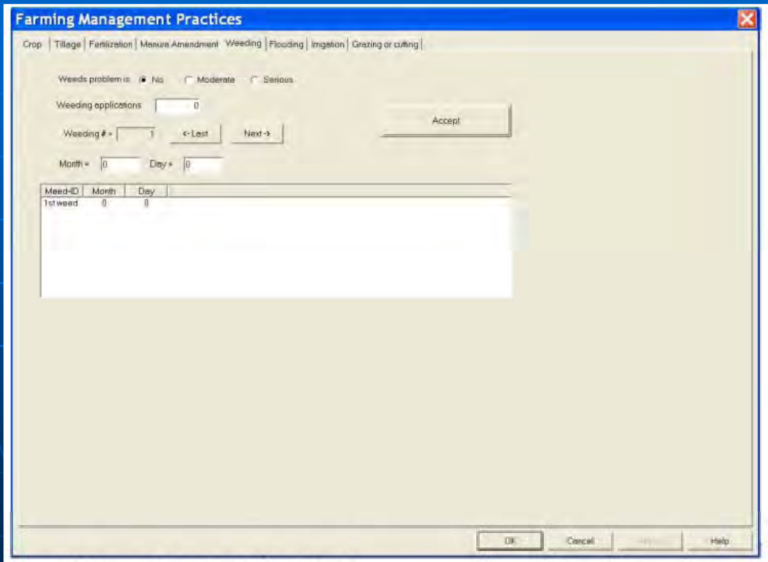


Figure 11. Input information for weeding

Farming management practices

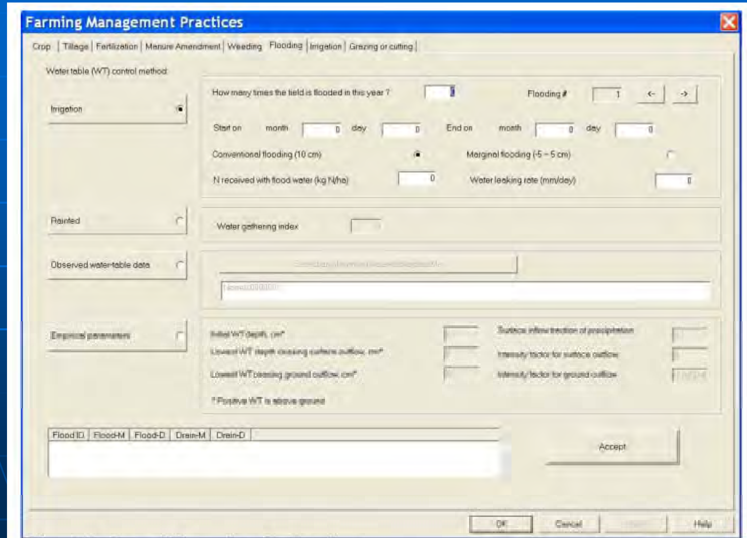


Figure 12. Input information for flooding

Farming management practices

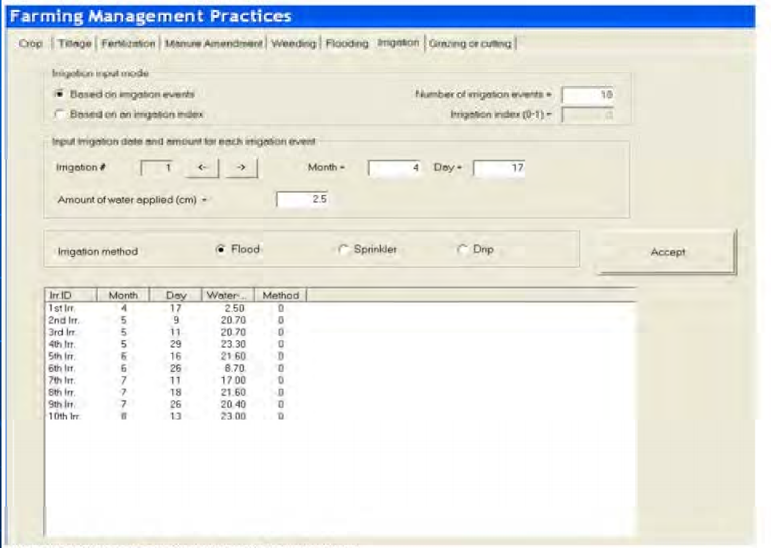


Figure 13. Input information for irrigation

Farming management practices

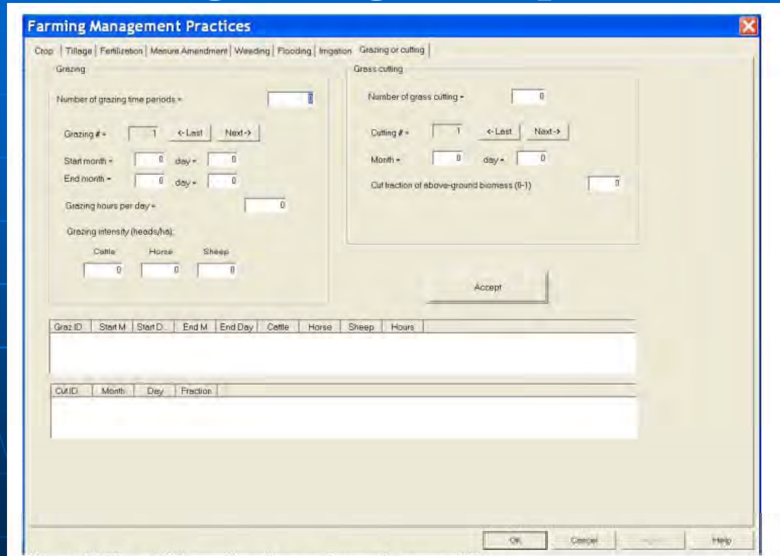
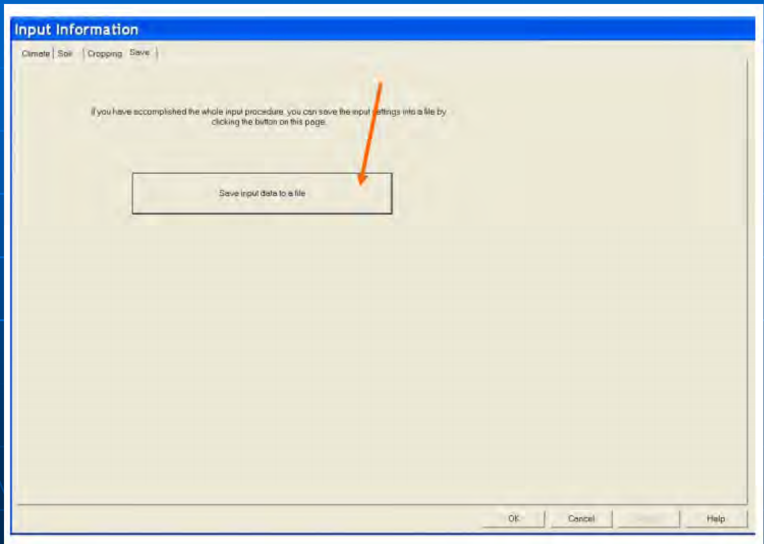


Figure 14. Input information for grazing and grass cutting

Save and open an input file



Input file

```
Input_Parameters:
----------------------------------------
Site_data:                    Arrou9899
Simulated_Year:               2
Latitude:                     48.100
Daily_Record:                      1
----------------------------------------
Climate_data:
Climate_Data_Type:            1
NO3NH4_in_Rainfall              1.0000
NO3_of_Atmosphere               0.0600
BaseCO2_of_Atmosphere         350.0000
Climate_file_count=           2
    1    C:\DNDC\N2O\Arrou\Climate\Arrou_1998.txt
    2    C:\DNDC\N2O\Arrou\Climate\Arrou_1999.txt
Climate_file_mode                  0
```

Input file

```
CO2_increase_rate           0.000000
----------------------------------------
Soil_data:
   Soil_Texture              4
   Landuse_Type              1
   Density                   1.29000
   Soil_pH                   6.40000
   SOC_at_Surface            0.00960
   Clay_fraction             0.13700
   BypassFlow                0.00000
   Litter_SOC                0.01000
   Humads_SOC                0.04800
   Humus_SOC                 0.94200
   Soil_NO3(-)(mgN/kg)       0.59875
   Soil_NH4(+)(mgN/kg)       0.05988
   Moisture                  0.30000
   Temperature               7.45000
Field_capacity              0.400000
Wilting_point               0.200000
Hydro_conductivity          0.025920
Soil_porosity               0.485000
SOC_profile_A               0.200000
SOC_profile_B               2.000000
DC_litter_factor            1.000000
DC_humads_factor            1.000000
DC_humus_factor             1.000000
Humad_CN                    10.000000
Humus_CN                    10.000000
Soil_PassiveC               0.000000
Soil_microbial_index        1.000000
Highest_WT_depth               9.990000
Depth_WRL_m                 9.990000
Slope                       0.000000
Use_ION_file                0
----------------------------------------
```

Input file

```
Crop_data:
Rotation_Number=                 1
  Rotation_ID=                   1
  Totalyear=                     2
  Years_Of_A_Cycle=              2
    YearID_of_a_cycle=           1
    Crop_total_Number=           2
      Crop_ID=                   1
        Crop_Type=               25
        Plant_time=              1 1
        Harvest_time=            6 1
        Year_of_harvest=         1
      Ground_Residue=          1.000000
      Yield=                   2400.000000
      Rate_reproductive=       0.020000
      Rate_vegetative=         0.040000
      Psn_efficiency=          0.480000
      Psn_maximum=             35.000000
      Initial_biomass=         12.500000
      Cover_crop=              0
      Perennial_crop=          0
      Grain_fraction=   0.450000
      Shoot_fraction=   0.400000
      Root_fraction=   0.150000
      Grain_CN=   12.000000
      Shoot_CN=   45.000000
      Root_CN=   52.000000
      TDD=   700.000000
      Water_requirement=   450.000000
      Max_LAI=   4.000000
      N_fixation=   1.000000
      Vascularity=   0.000000
    Crop_ID=                   2
      Crop_Type=               2
      Plant_time=              10 21
      Harvest_time=            7 12
      Year_of_harvest=         2
```

Input file

```
      Tillage_number=          1
        Tillage_ID=            1
          Month/Day/method=    6 2 5
      Fertil_number=           1
        fertilization_ID=      1
          Month/Day/method=    1 1 0
          Depth=               0.200000
          Nitrate=             0.000000
          AmmBic=              0.000000
          Urea=                0.000000
          Anh=                 0.000000
          NH4NO3=              90.000000
          NH42SO4=             0.000000
          NH4HPO4=             0.000000
        Release_rate=          1.000000
        Inhibitor_efficiency=  0.000000
        Inhibitor_duration=    0.000000
        FertilizationOption=   0
      Manure_number=           0
      Weed_number=             0
      Weed_Problem=            0
      Flood_number=            0
      Leak_type=               1
      Water_control=           0
      Leak_rate=               0.000000
```

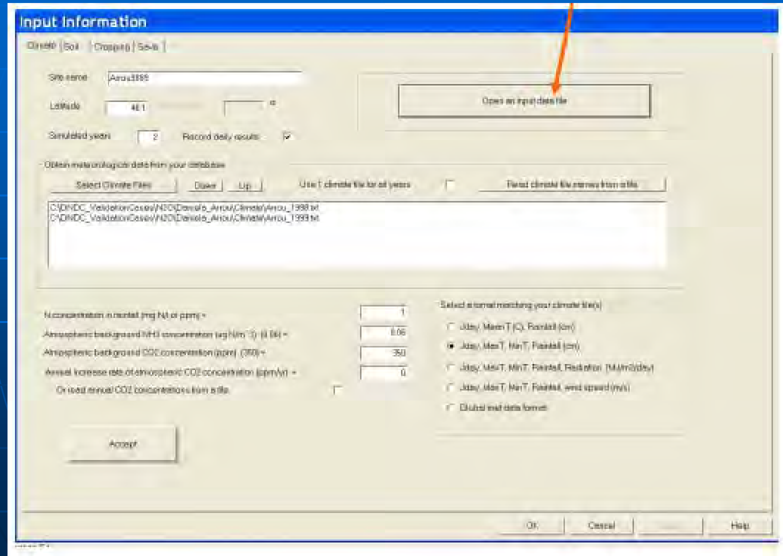
Input file

```
      Water_gather=    1.000000
      WT_file=         None0.000000
      Empirical_parameters= 0.0 0.0 0.0 0.0 0.0 0.0
    Irrigation_number=        0
    Irrigation_type=          0
    Irrigation_Index=         0.000000
    Grazing_number=             0
    Cut_number=             0
    YearID_of_a_cycle=        2
    Crop_total_Number=        0
    Tillage_number=           1
      Tillage_ID=             1
        Month/Day/method=     7 13 5
    Fertil_number=            3
      fertilization_ID=       1
        Month/Day/method=     2 6 0
        Depth=                0.200000
        Nitrate=              0.000000
        AmmBic=               0.000000
        Urea=                 0.000000
        Anh=                  0.000000
        NH4NO3=               58.000000
        NH42SO4=              0.000000
        NH4HPO4=              0.000000
      Release_rate=           1.000000
      Inhibitor_efficiency=   0.000000
      Inhibitor_duration=     0.000000
      fertilization_ID=       2
        Month/Day/method=     3 12 0
        Depth=                0.200000
        Nitrate=              0.000000
        AmmBic=               0.000000
        Urea=                 42.000000
        Anh=                  0.000000
        NH4NO3=               41.000000
        NH42SO4=              0.000000
        NH4HPO4=              0.000000
      Release_rate=           1.000000
      Inhibitor_efficiency=   0.000000
      Inhibitor_duration=     0.000000
      fertilization_ID=       3
        Month/Day/method=     3 27 0
        Depth=                0.200000
```

Input file

```
        fertilization_ID=      3
          Month/Day/method=    3 27 0
          Depth=               0.200000
          Nitrate=             0.000000
          AmmBic=              0.000000
          Urea=                20.000000
          Anh=                 0.000000
          NH4NO3=              20.000000
          NH42SO4=             0.000000
          NH4HPO4=             0.000000
        Release_rate=          1.000000
        Inhibitor_efficiency=  0.000000
        Inhibitor_duration=    0.000000
        FertilizationOption=   0
      Manure_number=           0
      Weed_number=             0
      Weed_Problem=            0
      Flood_number=            0
      Leak_type=               1
      Water_control=           0
      Leak_rate=               0.000000
          Water_gather=    1.000000
          WT_file=         None0.000000
          Empirical_parameters= 0.0 0.0 0.0 0.0 0.0 0.0
      Irrigation_number=       0
      Irrigation_type=         0
      Irrigation_Index=        0.000000
      Grazing_number=            0
      Cut_number=            0
  Crop_model_approach          0
```

Open an input data file



Run model at site mode

Figure 15. The seven windows allow users to monitor daily dynamics of several major simulated factors during the model run.

Quick view of modeled results

Figure 16. Main menu for quick view of modeled results

Modeled results

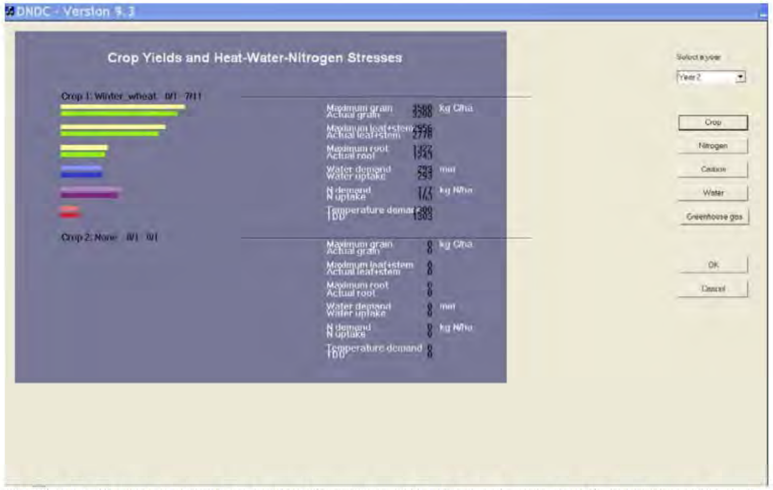


Figure 17. Modeled result 1: Crop biomass production and stresses of temperature, water or nitrogen. (TDD – accumulative thermal degree days of crop growth season)

Modeled results

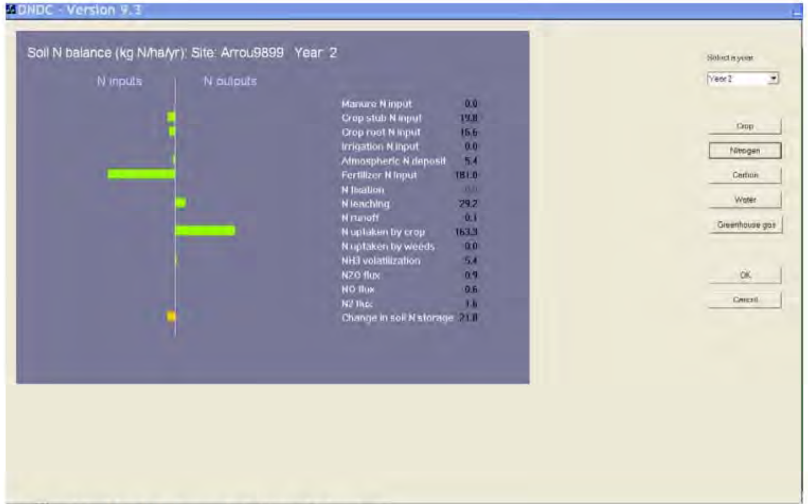


Figure 18. Modeled result 2: Soil N budget.

Modeled results

Figure 19. Modeled result 3: Soil C budget.

Modeled results

Figure 20. Modeled result 4: Water budget

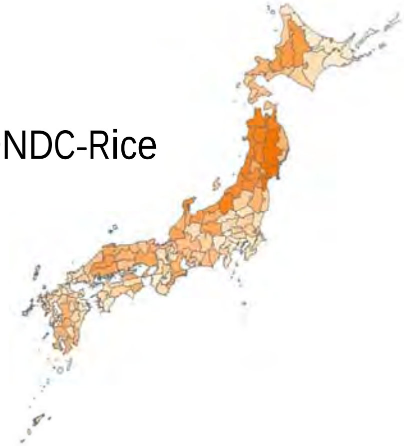
Modeled results

Figure 21. Modeled result 5: Net greenhouse gas emission

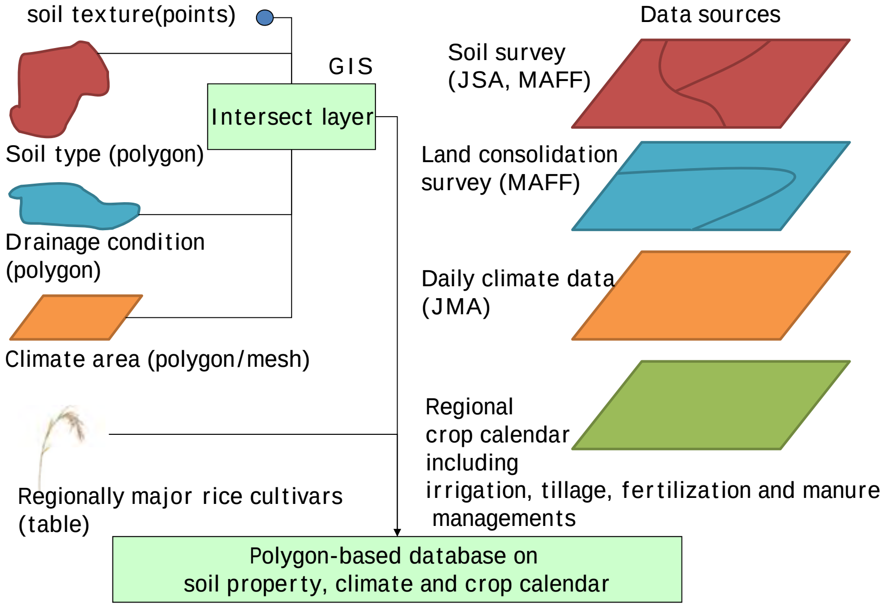
Practice on input data preparation

Michiko Hayano, NIAES, Japan
Yoshitaka Uchida, Hokkaido Univ, Japan

Create Input files
for region mode of DNDC-Rice



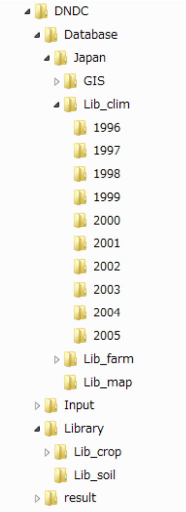
Construction of the database for Japan



Install DNDC-Rice

- Software
  - The DNDC-Rice model predicts C and N biogeochemistry in agricultural ecosystems at site or regional scale.
  - For regional simulations, DNDC reads all of the driving parameters from a preset database that contains the spatially differentiated information of weather, soil , vegetation and management on a polygon or grid cell basis for the modeled domain.
  - The DNDC-simulated time span is through a year to centuries.
- Hardware
  - The DNDC model requires a PC or compatible with Windows installed. A minimum memory of 64M is required. The output files resulted from a 100-year simulation requires about 0.5MB of disk space.
- Install
  - Copy DNDC folder to C drive on your PC.

Create Input Database



- (1) GIS
- (2) Lib_clim
- (3) Lib_farm
- (4) Library

(1) GIS folder

- GIS file 1(Japan_1.txt)
- GIS file 2 (Japan_2.txt)
- GIS file 3(Japan_3.txt)
- GIS file 4(Japan_4.txt)
- GIS file 5(Japan_5.txt)

GIS file 1 / GIS folder

Country characters

	Country folder name		longitude	latitude
62403311	Japan	Shiriuchi	140.3875	41.5917
62403312	Japan	Shiriuchi	140.4	41.5917
62406525	Japan	Nanae	140.6875	41.85
62406592	Japan	Toshima_Ono	140.65	41.9083
63395711	Japan	Kitahiyama	139.8875	42.425
63395721	Japan	Kitahiyama	139.8875	42.4333
63405722	Japan	Date	140.9	42.4333
63406762	Japan	Toyako	140.9	42.55
63417734	Japan	Atsuma	141.925	42.6083
63424360	Japan	Niikappu	142.375	42.3833

Simulation unit code up to 8 digit number

GIS file 2 / GIS folder

Climate information

	Climate station ID	N concentration in rainfall(ppm) Default = 0.5
62403311	105	0.5
62403312	102	0.5
62406525	88	0.5
62406592	340	0.5
63395711	234	0.5
63395721	232	0.5
63405722	178	0.5
63406762	227	0.5
63417734	167	0.5
63424360	191	0.5

GIS file 3 / GIS folder

Soil properties

Simulation unit code

	SOC_max (g/g)	SOC_min (g/g)	Clay_max (g/g)	Clay_min (g/g)	pH_max (-)	pH_min (-)	BD_max (g/cm3)	BD_min (g/cm3)	Fe_max (mol/kg)	Fe_min (mol/kg)	FWC_max (-)	FWC_min (-)
62403311	0.0018	0.0018	0.3	0.3	5.3	5.3	1.14	1.14	0.085	0.028	0.75	0.75
62403312	0.0018	0.0018	0.3	0.3	5.8	5.8	1.14	1.14	0.176	0.059	0.85	0.85
62406525	0.0012	0.0012	0.11	0.11	5.2	5.2	1.24	1.24	0.078	0.026	0.85	0.85
62406592	0.0095	0.0095	0.25	0.25	5.9	5.9	0.28	0.28	0.07	0.023	0.85	0.85
63395711	0.0028	0.0028	0.06	0.06	5.7	5.7	0.94	0.94	0.086	0.029	0.75	0.75
63395721	0.0013	0.0013	0.08	0.08	5.5	5.5	1.22	1.22	0.146	0.049	0.75	0.75
63405722	0.0021	0.0021	0.06	0.06	5.8	5.8	1.01	1.01	0.072	0.024	0.75	0.75
63406762	0.0006	0.0006	0.13	0.13	5.3	5.3	1.34	1.34	0.055	0.018	0.75	0.75
63417734	0.0018	0.0018	0.18	0.18	5.4	5.4	1.12	1.12	0.06	0.02	0.95	0.95
63424360	0.0024	0.0024	0.24	0.24	5.6	5.6	1.07	1.07	0.103	0.034	0.85	0.85

SOC Clay pH Bulk density Reducible Fe Field water capacity

To estimate the range of simulated variables, max and min value of soil data in each unit are used.

GIS file 4/ GIS folder

Cropping area data

number of farming system code

Farming system code

Japan crop acreage census data (ha)

System	CF_AS	CF_SS	CF_NS	Jun D_AS	Jun D_SS	Jun D_NS	Jul D_AS	Jul D_SS	Jul D_NS	J&J D_AS	J&J D_SS	J&J D_NS
12	11	12	13	21	22	23	31	32	33	41	42	43
62403311	0	0	40.5	0	0	0	0	0	0	0	0	0
62403312	0	0	0	0	0	0	0	0	0	0	0	23.1
62406525	0	73.9	0	0	0	0	0	0	0	0	0	0
62406592	48	0	0	0	0	0	48	0	0	0	0	0
63395711	0	0	35.2	0	0	0	0	0	0	0	0	0
63395721	0	0	22.8	0	0	0	0	0	0	0	0	0
63405722	0	0	0	0	0	0	0	0	18.1	0	0	0
63406762	0	0	0	0	0	0	0	0	0	18.1	0	0
63417734	71.1	0	0	0	0	0	0	0	0	0	0	0
63424360	0	0	0	14.3	0	0	0	0	0	0	0	0

area of specific farming system (ha)

Simulation unit code

GIS file 5 /GIS folder

Map file ID

```
3612601 11111111
3612602 11111111
3612603 11111111
3612604 11111111
3612605 11111111
3612606 11111111
3612607 11111111
3612608 11111111
3612609 11111111
3612610 11111111
3612611 11111111
```

(2) Lib_clim folder

- Lib_clim include folders for each year in which text files are stored. The name of those text files is the same as the climate station_ID described in GIS file 2.

Climate file / Lib_clim folder

105-00

Date (1-365)	Temp max.	Temp min.	Precipitation(cm)
1	2.1	-5.2	0.3
2	2	-5.2	0
3	1.9	-5.3	0.1
4	1.9	-5.4	0
5	1.8	-5.5	0
6	1.7	-5.6	0
7	1.6	-5.6	0
8	1.6	-5.7	1.5
9	1.5	-5.8	0.6
10	1.5	-5.8	0
11	1.4	-5.9	0.1

Farm file / Lib_farm folder

1	number_of_crops	
20	rice	Crop code
8444.2	optimum_yield	Maximum yield (kg/ha)
5	planting_month	Transplanting month
25	planting_day	Transplanting day
9	harvest_month	Harvesting month
10	harvest_day	Harvesting day
1	percent_residue_left	Ratio percent of crop residue(0-1)
999	season_flag	Season flag(999 indicates the crop is the last crop planted in the year)
3	till_applications	
5	month	
5	day	
3	method	
5	month	
20	day	
3	method	
11	month	
1	day	
3	method	
2	number_of_fert	
5	fert_month1	
20	fert_day1	
70	fert_rate1	
6	fert_month1	
30	fert_day1	
20	fert_rate1	
0	manure_applications	
1	irrigation_index	
2	flooding	
5	month(flooded)	
20	day	
6	month(drained)	
23	day	
6	month(flooded)	
28	day	
8	month(drained)	
20	day	

Till method: define tilling depth by selecting method as
(1) Ploughing slightly, 5cm (2) Ploughing with disk of chisel(10cm), (3) Ploughing with moldboard, 15cm

Fertilization rate(kg N/ha)

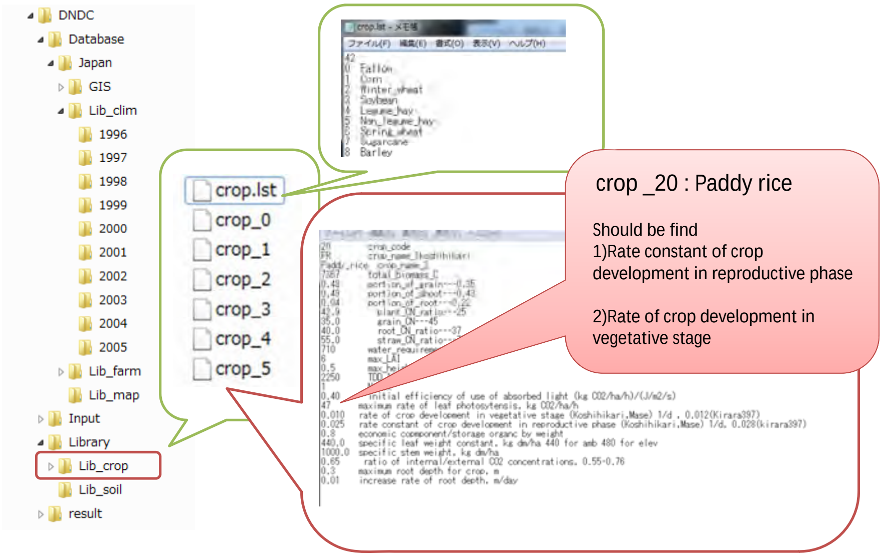
Amount (kg C/ha): Amount of manure application rate (kg C/ha)
C/N ratio: Ratio of C/N in the manure. Manure type is specified using CN ratio.

Irrigation index (0-1)
2 Times of flooding
Flooding month
Flooding day
Draining month
Draining day

*A flooding event is defined by specifying its start date and end date

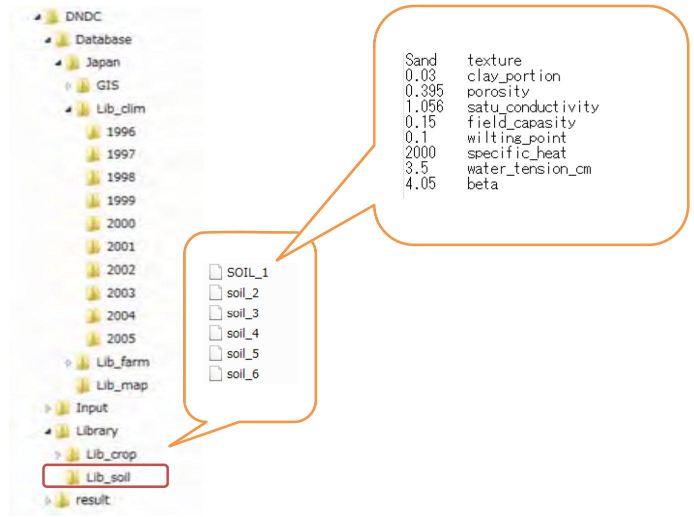
Lib_crop / Library

Crop physiological and phonological data for each type of crop

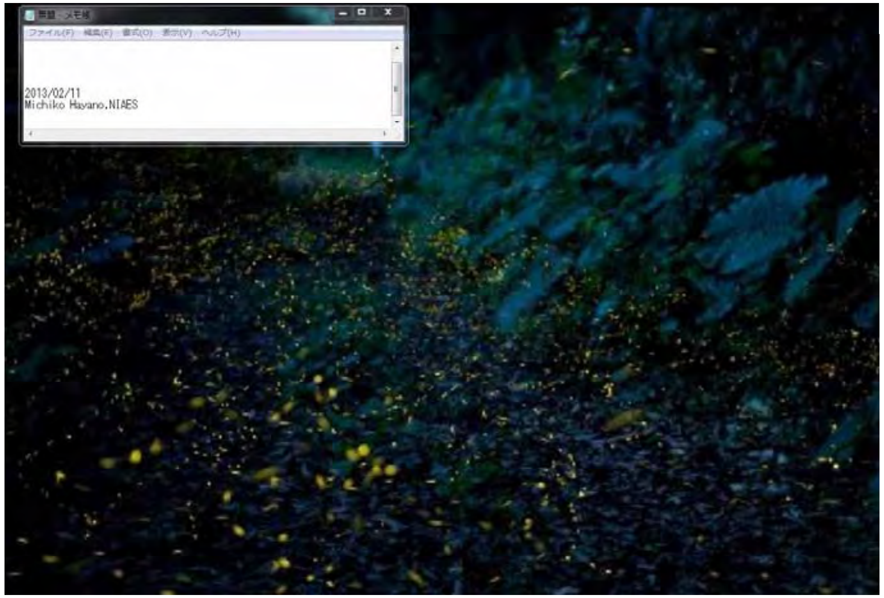


Lib_soil / Library

soil thermal and hydraulic data for each type of soil



Demonstration DNDC-Rice (7m30s)



Appendix 8

Capacity building workshop on “Strategic rice cultivation with energy crop rotation in South East Asia – A path toward climate change mitigation in the agricultural sector”

Capacity Building Workshop on:

"Strategic rice cultivation with energy crop rotation in South East Asia **–** A path toward climate **change mitigation in the agricultural sector"**

Funded under the APN-ARCP Project on:

Strategic Rice Cultivation for Sustainable Low Carbon Society Development in South East Asia

Held during 29-31 May 2013
Phuttaraksa Room (3rd floor), Seminar Building, Continuing Education Center
King Mongkut's University of Technology Thonburi, Bangkok, Thailand

Organized by
The Joint Graduate School of Energy and Environment (JGSEE)

Purpose of the workshop

This workshop aims at providing scientists and policy makers with improved knowledge on strategic rice cultivation including rotation with energy crop in SEA with a focus on GHG emissions reduction via improved rice cultivation management. This should contribute promoting adequate policies for climate change mitigation in the agricultural sector.

Date and venue

The event will be held on May 29-31, 2013, Phuttaraksa Room (3rd floor), Seminar Building, Continuing Education Center, King Mongkut's University of Technology Thonburi, Bangkok, Thailand

Participants

Researchers, scientists, government officers, from the agricultural and environmental sector

Registration

Free of charge

Language

The capacity building workshop will be held in English

Programme of capacity building workshop

29 May 2013 - Strategic rice cultivation with energy crop rotation in SEA

08.30 – 9.00	Registration	
9.00 – 9.10	Welcome Address	Assoc. Prof. Dr. Sirintornthep Towprayoon Director, JGSEE, Thailand
9.10-9.20	Opening Address	Assoc. Prof.Dr. Bundit Fungtammasan Vice President, KMUTT, Thailand
9.20 – 10.00	Strategic rice cultivation with energy crop rotation in Southeast Asia – A path toward climate change mitigation in the agricultural sector	Dr. Sebastien Bonnet APN Project Manager, JGSEE, Thailand
10.00 – 10.30	Group Photo and Coffee Break	
	SESSION 1: KEYNOTE PRESENTATIONS	
10.30 – 11.15	Influence of rice cultivation practices on GHG emissions	Dr. Shigeto Sudo NIAES, Japan
11.15 – 12.00	Sustainable rice cultivation – a path toward climate change mitigation and adaptation	Dr. Chitnucha Buddhaboon Rice Department, OAE, Thailand
12.00 – 13.30	Lunch Break	
	SESSION 2: COUNTRY REPORTS	
13.30 – 14.00	Sustainable agricultural production – Focus on rice production in Thailand	Assoc. Prof. Dr. Amnat Chidthaisong Deputy Director, JGSEE, Thailand
14.00 – 14.30	Sustainable agricultural production – Focus on rice production in Cambodia	Dr. Seng Vang APN Project collaborator, CARDI, Cambodia
14.30-15.00	Sustainable agricultural production – Focus on rice production in Indonesia	Dr. Iman Rusmana APN Project collaborator, Bogor University, Indonesia
15.00 – 15.30	Coffee Break	
15.30 – 16.00	Sustainable agricultural production – Focus on rice production in Lao PDR	Mr. Immala Inthaboulay APN Project collaborator, Climate Change Office, Department of Environment, Lao PDR
16.00 – 16.30	Sustainable agricultural production – Focus on rice production in Myanmar	Dr. Khin Lay Swe Yesin Agricultural University, Myanmar
16.30 – 17.00	Sustainable agricultural production – Focus on rice production in Vietnam	Dr. Nguyen Thi Phuong Thao Hanoi University of Agriculture, Vietnam
17.00 –17.30	Discussions on Sustainable agricultural production – Focus on rice production in SEA	All participants
18.00 – 20.00	Working Dinner	

May 30, 2013 – Training on DeNitrification-DeComposition (DNDC) Model

8.30 – 9.00	Registration	
	SESSION 3: DNDC TRAINING	
9.00 – 9.45	Introduction to DNDC model	Dr. Kruamas Smakgahn Lecturer, Kasetsart University, Thailand
9.45 – 10.30	Experience in using DNDC-Rice model – Case of Japan	Dr. Kazunori Minamikawa Researcher, NIAES, Japan
10.30 – 11.00	Coffee Break	
11.00 – 12.00	Data requirement and formatting for DNDC site and regional mode and Demonstration for on-site Mode (Case of Ratchaburi site in Thailand)	Ms. Nittaya Cha-un and Mr. Uday Pimple APN project researchers, JGSEE, Thailand
12.00 – 13.30	Lunch Break	
13.30 – 14.30	DNDC site mode practice	Ms. Nittaya Cha-un and Mr. Uday Pimple APN project researchers, JGSEE, Thailand
15.00 – 15.30	Coffee Break	
15.30 – 16.30	DNDC regional mode demonstration, conclusion results from DNDC site mode simulations, and discussion on regional mode	Ms. Nittaya Cha-un and Mr. Uday Pimple APN project researchers, JGSEE, Thailand
16.30 – 17.00	Discussions on adaptation options and suggestions for sustainable rice cultivation in SEA	All participants

May 31, 2013 – Training on the Agriculture and Land Use Greenhouse Gas Inventory (ALU) Software

08.30 – 9.00	Registration	
	SESSION 4: ALU TRAINING	
9.00 – 10.00	Introduction to ALU software	Assoc. Prof. Dr. Savitri Garivait APN project contributor, JGSEE, Thailand
10.00 – 10.30	Coffee Break	
10.30 – 12.00	Hands-on Session I: Estimation of GHG emissions and carbon stock from rice cultivation in rotation with energy crops using ALU (part 1)	Dr. Savitri Garivait and Dr. Agapol Junpen APN project contributors, JGSEE, Thailand
12.00 – 13.30	Lunch Break	
13.30 – 15.00	Hands-on Session II: Estimation of GHG emissions and carbon stock from rice cultivation in rotation with energy crops using ALU (part 2)	Dr. Savitri Garivait and Dr. Agapol Junpen APN project contributors, JGSEE, Thailand
15.00 – 15.30	Coffee Break	
15.30 – 16.30	Discussion on networking and ways forward	All participants
16.30 – 17.00	Overall conclusion	All participants

Newsletter article

The Capacity Building Workshop on "Strategic rice cultivation with energy crop rotation in Southeast Asia – A path toward climate change mitigation in the agricultural sector" under the APN-ARCP Project on "Strategic Rice Cultivation for Sustainable Low Carbon Society Development in South East Asia" was organized by the Joint Graduate School of Energy and Environment (JGSEE) & Centre of Excellence on Energy Technology and Environment (CEE-PERDO), King Mongkut's University of Technology Thonburi, during 29-31 May 2013 at Pullman Bangkok King Power Hotel in Bangkok.

This 3 day workshop aimed at providing scientists and policy makers in the region with improved knowledge and understanding regarding strategic rice cultivation including rotation with energy crops in SEA with a focus on GHG emissions reduction via improved rice cultivation management. A total of 35 participants joined the workshop, including, aside from the project team, experts from Cambodia, Indonesia, Myanmar, Vietnam, and Japan, as well as officers and researchers from government agencies and universities in Thailand. Prior to start the event, a welcome address was delivered by Assoc. Prof. Dr. Sirintornthep Towprayoon, Director of JGSEE and APN Project Leader and an opening address by Assoc. Prof. Dr. Bundit Fungtammasan, Vice President for Research at KMUTT.

The first day of the workshop focused on providing an overview of the project main outcomes. At that occasion, a summary of the project activities and main results were presented, and keynote and country report presentations delivered by experts from the SEA region. The second day of the event focused on providing training on the DeNitrification-DeComposition (DNDC) model and the last day on the "Agriculture and Land-Use" (ALU) model. Both the tools were used in the project to simulate and assess GHG emissions and soil carbon stock dynamics associated to rice cultivation and rotation with energy crops. This capacity building workshop was very successful in enabling to transfer the knowledge gathered over the entire duration of the project and potentially opening new opportunities for further collaboration with scientists and policy-makers in the region.

List of participants

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Presentation materials

Strategic Rice Cultivation for Sustainable Low Carbon Society Development in South East Asia

Dr Sebastien Bonnet
The Joint Graduate School of Energy and Environment

Capacity Building Workshop on:
"Strategic rice cultivation with energy crop rotation in Southeast Asia – A path toward climate change mitigation in the agricultural sector"
29-31 May 2013, Pullman King Power Hotel, Bangkok, Thailand

The Asia-Pacific Network for Global Change Research - APN

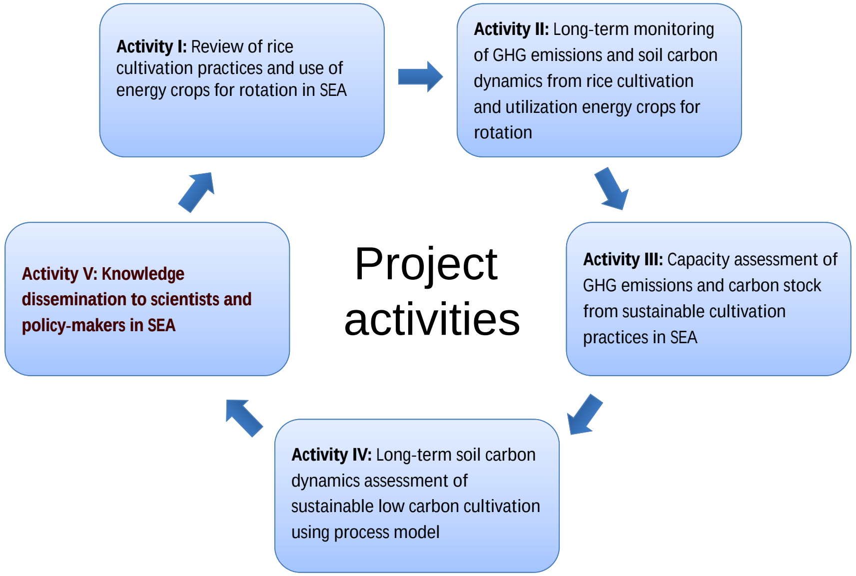
- APN: The Asia-Pacific Network for Global Change Research
- APN is a network of 22 member countries promoting global change research in the region and strengthening interactions between scientists and policy-makers
- The APN funds its research programmes based on an annual open call for proposals under its regional research and capacity development programmes (ARCP and CAPaBLE).
- ARCP: Asia Pacific Network - Annual Regional Call for Research Proposals
- ARCP is one of the scientific pillars of the APN to encourage and promote global change research in the Asia-Pacific region, establishing a sound scientific basis for policy-making.

APN-ARCP project led by JGSEE

- Project title: Strategic Rice Cultivation for Sustainable Low Carbon Society Development in South East Asia
- Project duration: 2 years
- Budget: 40,000 USD per year
- Organizations involved:
  - The Joint Graduate School of Energy and Environment (JGSEE), Thailand Lead organization (Assoc. Prof. Dr. Sirintornthep Towprayoon)
  - The National Institute for Agro-Environmental Sciences (NIAES), Japan
  - Bogor Agricultural University, Indonesia

Project objectives

- The overall goal of the project is to identify strategic rice cultivation practices enabling SEA to develop towards a sustainable low carbon society while enhancing the adaptive capacity in the agriculture sector
- The specific objectives are:
  - To develop long-term field studies to measure, monitor and evaluate the impacts of various cultivation practices on climate change and identify potential adaptive measures and mitigation options
  - To identify strategic rice cultivation practices, in rotation with selected energy crops, enabling to fully utilize the rice plantation fallow period and therefore to optimize rice and energy feedstock production
  - To enhance regional capacity of scientists and policy makers in SEA for sustainable low carbon development of their society



Activity I: Review of rice cultivation practices and use of energy crops for rotation in SEA

Description of Tasks

- Review of information on current rice cultivation practices in SEA and state-of-the-art of regional traditional practices as well as potential for introducing selected energy crops to be cultivated in rotation with rice.
- Involvement of SEA experts in the agricultural sector to contribute information to the review study as part of an expert meeting organised in Thailand by JGSEE

Deliverables

- Report on the state-of-the-art of rice cultivation practices and use of energy crops as the potential rotation crops for SEA countries.
- Database of rice cultivation practices in SEA
- Identification of country specific rice cultivation practices and potentials for energy crop cultivation in SEA countries
- Background data for preparation of Activity II and III

Activity I: Review of rice cultivation practices and use of energy crops for rotation in SEA

- Literature survey to assess current practices of rice cultivation in SEA including land management.
- Review supported with a questionnaire survey (in Thailand and Indonesia) to collect information from farmers regarding their agricultural practices and assessing potentials for rotation with selected energy crops, i.e. maize and sorghum.
- Expert meeting organized by JGSEE in June 2011 gathering selected experts from SEA countries including: Indonesia, Japan, Cambodia, Lao PDR, Myanmar, Vietnam and Thailand to help evaluating and confirming the results from the literature review.
- Production of a Report on: "State-of-the-art of rice cultivation practices in SEA and rotation with energy crops".
- Presentation on "Rice Cultivation and Potential Areas for Rotation with Energy Crops in South-east Asia" at the 17th Inter-Governmental Meeting (IGM) and Scientific Planning Group (SPG) Meeting in Jakarta (Indonesia), on 14 March 2012.

JGSEE CEE-PERDO Center for Energy Technology and Environment APN

Expert Meeting on
"State-of-the-Art of Rice Cultivation Practices in South-East Asia"

2-3 June 2011
JGSEE, Bangkok, Thailand

Under APN-ARCP Funded Project on:
Rice Cultivation for Sustainable Low Carbon Society Development in South-East Asia

Organized by
The Joint Graduate School of Energy and Environment (JGSEE)

Activity I: Report on “State-of-the-art of rice cultivation practices for selected countries in SEA and rotation with energy crops”

- The report provides background information on statistics of rice cultivation in selected SEA countries including harvested area, production, yield, trade as well as rice varieties and ecosystems
- The report also provides country specific information for : Cambodia, Indonesia, Lao PDR, Myanmar, Thailand and Vietnam
- The information reviewed and reported includes:
  - Rice variety
  - Agro-cosystem
  - Land preparation
  - Rice plantation and cultivation practices (water, fertiliser, pesticide, etc.)
  - Harvesting method
  - Management of rice residues
  - Rotation crops
  - Soil organic carbon
  - Socio-economic status of farmers

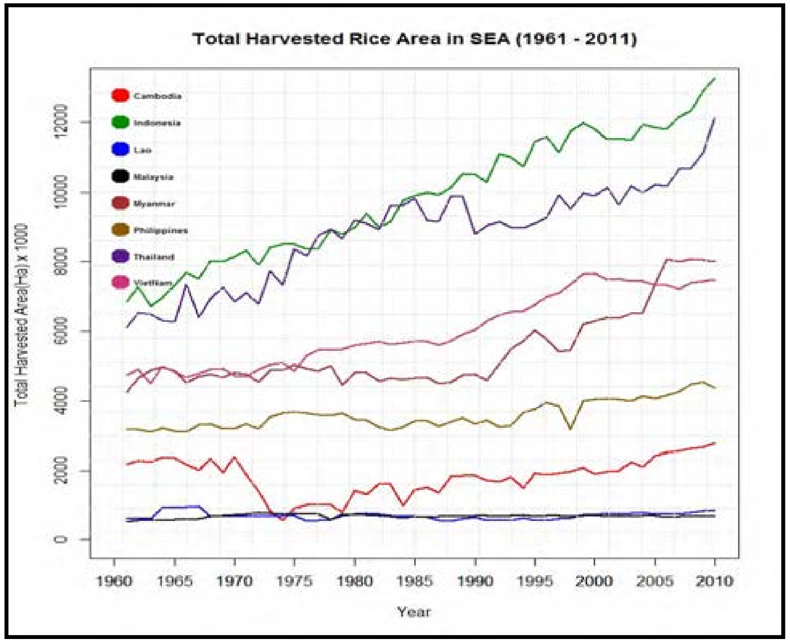
Activity I: Overview on rice production

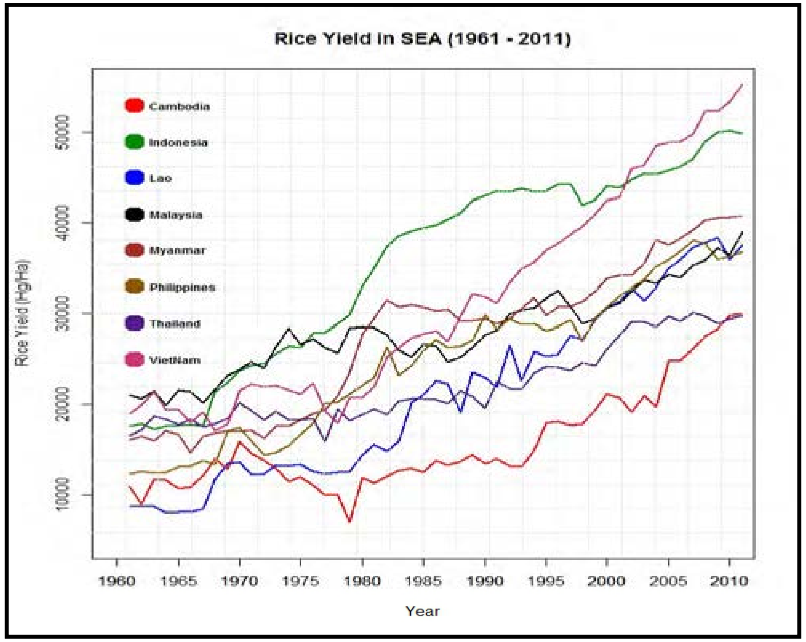
- Rice is grown in more than 100 countries
- Global rice plantation covering 12.5% of total crop plantation area
- The global rice area harvested at present represents more than 150 Mha, but the amount of land used for rice is less, in the order of about 125 million hectares, because in some fields farmers plant two, or even three, rice crops each year,
- Annual production is nearing 630 Mt of rough (unmilled) rice → 95 kg for each person on Earth

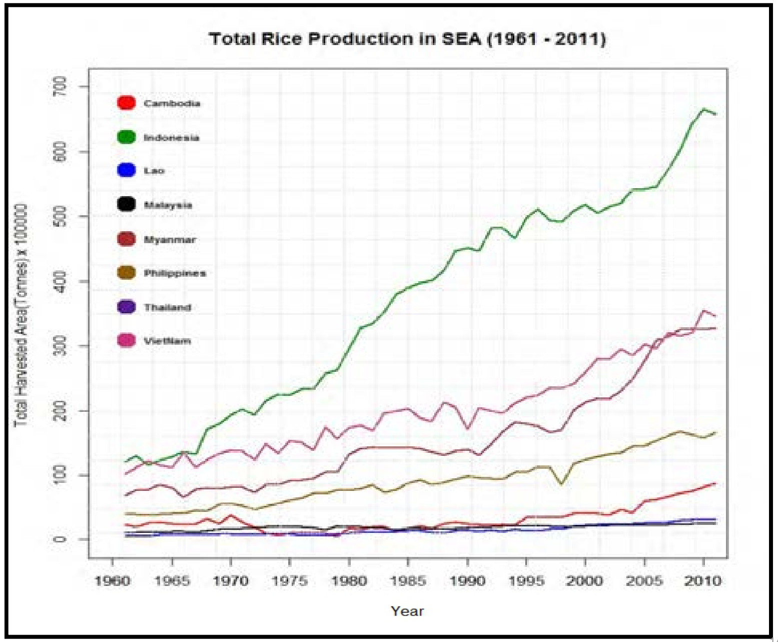
Activity I: Overview on rice production

- Rice is most closely associated with South, Southeast, and East Asia, where 90% of the world's rice is produced.
- Almost half of the global rice area is in India and China, the 2 largest world producer of rice
- The eight countries with the largest area of rice are all in South and Southeast Asia (80%), including:
  - India,
  - China,
  - Indonesia,
  - Bangladesh,
  - Thailand,
  - Vietnam,
  - Myanmar, and
  - the Philippines

→ 30 % of the global rice area is found in SEA







Activity I: Rice agro-ecosystems

There are primarily four agro-ecosystems where rice is grown:

- Irrigated rice (80 Mha, 75% global rice production, typically found in China, Japan, Indonesia, Vietnam and Korea)
- Rainfed lowlands (60 Mha (46Mha in Asia), 20% global rice production, typically found in eastern India and SEA)
- Upland rice (14Mha, 4% global rice production, typically found in Indonesia, the Philippines and Southwest China)
- Flood-prone ecosystem (11Mha, 1% global rice production, typically found in Bangladesh, the Irrawaddy of Myanmar, the Mekong region of Vietnam and Cambodia, and the Chao Phraya basin of Thailand)

Activity I: Main features of rice production in SEA

- Cultivation practices of rice in SEA do not differ much.
- Climate is a factor that classifies rice cultivation into wet and dry season, and each country in SEA refers to wet and dry season in a different way, e.g.
  - Wet season of rice (WS) and dry season of rice (DS) in Cambodia;
  - Monsoon rice and summer rice in Myanmar; and
  - Major rice and second rice in Thailand.
- There are 2 main planting methods used for rice,
  - Broadcasting - large scale production, not labor intensive
  - Transplanting - traditional method, labour intensive, found mainly in NE of Thailand, small farms in Cambodia, most areas in Lao PDR, 80% of rice farms in Myanmar, and traditional farms in Vietnam).

Activity I: Main features of rice production in SEA

- Chemical fertilizers are applied in paddy fields in most SEA countries, especially for rice cultivated via modern methods. For traditional farming in mountainous areas, organic fertilizers are still mainly applied.
- The harvesting of rice can be performed either manually (using sickles) or by machine. In SEA, harvesting machines are mainly used in lowland areas (dominant in ASEAN) easy of access.
- Rotation crops are planted mostly in non-irrigated paddy fields during the fallow period and with enough water for cultivation. The rotation crops are legumes, fruits, and vegetable.

Activity II: Long-term monitoring of GHG emissions and soil carbon dynamics from rice cultivation and rotation with selected energy crops

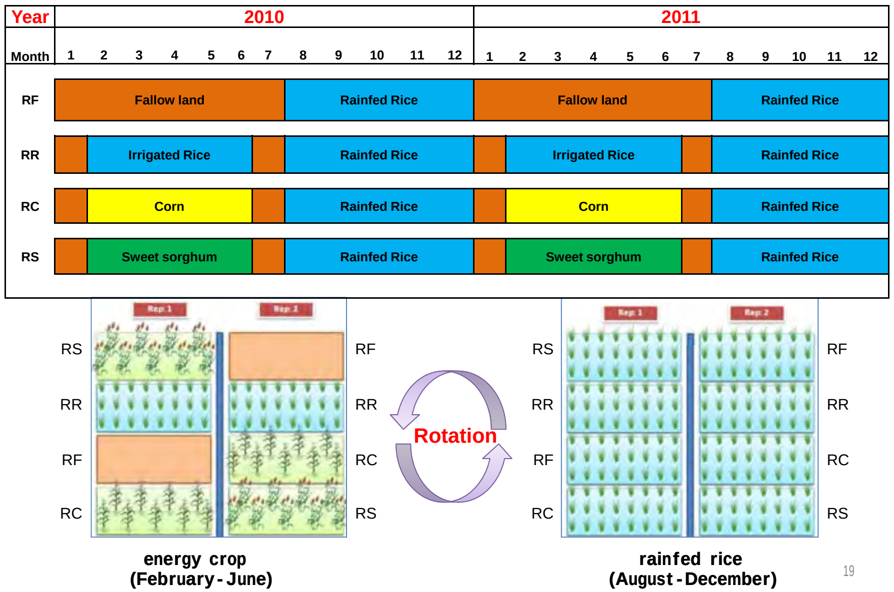
Description of Tasks

- Assessment of GHG emissions and soil carbon dynamics associated to rice cultivation and rotation with selected energy crops (corn and sorghum) during fallow period at KMUTT - Ratchaburi campus experimental site (Thailand)
- Continuous monitoring of trace gas emissions, soil carbon stock, biological and physical parameters associated to above-ground and below-ground biomass

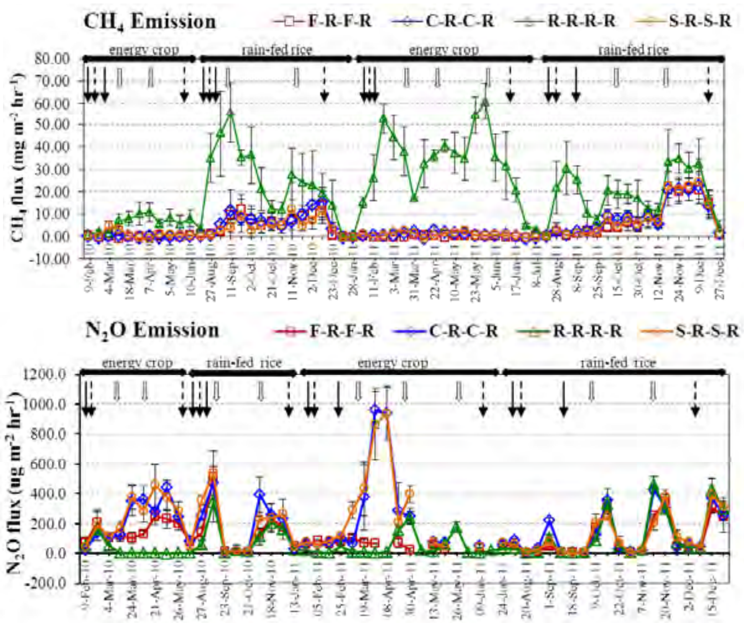
Deliverables

- long-term monitoring data on GHG emissions and soil carbon dynamics associated to rice cultivation and rotation with corn and sorghum.
- Comparative evaluation of specific crop rotation practices in terms of carbon cycle, economics, social benefits, potential barriers, etc.
- Identification of potentially sustainable rice-energy crop cultivation practices under well-defined conditions

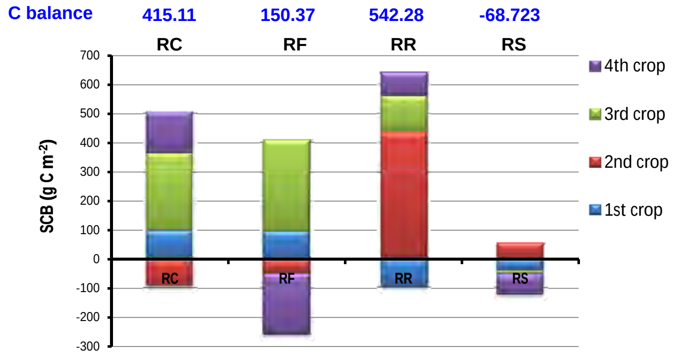
Activity II: Field experiments in Ratchaburi



Activity II: GHG emissions monitoring



Activity II: Soil carbon budget



Remark: RC is corn-rice-corn-rice cropping system. RF is fallow-rice-fallow-rice cropping system. RR is rice-rice-rice-rice cropping system. RS is sorghum-rice-sorghum-rice cropping system

- Manure incorporation for the1st and 2nd crop was the main contributor to carbon input into the soil.
- Crop residue incorporation for the 3rd and 4th crop was the main contributor to carbon input into the soil.
- In case of rotation with energy crop, corn provided the highest benefit in terms of soil carbon budget for the 4th crop (second year of cultivation).

Activity II: Comparative evaluation of specific crop rotation practices

Carbon cycle:

The cultivation system of corn rotation with rainfed rice enabled to achieve the highest soil carbon sequestration benefit (after 4th crop harvesting). This is due mainly to the organic matter added to the soil in the form of manure and crop residue re-incorporation.

Some socio-economic benefits:

Double cropping systems (rice-rice or rice with another crop) enable to enhance farmers' income as compared to single crop. Income to farmers for the cropping systems investigated in this research were estimated, as follows:

- For rice-rice cropping systems: 21,469-50,226 THB/ha/year
- For corn-rice rotation systems: 22,749-51,017 THB/ha/year
- For sweet sorghum-rice rotation systems: 18,029-58,581 THB/ha/year

Crop rotation systems not only contribute to provide more income to farmers but also job opportunity in the agricultural sector.

Activity III: Capacity assessment of GHG emissions and soil carbon stock from sustainable cultivation practices in SEA

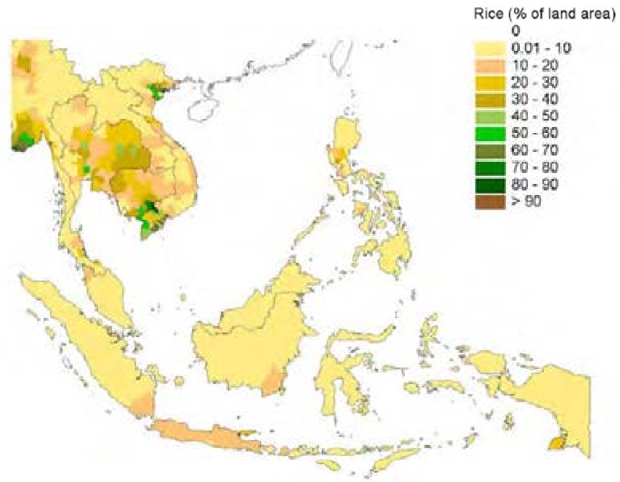
Description of Tasks

- Assessment of the capacity of C budget in terms of emissions and soil carbon stock of rice fields in SEA using ALU software
- Assessment of potential mitigation options based on different cultivation scenarios

Deliverables

- GIS based maps of GHG emissions and carbon stock from rice fields for selected cultivation practices in SEA
- Database of GHG emissions inventory using ALU software
- Assessment of C budget of the rice cultivation systems investigated under existing situation and rotation with energy crops

Activity III: Spatial distribution of paddy rice cultivation area in SEA (2002)



Reference: X. Xiao *et al. / Remote Sensing of Environment (2006)*

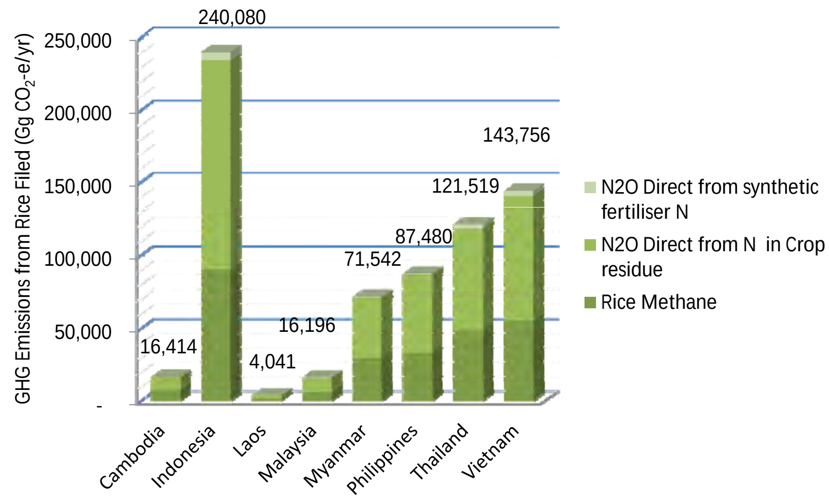
Activity III: Rice cultivation area vs. Agro-ecosystems in SEA

Country	Rice Cultivation Area in SEA (1,000 ha)			
	Irrigated rice[a]	Rainfed lowland rice	Upland rice	Flood prone
Cambodia	154	1,124	33	614
Indonesia	6,154	4,015	1,247	23
Laos	40	319	201	-
Malaysia	445	152	84	-
Myanmar	1,124	4,166	252	602
Philippines	2,334	1,304	120	-
Thailand	2,075	6,792	36	117
Vietnam	3,687	1,955	345	778
Total	16,015	19,827	2,318	2,134

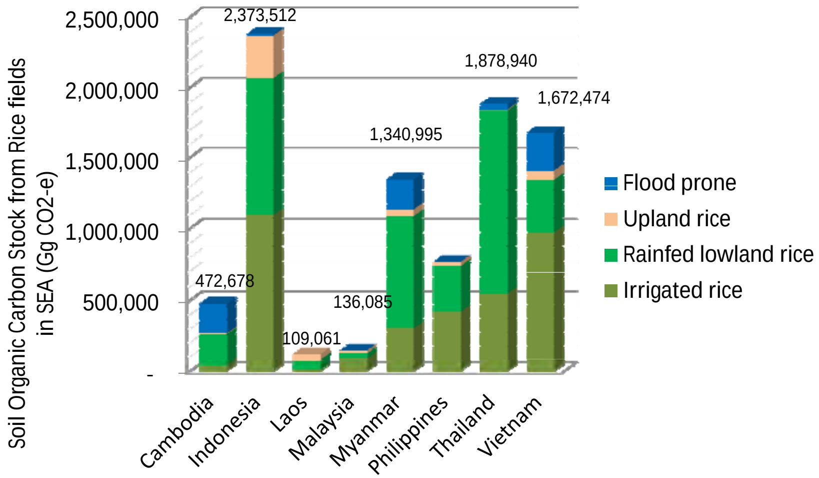
[a]Irrigated rice = 2.5 crops/yr

Reference: *IRRI Rice Facts, 2002*

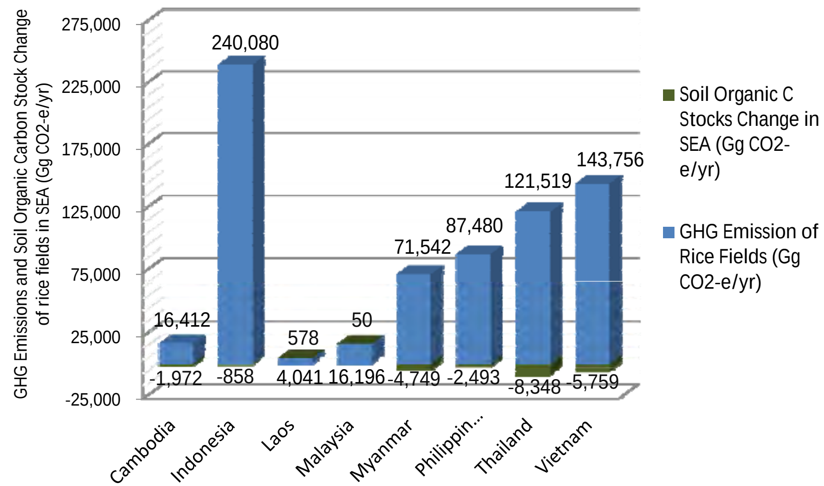
Activity III: Assessment of the GHG emissions of rice fields in SEA



Activity III: Assessment of the soil organic carbon stock of rice fields in SEA (Yr 2030)

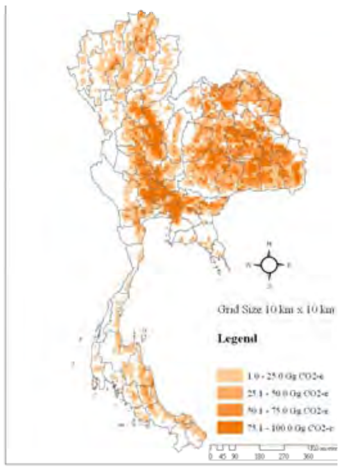


Activity III: Assessment of the carbon budget of rice fields in SEA

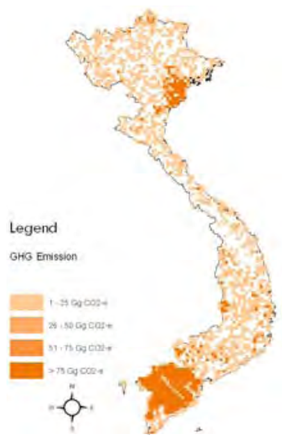


Activity III: GIS based maps of GHG emissions from rice fields: Case of Thailand and Vietnam

GHG Emission from Rice Fields

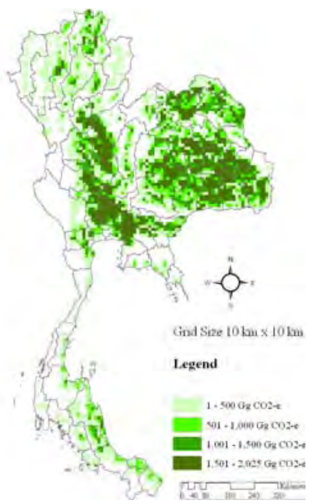


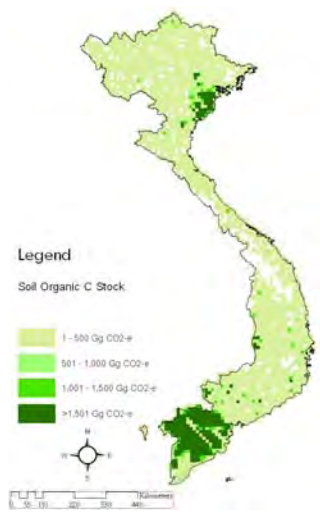
GHG Emission from Rice Field



Grid Size = 10 km x 10 km

Activity III: GIS based maps of carbon stock of rice fields: Case of Thailand and Vietnam

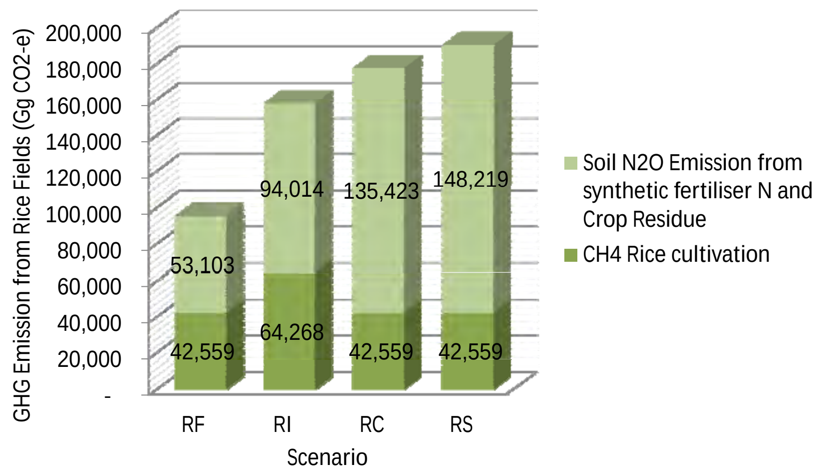




Activity III: Assessment of potential mitigation options based on different scenarios

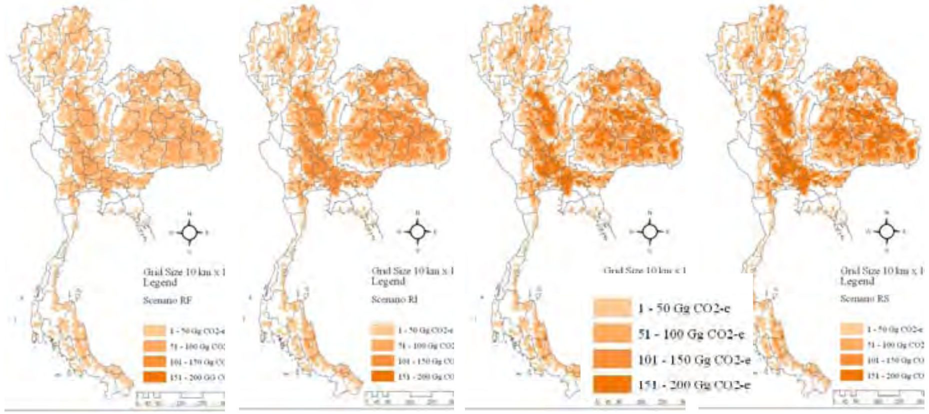
Month	1	2	3	4	5	6	7	8	9	10	11	12
RF	Fallow land							Rainfed Rice				
RI		Irrigated Rice						Rainfed Rice				
RC		Corn						Rainfed Rice				
RS		Sweet sorghum						Rainfed Rice				

Activity III: Assessment of potential mitigation options based on different scenarios - Thailand



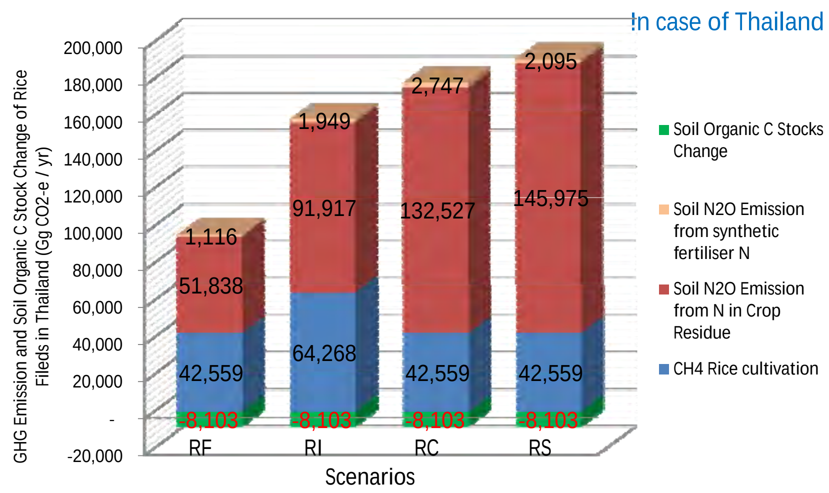
Activity III: Assessment of potential mitigation options based on different scenarios - Thailand

Assessment of total GHG emission mitigation options based on different scenarios



RF RI RC RS

Activity III: Assessment of potential mitigation options based on different scenarios - Thailand



Activity IV: Long-term soil carbon dynamics assessment of sustainable low carbon cultivation using process model

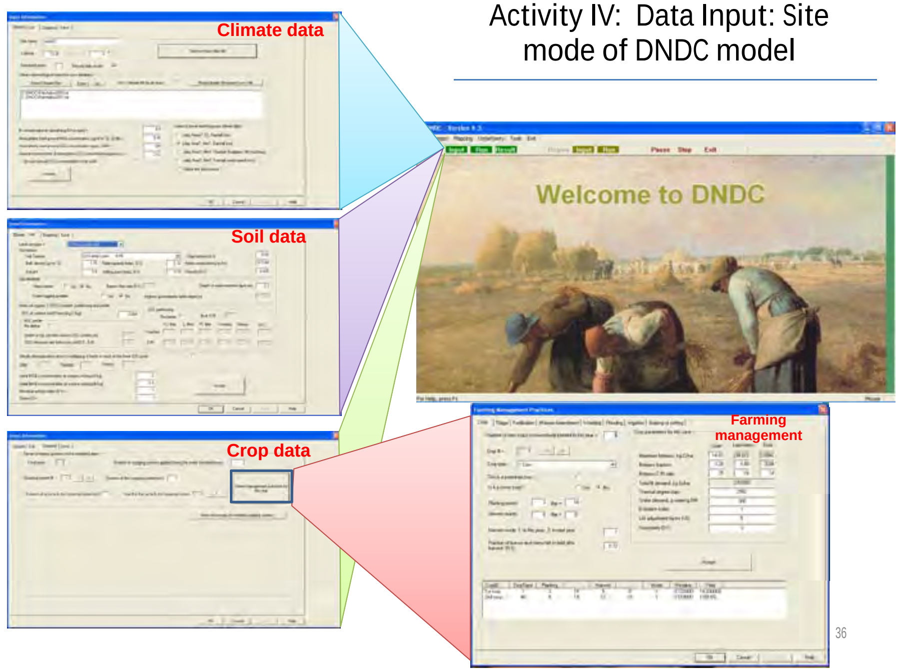
Description of Tasks

- Assessment of long-term soil carbon dynamics of sustainable low carbon cultivation using DNDC model
- Assessment of long-term soil carbon storage and sequestration of specific rice-energy crop systems based on monitoring and modeling data.
- Use of Relevant data generated from activity II as input to DNDC for analyzing the time-series change in carbon storage vs. the corresponding GHGs emissions.

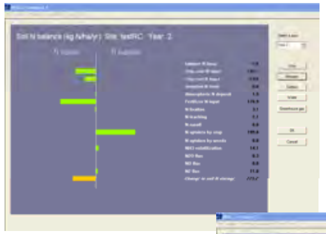
Deliverables

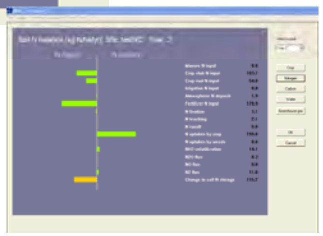
- Informative data on long-term soil carbon storage incl. rotation with selected energy crops and cultivation practices
- Comparative assessment of soil carbon sequestration for selected rice-energy crop rotation systems
- Assessment of appropriate cultivation practices as mitigation options for reduced carbon emissions in the agricultural sector

Activity IV: Data Input: Site mode of DNDC model



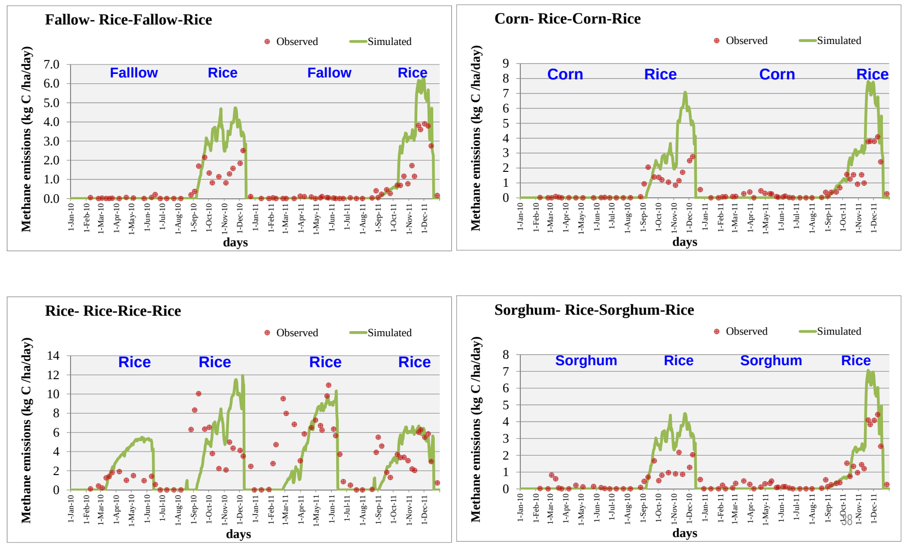
Activity IV: DNDC simulation results



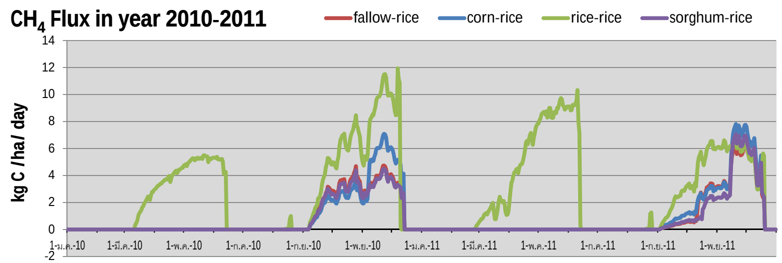


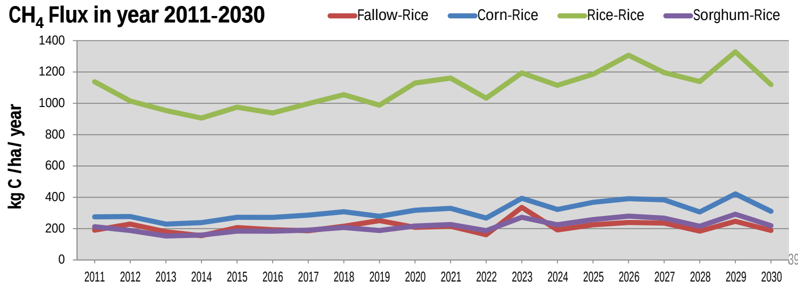
Example;
Corn-Rice

Activity IV: Comparison between observation and DNDC simulations of daily pattern of CH_4 emissions from crop rotation systems

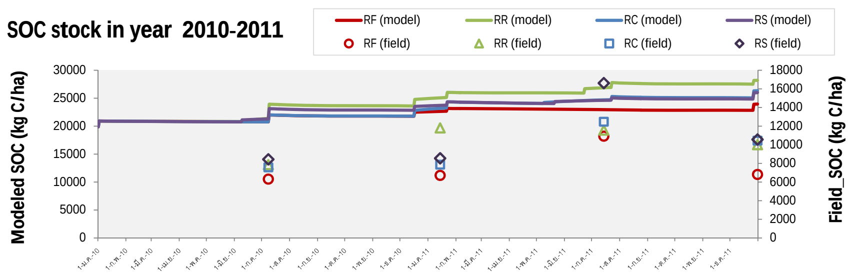


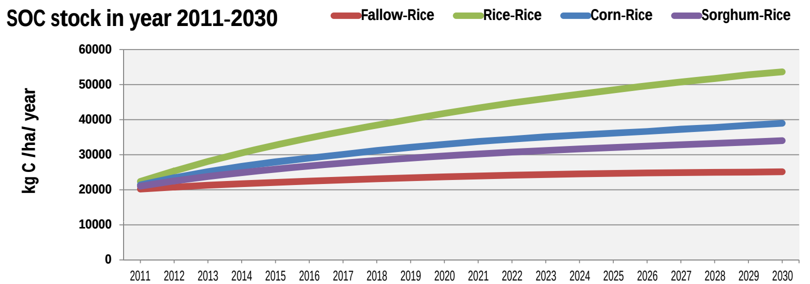
Activity IV: Long-term DNDC simulations for CH_4 emissions





Activity IV: DNDC validation; soil organic carbon stock





Training Workshop: Capacity Building on Estimation of GHG Emissions from Rice Fields-The Application of DNDC Model

- **Objective:**
  Providing participants with an improved understanding of carbon and nitrogen biogeochemistry in agro-ecosystem and enhanced knowledge of spatio-temporal dynamics of GHGs from rice fields
- **Participants:**
  Researchers involved in ARCP-APN project and JGSEE students

Activity V: Knowledge dissemination to scientists and policy-makers in SEA

Description of Tasks

– Capacity building workshop for knowledge transfer to scientists and policy-makers in SEA regarding the strategic approach to follow for sustainable rice cultivation i.e. reducing GHG emissions while increasing energy crop production.

Deliverables

– Capacity building of scientists on inventories of GHG emissions and soil organic carbon stock using ALU and DNDC.
– Capacity building of scientists and policy-makers on mitigation options in the agricultural sector for a low carbon society.

JGSEE The Joint Graduate School of Energy and Environment
CEE-PERDO Center for Energy Technology and Environment
APN

Capacity Building Workshop on: "Strategic rice cultivation with energy crop rotation in SEA A path toward climate change mitigation in the agricultural sector"

29-31 May 2013

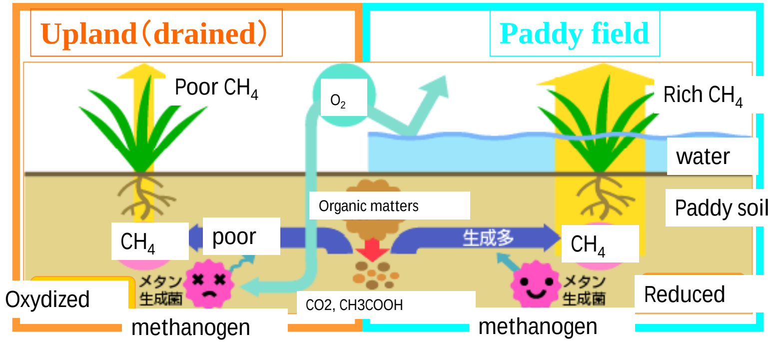
Pullman Bangkok King Power Hotel

Capacity Building Workshop on:
"Strategic rice cultivation with energy crop rotation in Southeast Asia – A path toward climate change mitigation in the agricultural sector"

Implications of rice cultivation practices on GHG emissions

Shigeto Sudo
National Institute for Agro-Environmental Sciences (NIAES)

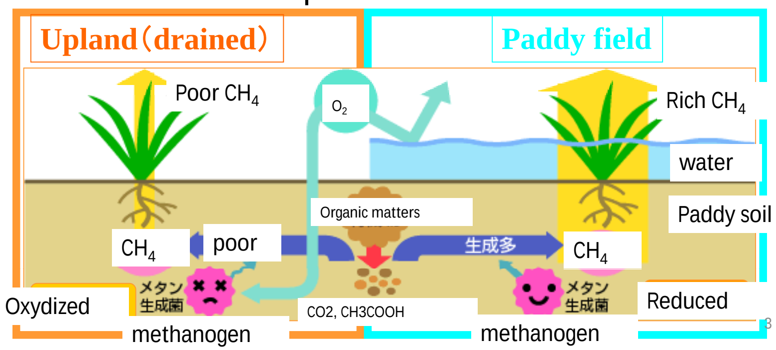
Mechanisms of CH4 emission from rice paddy field



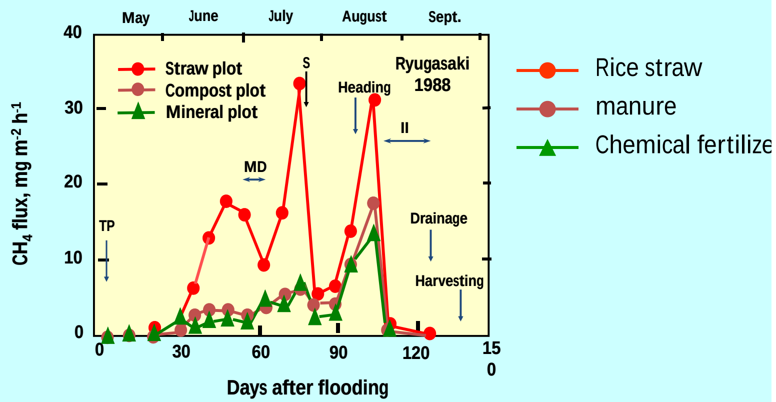
● CH_4 in paddy soil is emanated by the activities of anaerobic bacteria which is called methane producer through reduction of CO_2 or decomposition of acetic acid
● It is effective to control methane emission from rice paddy that period is prolonged on intermittent irrigation drainage, composted rice straw is incorporated as fertilizer instead of flesh one, or other.

Paddy rice CH_4 (methane) is produced….

- Anaerobic condition by methanogen bacteria >> <u>water management</u>
- With organic substances such as rice straw residues, organic manures, and other organic matters >> OM management
- Under suitable soil temperature >> uncontrollable!!



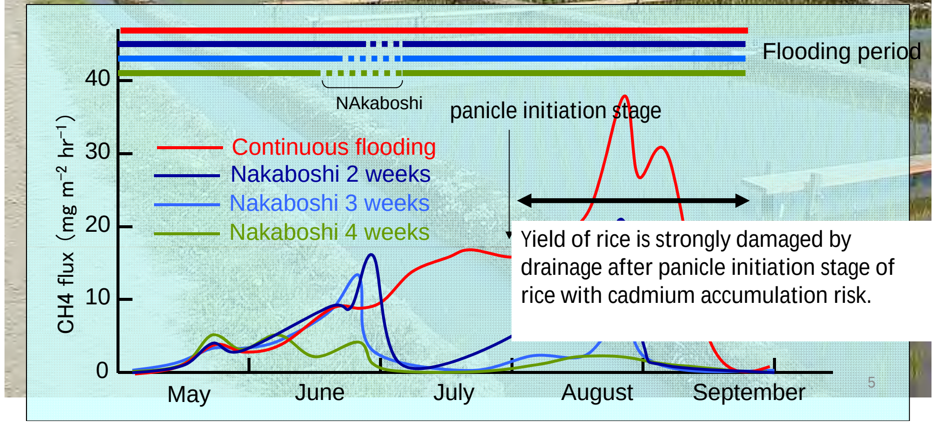
Organic Matter application and CH4 emission in rice paddy



●Manure application alternate with rice straw incorporation reduces CH4.

Reduction of CH_4 emission by prolonged Nakaboshi (mid-season-drainage) period; Fukushima Prefectural Agricultural Center in 2004.

●CH4 emission in paddy field is able to reduce prolonged 'Nakaboshi' treatments.



Yield of rice is strongly damaged by drainage after panicle initiation stage of rice with cadmium accumulation risk.

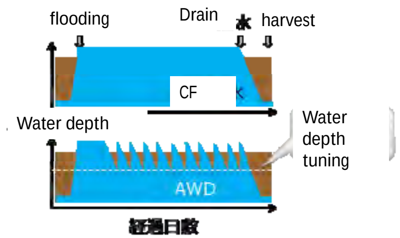
Alternate Wet and Dry (AWD)

Results of water management studies in Tamil Nadu,India.

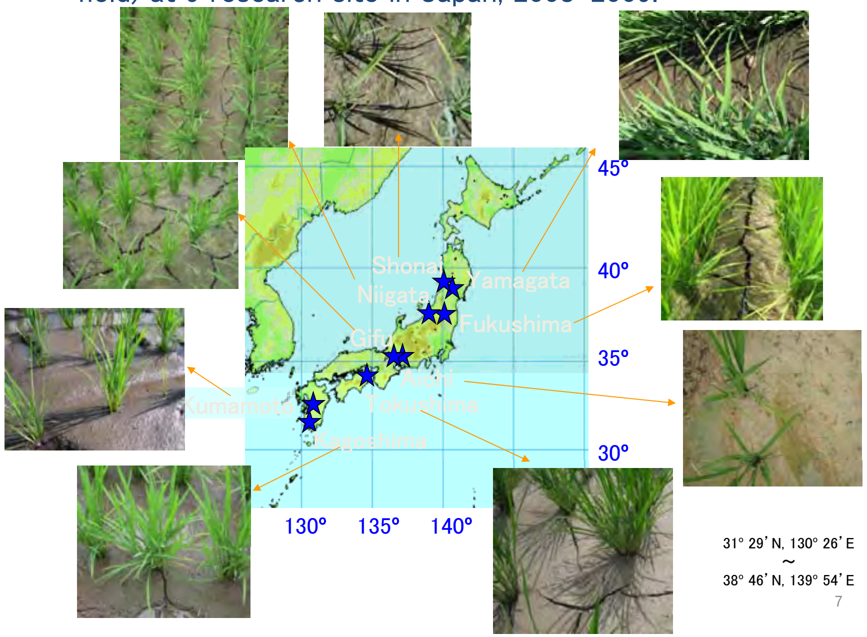
Description	Conventional		AWDI		Rotational water	
	Rabi[a]	Kharif[b]	Rabi	Kharif	95	Kharif 95/96
Total water used (cm)	117.4	80.2	96.8	77.0	107.8	76.3
Water use efficiency (kg/m³)	0.45	0.58	0.54	0.67	0.49	0.68
Yield (t/ha)	5.32	4.63	5.21	5.17	5.24	5.22
Percentage of water saved over	-	-	17.2	4.5	8.2	5.6

Wim van der Hoek et al,., Report of International Water Management Institute, Report 47,

AWD has CH4 reduction potential with average of 30% by frequent drying in paddy.



Photos of Nakaboshi (mid- season- drainage in rice paddy field) at 9 research site in Japan, 2008-2009.



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38° 46' N, 139° 54' E

Overview of the Study

- Verification of reduction effect by prolonged Nakaboshi (mid-season-drainage) period.
- Methane flux observation once per week.
- 3 treatments, 3 replications per site.

Points:
1. How much amount of CH4 is reduced by modified water managemet compared with BAU method.
1. Can we go water management uniformly all paddy fields in Japan？
2. How can we change water management policy if reduction result are different？

BAU:Business As Usual
= conventional water management at each site guided by the prefecture government.

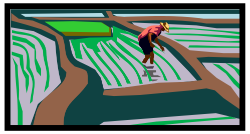
BAU is different in each prefecture!

BAU: Business As Usual = conventional water management at each site guided by the prefecture government.

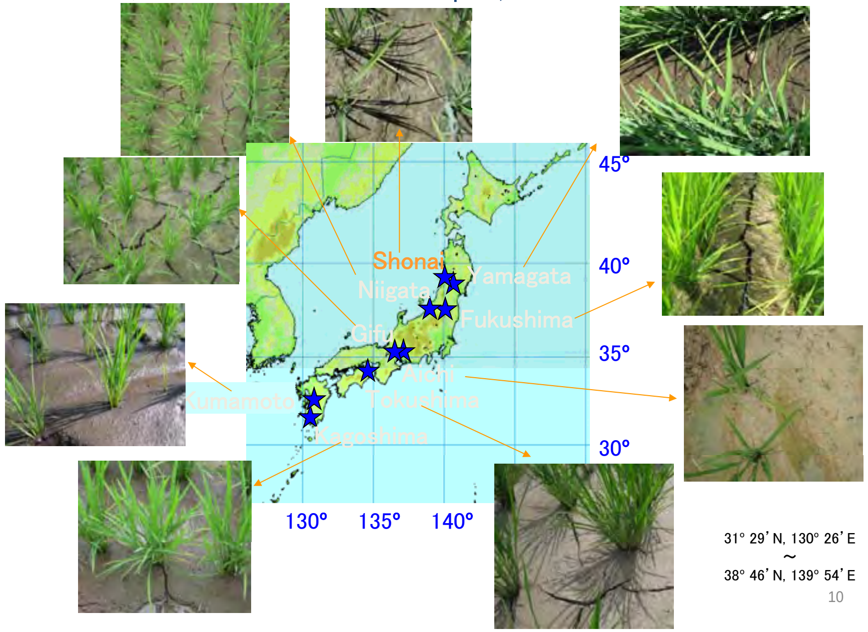
- Recommended rice variety is different in each prefecture.
  - Each rice variety is original brand of each prefecture which has a fierce competition with others in yield, taste, etc.
    - Niigata – Koshihikari
    - Yamagata – Haenuki
    - Gifu – Hatsushimo
    - Kumamoto – Morinokumasan
    - Kagoshima – Hinohikari

    etc.

- Each variety has each suitable cultivation method of fertilization, water management, soil type, cultivation period, harvesting season etc.
  - It is impossible to unify cultivation method beyond prefecture border.
- It is necessary to find suitable cultivation method one by one to elucidate win-win solution to obtain the best harvest yield and taste with minimum methane emission from paddy field.



Photos of Nakaboshi (mid– season– drainage in rice paddy field) at 9 research site in Japan, 2008–2009.



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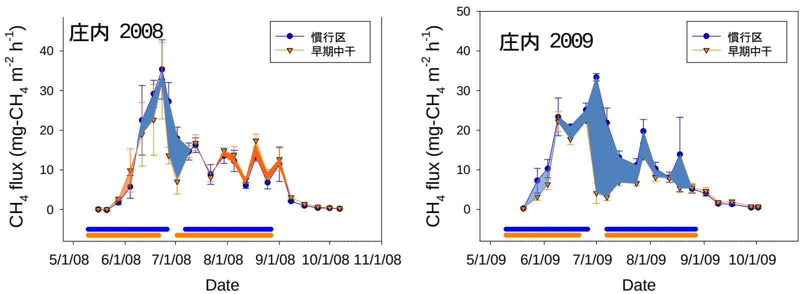
38° 46' N, 139° 54' E

CH_4 emission in paddy field (Shonai)

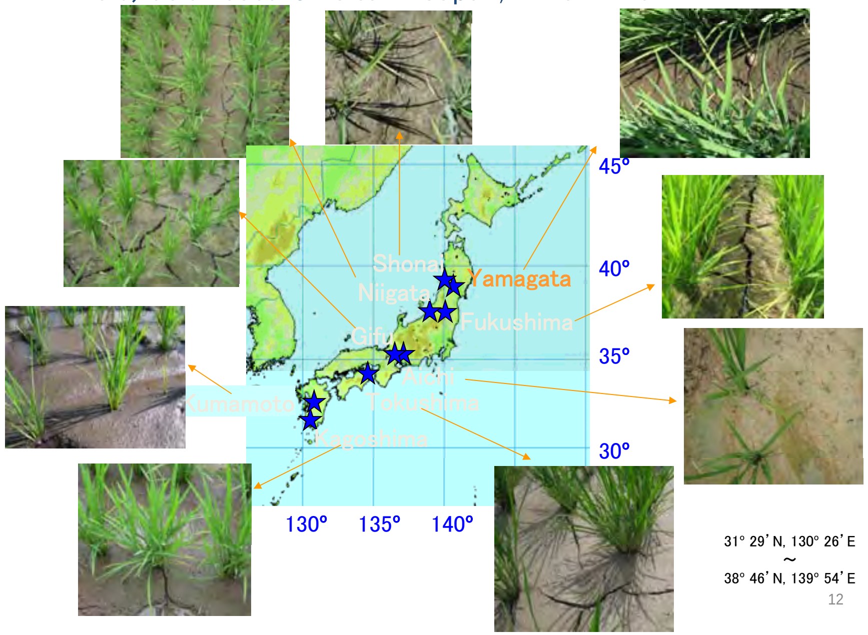
1 week ahead Nakaboshi treatment **5 days prolonged Nakaboshi treatment**



		2008			2009	
Total CH_4 flux (BAU)	7d	37.0		10d	38.0	
($g\text{–}CH_4/m^{-2}$) (1 week ahead)	10d	34.8	– 6 %	15d	24.1	– 37 %
Yield (BAU)		614				
(Kg/10a) (1 week ahead) (変更 2)		603	– 2 %			
放出パターン		前半				

** $p < 0.01$

Photos of Nakaboshi (mid– season– drainage in rice paddy field) at 9 research site in Japan, 2008–2009.



31° 29' N, 130° 26' E
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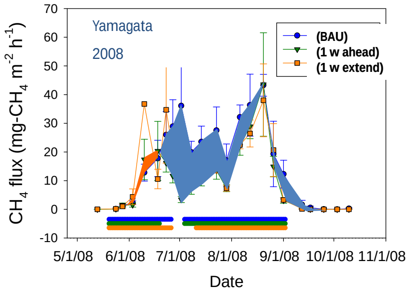
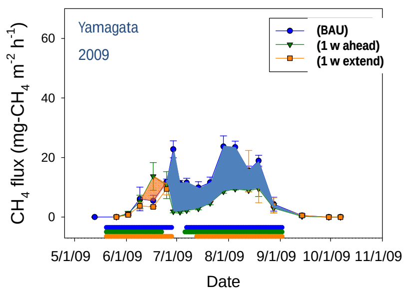
38° 46' N, 139° 54' E

CH4 emission in paddy field (Yamagata)

Same treatments in 2008 and 2009

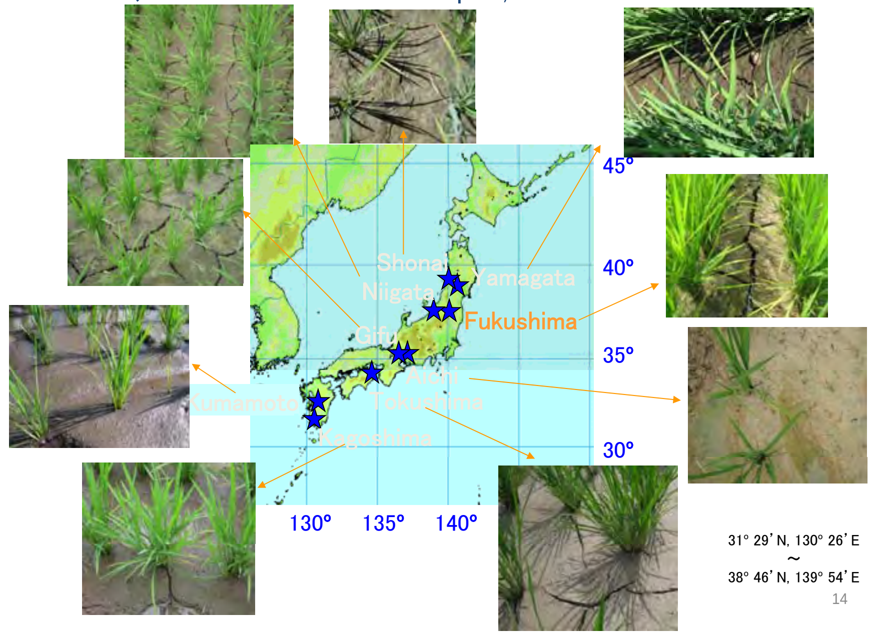




		2008		2009	
CH_4 (g-CH_4/m^{-2})	(BAU)	57.0		28.7	
	(1 week ahead)	36.1	− 37 %	14.8	− 48 %
	(1 week extend)	48.2	− 16 %	18.0	− 37 %
Yield (Kg/10a)	(BAU)	667			
	(1 week ahead)	643	− 4 %		
Haenuki	(1 week extend)	673	+ 1 %		

BAU: 1 week Nakaboshi, while other 2 are 2 weeks (ahead and extend)

Photos of Nakaboshi (mid– season– drainage in rice paddy field) at 9 research site in Japan, 2008–2009.



31° 29' N, 130° 26' E
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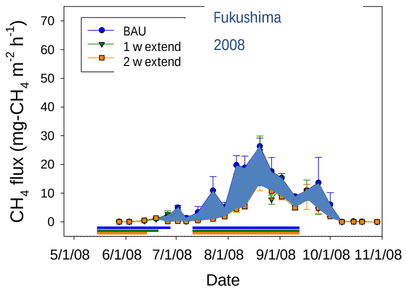
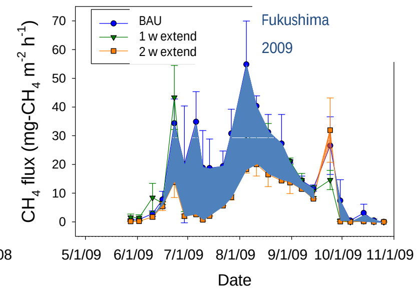
38° 46' N, 139° 54' E

CH_4 emission in paddy field (Fukushima)

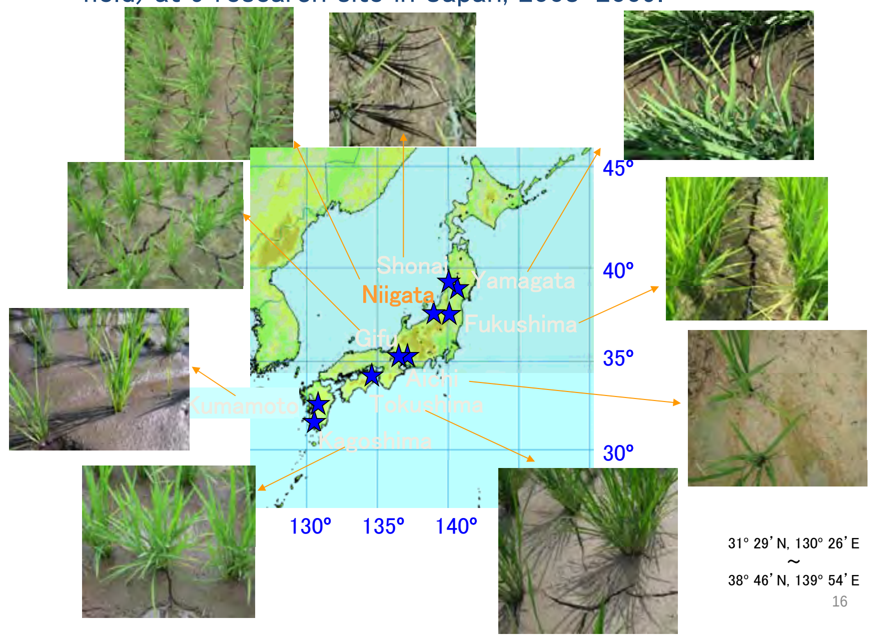




		2008		2009	
CH_4 flux (g-CH_4/m^{-2})	(BAU)	28.3		68.4	
	(1 w extend)	18.6	− 34 %	45.2	− 34 %
	(2 w extend)	11.8	− 58 %**	35.9	− 52 %
Rice yield (Kg/10a)	(BAU)	701			
	(1 w extend)	662	− 6 %		
	(2 w extend)	587	− 16 %		

Koshihikari

Photos of Nakaboshi (mid– season– drainage in rice paddy field) at 9 research site in Japan, 2008–2009.



31° 29' N, 130° 26' E
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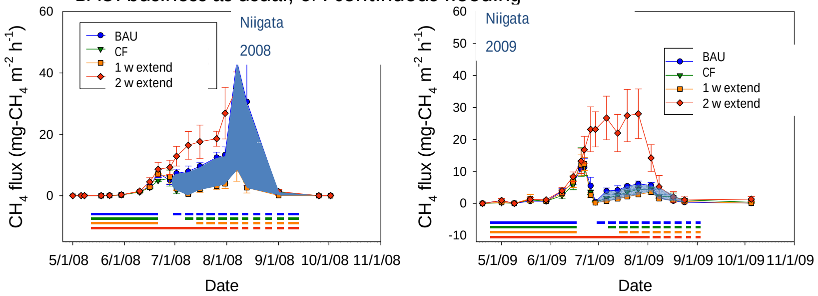
38° 46' N, 139° 54' E

CH_4 emission in paddy field (Niigata)

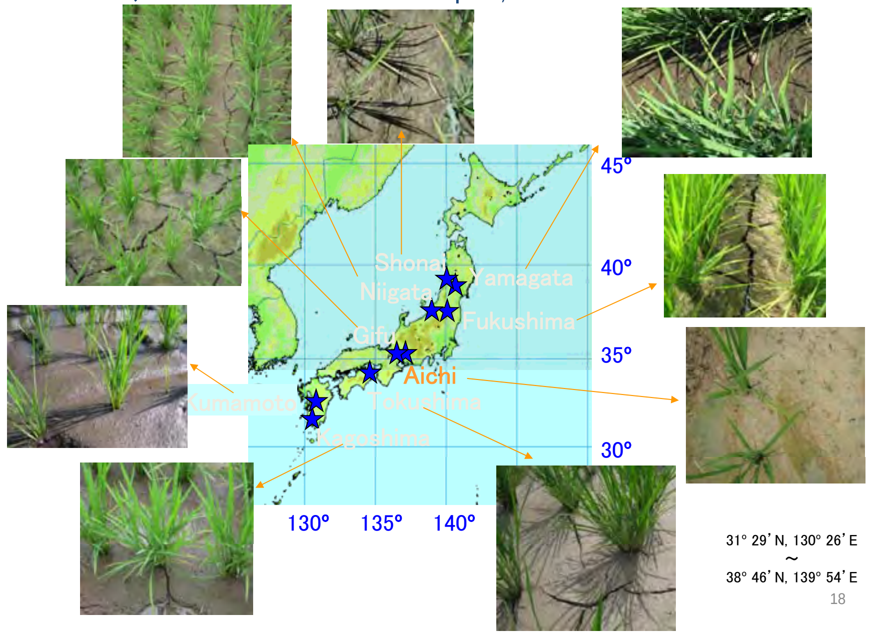
BAU: business as usual; CF: continuous flooding



		2008		2009	
CH4 flux (g−CH_4/m^{-2})	(BAU)	24.9		9.2	
	(1 w extend)	12.4	− 50 %	8.2	−
	(2 w extend)	6.9	− 72 %	6.9	11 %
	(CF)	30.6		31.8	−
Rice yield (Kg/10a)	(BAU)	621			25 %
	(1 w extend)	597	− 4 %		
	(2 w extend)	609	− 2 %		
	(CF)				

Koshihikari

Photos of Nakaboshi (mid− season− drainage in rice paddy field) at 9 research site in Japan, 2008−2009.



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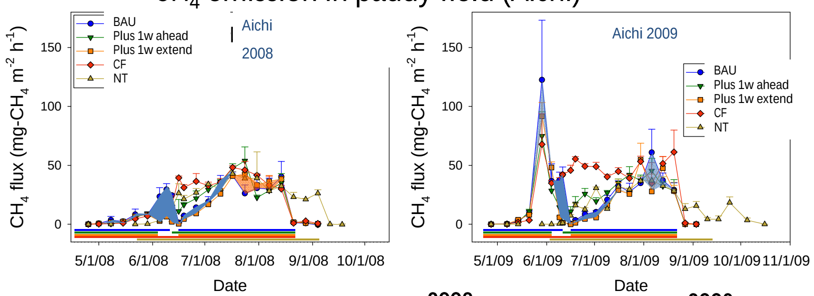
38° 46' N, 139° 54' E

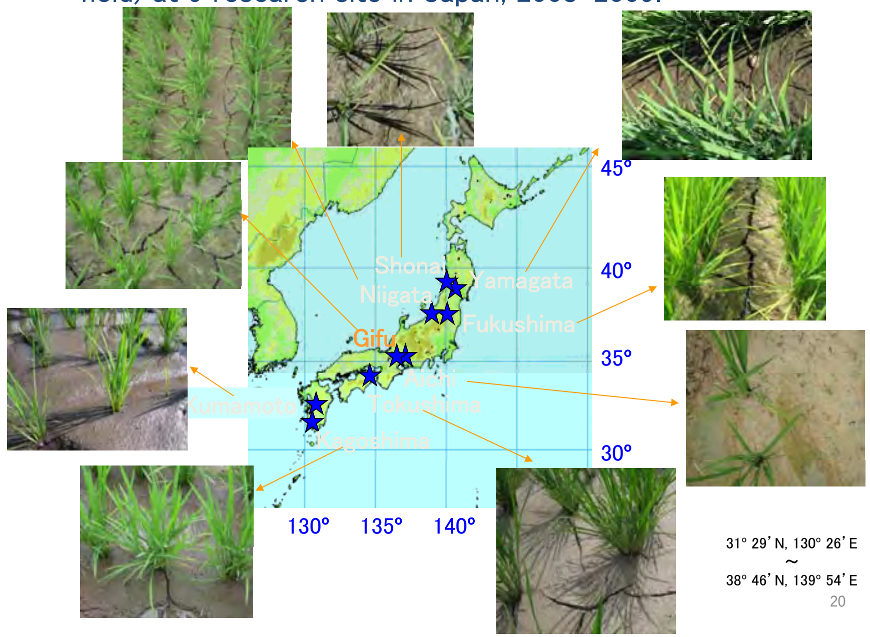
CH_4 emission in paddy field (Aichi)



		2008		2009	
CH4 flux (g−CH_4/m^{-2})	(BAU)	54.0		78.6	
	(plus1w ahead)	55.2	+ 2 %	71.7	− 9 %
	(plus 1w extend)	45.1	− 17 %	64.7	−
	(CF)	66.2		104.4	18 %
	(NT)	64.8			
Rice yield (Kg/10a)	(BAU)	581			
	(plus 1w ahead)	497	− 10 %		
Koshihikari	(plus 1w extend)	520	− 6 %		

BAU: business as usual, CF: continuous flooding, NT: non tillage

Photos of Nakaboshi (mid− season− drainage in rice paddy field) at 9 research site in Japan, 2008−2009.



31° 29' N, 130° 26' E
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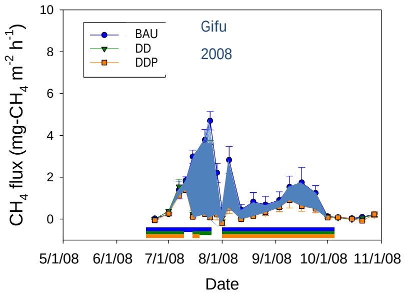
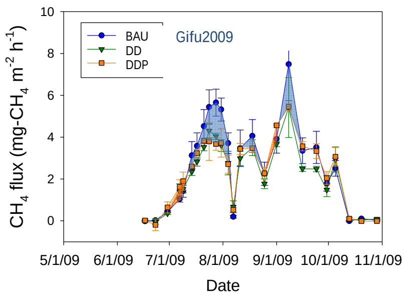
38° 46' N, 139° 54' E

CH_4 emission in paddy field (Gifu)

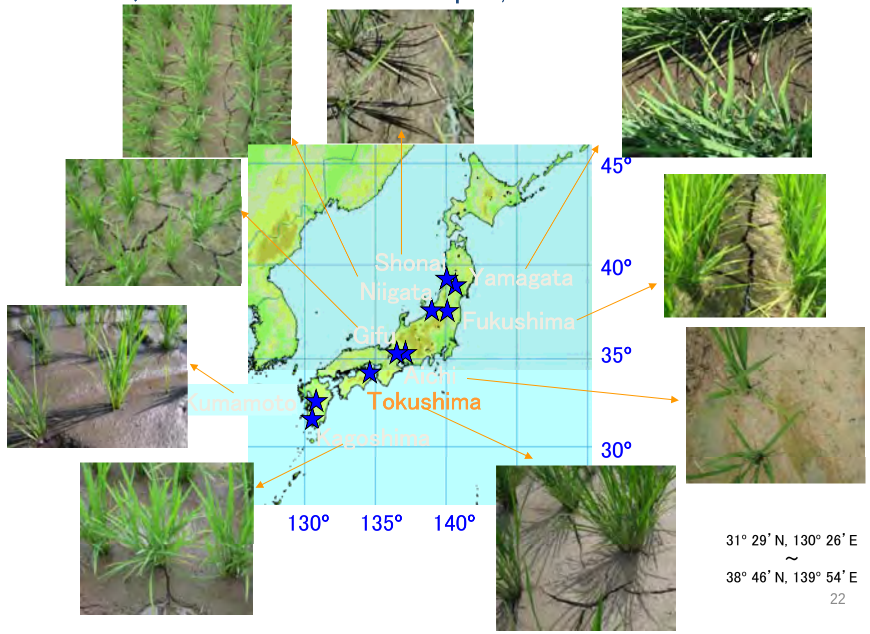
BAU: business as usual, DD: double drainage,
DDP: double drainage plus 1week





		2008		2009	
CH4 flux	(BAU)	3.9		8.4	
(g-CH_4/m^{-2})	(double drainage)	2.4	– 40 %	6.8	–
	(double drainage plus 1w)	1.1	– 73 %**	7.6	19 %
					– 9 %
Rice yield	(BAU)	499			
(Kg/10a)	(double drainage)	429	– 14 %		
	(double drainage plus 1w)	407	– 18 %		

Photos of Nakaboshi (mid– season– drainage in rice paddy field) at 9 research site in Japan, 2008–2009.



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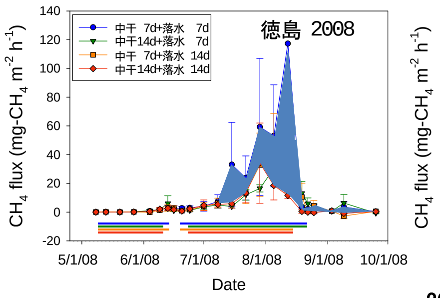
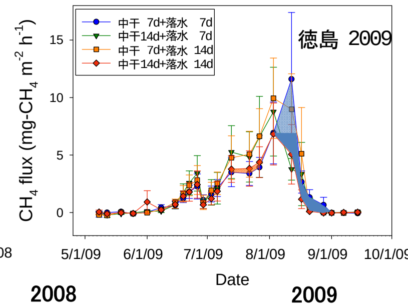
38° 46' N, 139° 54' E

Tokushima

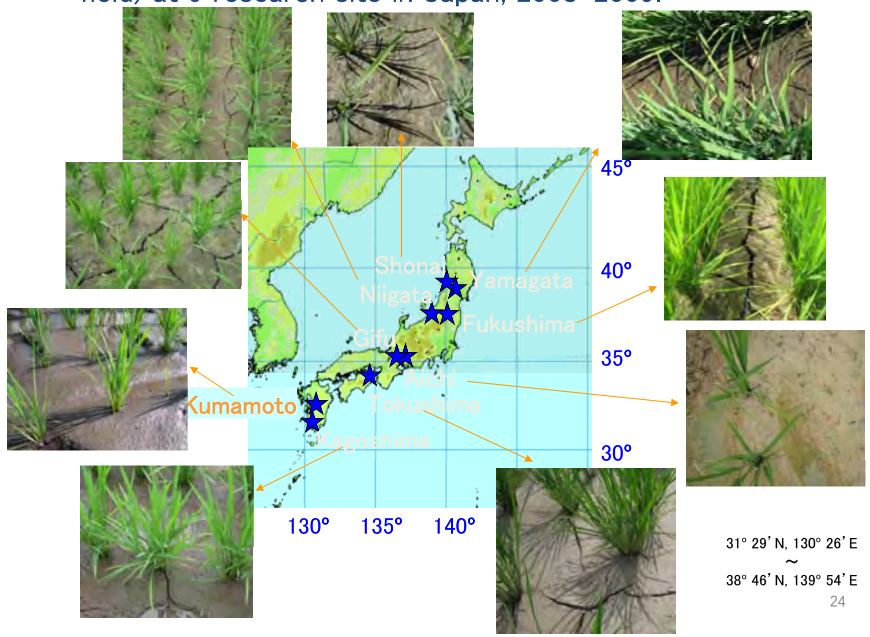
In 2008, one replication include the treatment of green manure…





		2008		2009	
Methane emission	(Conventional)	53.5		6.7	
(g-CH_4/m^{-2})	(MD14d)	23.3	– 56 %	6.7	+ 18 %
	(MD7d)	26.8	– 50 %	7.9	– 0.4 %
	(MD14d+ ED7d	16.7	– 69 %	5.4	– 19 %
Yield	(Conventional)	700			
(Kg/10a)	(MD14d)	663	– 5 %		
	(MD7d)				
	(MD14d+ED7d))	666	– 5 %		

Photos of Nakaboshi (mid– season– drainage in rice paddy field) at 9 research site in Japan, 2008–2009.



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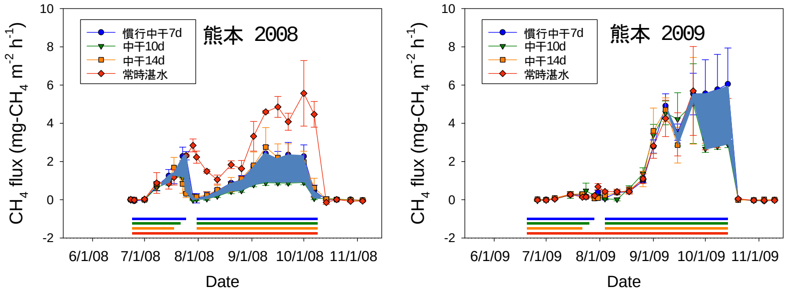
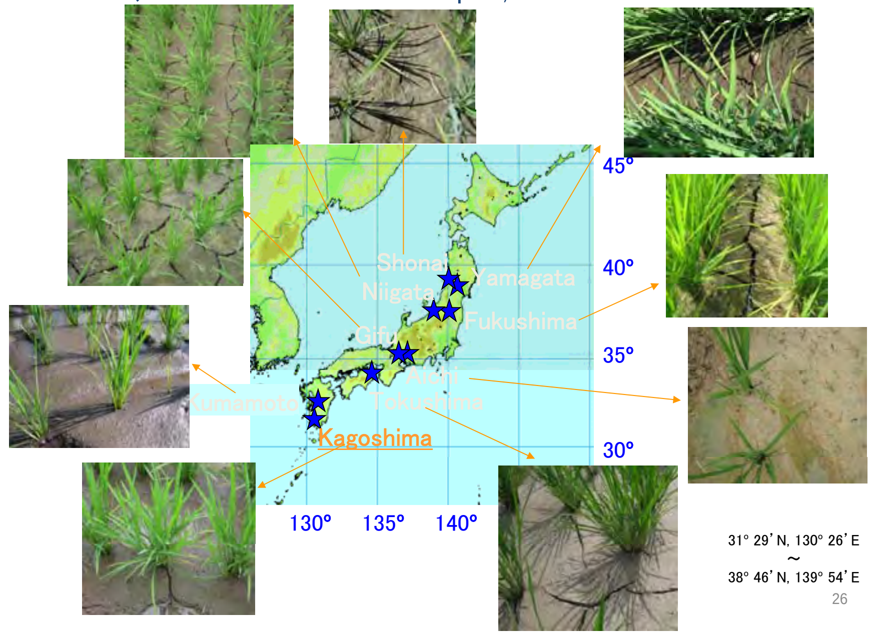
38° 46' N, 139° 54' E

Kumamoto



		2008		2009	
期間メタン放出	(Conventional)	3.1		6.1	
(g−CH_4/m^{-2})	(MD10d)	1.4	− 55 %**	4.9	−
	(MD14d)	2.9	− 6 %	5.0	21 %
	(CF)	6.5		5.2	−
Yield	(Conventional)	715			19 %
(Kg/10a)	(MD10d)	649	− 9 %		
	(MD14d)		− 2 %		
	(CF)				

Photos of Nakaboshi (mid− season− drainage in rice paddy field) at 9 research site in Japan, 2008−2009.



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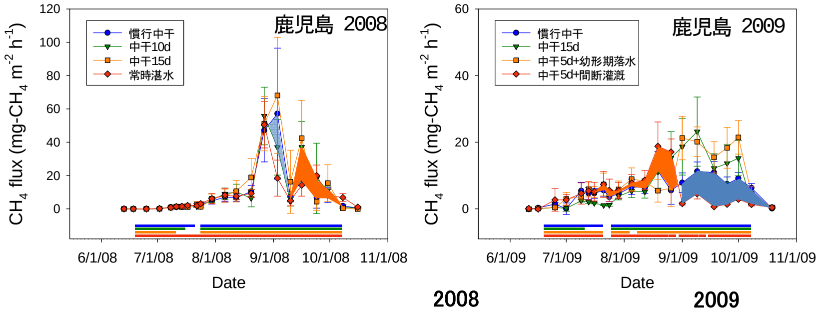
38° 46' N, 139° 54' E

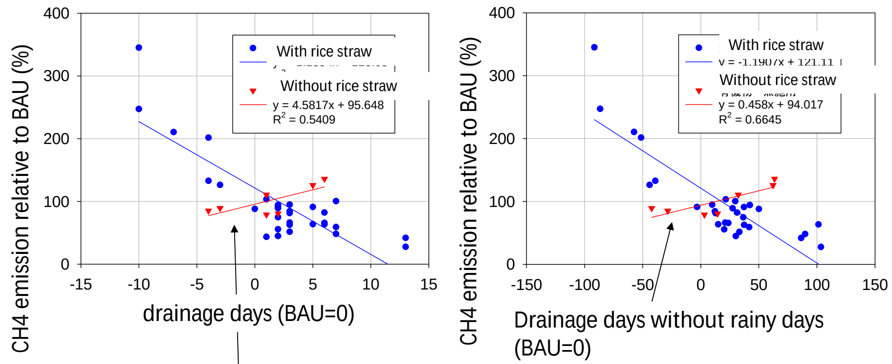
Kagoshima



		2008		2009	
Methane	(Conventional5d)	30.6		18.1	
(g−CH_4/m^{-2})	(MD10d)	33.8	+ 10 %	22.8	+
	(MD15d)	41.4	+ 35 %	26.7	25 %
	(CF)	27.0		15.5	+
Yield	(Conventional)	415			47 %
(Kg/10a)	(MD10d)	453			−
	(MD15d)	443			15 %
	(CF)				

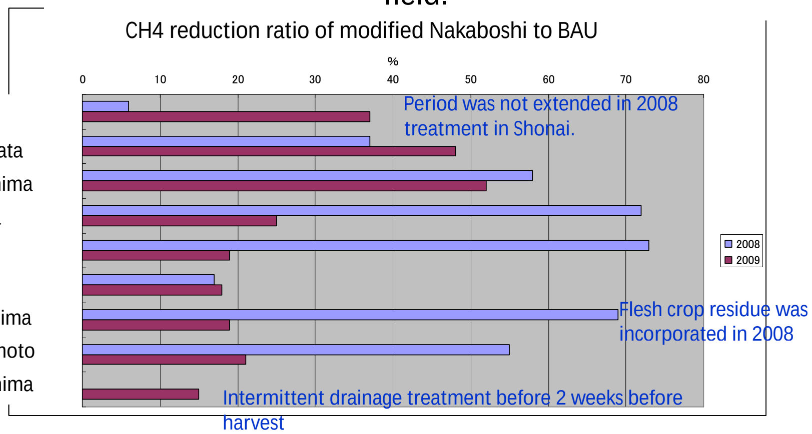
後半 後半

Change of methane emission from BAU by drainage (Nakaboshi) length
(horizontal: BAU is 0, vertical: BAU is 100)



No linear relationship was revealed in the plots in which rice straw residue were not incorporated.

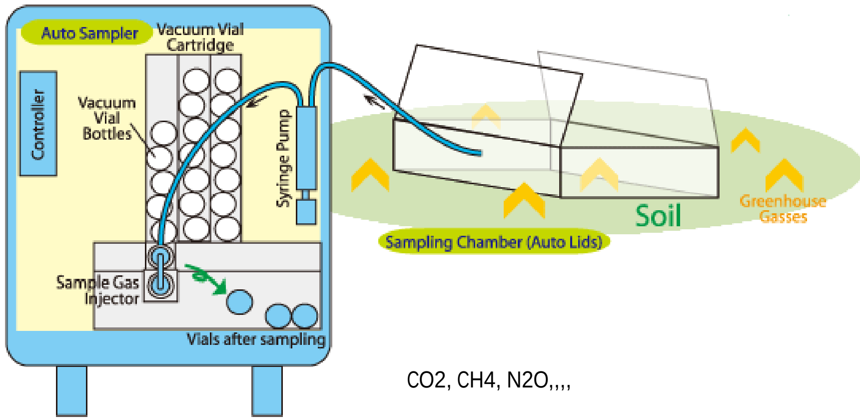
Summary of positive results to reduce CH_4 in paddy field.



Average reduction recovery in 2008 : 48.4%, in 2009年 : 31.5%

High reduction potentials were observed although differences of experimental sites, inter-annual variations were shown.

Automated Gas Sampling Sytem (AGSS) produced by Green Blue Company, Japan



CO2, CH4, N2O,,,,

1 unit of AGSS can be installed at Ratchaburi research site.

The samples collected by AGSS sampler are ready to be analyzed by the 3 (three) greenhouse gases auto-analyzer developed by National Institute of Agro-Environmental Sciences, Japan
Patent application : 2005-096918
Registered : September 2009

Conclusion

- We conducted tests to verify the improvements of water management in order to reduce CH_4 emission from rice paddy at 9 experimental sites in 8 prefectures.
- The longer length of Nakaboshi (mid-season-drainage) period was prolonged, the lesser amounts of CH_4 emitted even after when Nakaboshi period lasted, as a whole.
- In some cases, for example in Kagoshima, exceptional phenomena of that significant high emission were observed at a later stage of cultivation season (around the end of August). Adjusting of Nakaboshi periods was not effective in such cases.
- In most of cases, emission of N_2O was not increased during prolonged Nakaboshi period.

Thank you for your attention!

Sustainable rice cultivation:
A path toward climate change
mitigation and adaptation

Chitnucha Buddhaboon

Rice Department, MOAC, Thailand

Capacity Building Workshop on: "Strategic rice cultivation with energy crop rotation in Southeast Asia
– A path toward climate change mitigation in the agricultural sector"
29-31 May 2013, Bangkok, Thailand

Contents

Introduction

What does sustainable mean?

Sustainability- is a characteristic of a process or state that can be maintained at a certain level indefinitely. The term, in its environmental usage, refers to the potential longevity of vital human ecological support systems, such as the planet's climatic system, systems of agriculture, industry, forestry, fisheries, and the systems on which they depend.

Source(s):

http://en.wikipedia.org/wiki/Sustainabil…

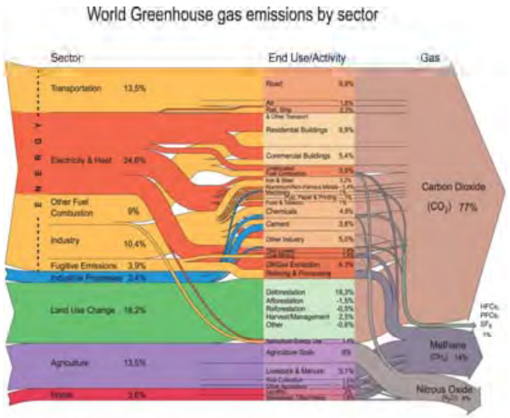
Introduction

Therefore, Sustainable Rice Cultivation means………

Rice cultivation system can be maintained to produce grain yield for world population consumption indefinitely. Sustainable Rice Cultivation also refers to sustainable of social (farmer to consumer), sustainable of environment (clinate, soil, water), sustainable of economic (equitability of among beneficially).

Introduction

How does rice cultivation implicate to the climate change?



All data is for 2000. All calculations are based on CO_2 equivalents, using 100-year global warming potentials from the IPCC (1996), based on a total global estimate of 41 755 $MtCO_2$ equivalent. Land use change includes both emissions and absorptions. Dotted lines represent flows of less than 0.1% percent of total GHG emissions.

Source: World Resources Institute, Climate Analysis Indicator Tool (CAIT), Navigating the Numbers: Greenhouse Gas Data and International Climate Policy, December 2005; Intergovernmental Panel on Climate Change, 1996 (data for 2000).

Sector	Emission %
Energy	61.4
Industrial	3.4
Agriculture	13.4
Land use change	18.2
West	3.6
Total emission 41,755 MtCO2e	

Agriculture	Emission %
Agricultural soil	44.4
Livestock &manure	37.8
Rice cultivation	11.1
Other agriculture	6.7
Total emission 5,595 MtCO2e	

Introduction

Thailand GHGs emission inventory by sector

Sector	Emission %
Energy	69.57
Industrial	7.15
Agriculture	22.64
Forestry	-3.44
West	4.07

Agriculture	Emission %
Rice cultivation	57.50
Agricultural soil	15.00
Field burning	1.90
Livestock & Manure	25.60
Total emission 51.9 MtCO2e	

SNC = Second National Communication, (2000) with total emission of 229.08 Tg

Introduction

Rice area of selected country (2011)

Country	Rice Area (ha)	% of world rice area
Brunei Darussalam	1,837	0.00
Cambodia	2,926,000	1.78
China	**30,311,300**	**18.47**
India	**44,100,000**	**26.87**
Indonesia	13,201300	8.04
Japan	1,576,000	0.96
Lao PDR	817,250	0.50
Malaysia	683,677	0.42
Mayan Mar	8,038,000	4.90
Philippines	4,536,640	2.76
Thailand	**11,630,300**	**7.09**
Vietnam	7,651,900	4.66
World Total	**164,124,977**	**100.00**

FAOSTAT | © FAO Statistics Division 2013 | 27 May 2013

Introduction

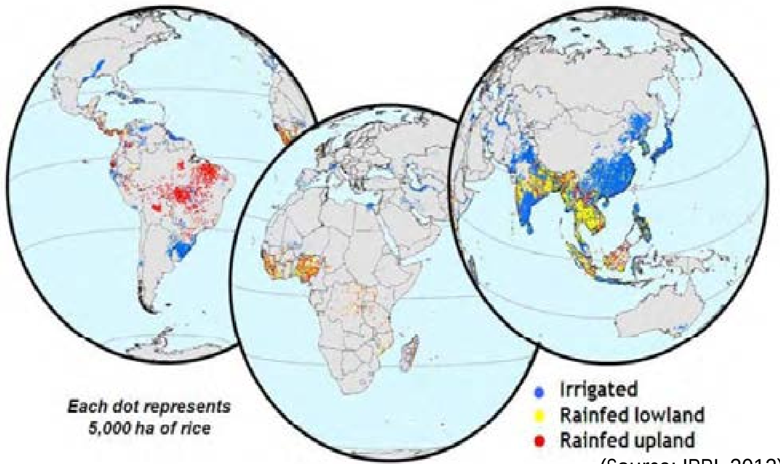
Top ten of rice producer/consumer in the world

Rank	Producer (2009)	Consumer (2007)	
		Country	Kg/capita
1	China	Brunei Darussalam	245
2	India	Vietnam	166
3	Indonesia	Loa PDR	163
4	Bangladesh	Bangladesh	160
5	Vietnam	Myanmar	157
6	Myanmar	Cambodia	152
7	Thailand	Philippines	129
8	Philippines	Indonesia	125
9	Brazil	Thailand	103
10	Japan	Madagascar	102

(Source: IRRI, 2012)

Introduction

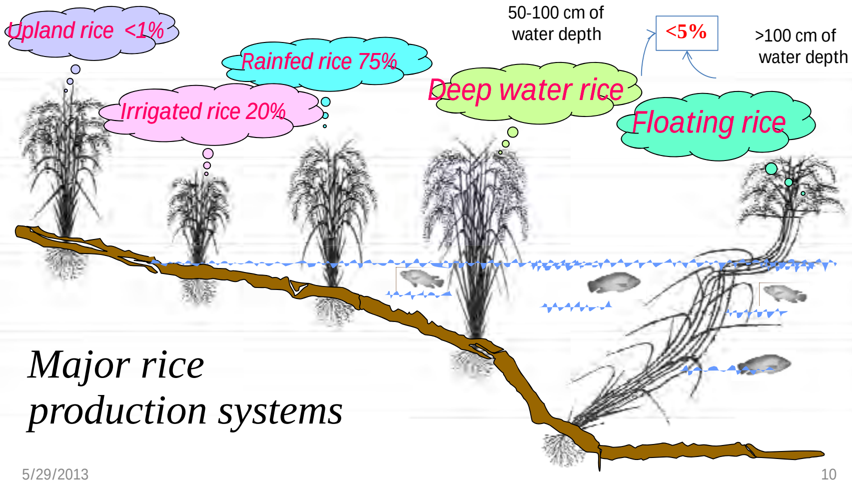
World rice production area



(Source: IRRI, 2012)

Introduction

Rice cultivation system in Thailand



Introduction

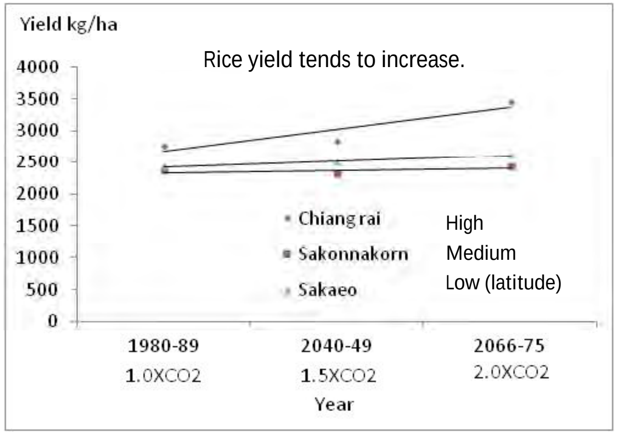
Introduction

Introduction

Effect of CO2 concentration on rice

-Base on the current technology
- Weather data, generated by CCAM model
-KDML105 Var.

Rice yield tends to increase.

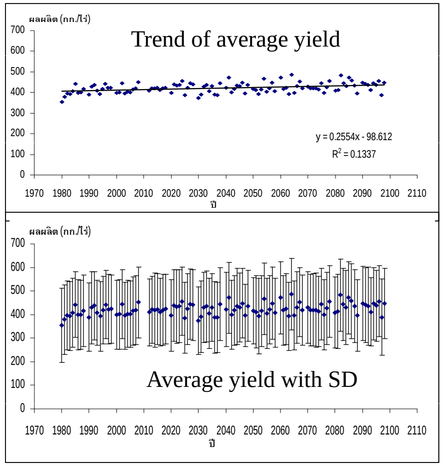


Introduction

Effect of climate change on rianfed rice production 1980 - 2099

-Base on current technology
- Weather data, A2 scenario
-KDML105 Var.

Rice yield increase 11% by 2099



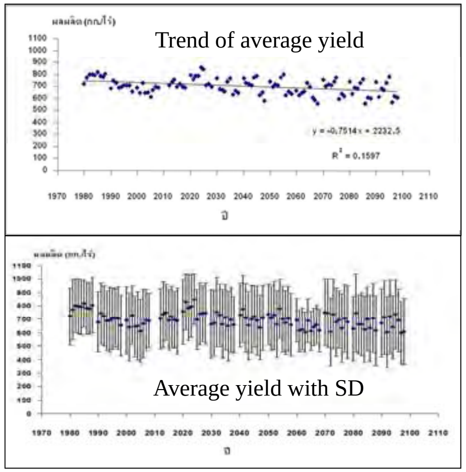
Introduction

Introduction

Effect of climate change on rainfed rice production 1980 - 2099

-Base on the current technology
-Weather data; A2 scenario
-SPR60 Var.

Rice yield tends to reduce 15% by 2099



Introduction

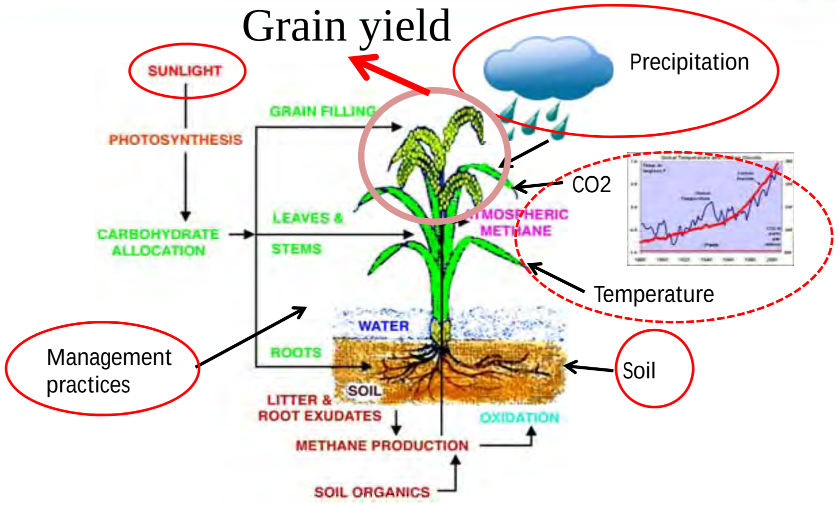
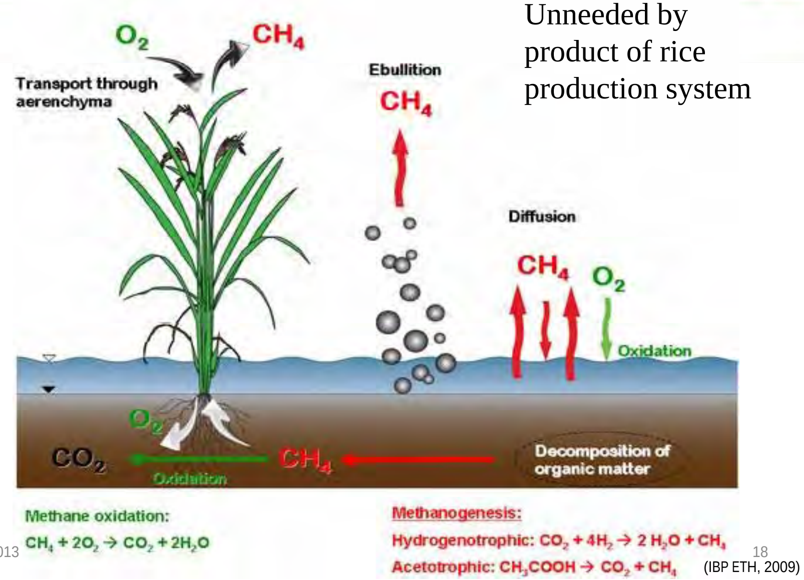


Diagram representing rice production system

Sass R L , Cicerone R J PNAS 2002 http://zfacts.com/p/226.html

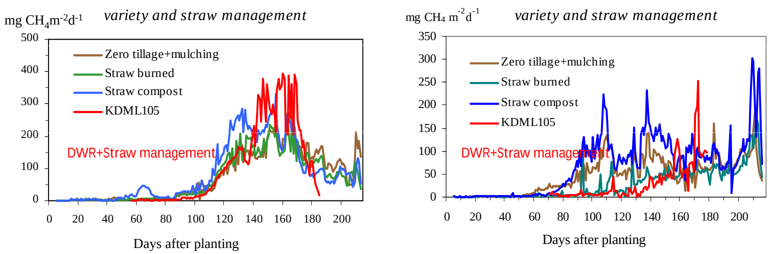
Introduction

Unneeded by product of rice production system

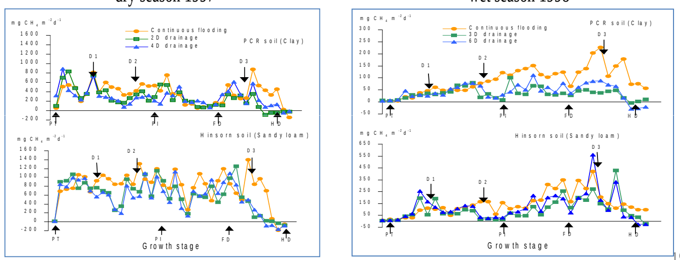


(IBP ETH, 2009)

Mitigation



Water drainage is able to reduce CH4 emission.



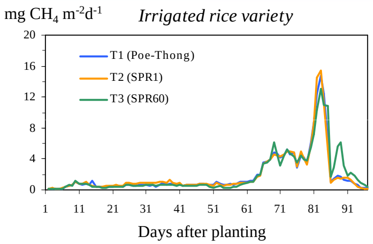
Soil series and water management

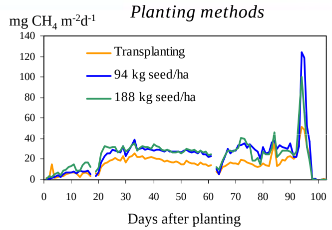
Mitigation

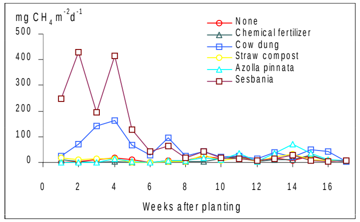
Mitigation options to reduce CH_4 from paddy field

Management s	CH_4 reduction rates (%)	Sources
Mid season drainage Multiple drainage (water management)	27 35	Towprayoon et al., (2005)
Pregerminated seed + intermittent (planting methods and water management)	60	Saenjan and Saisompan, (2004)
Irrigated rice (SPR2) + 2 days drainage	28	Chareonsilp et al, (2000)
Irrigated rice (SPE2) + 3 days drainage	44	
Irrigated rice (SPR2) + 4 days drainage	37	
Irrigated rice (SPR2) + 6 days drainage	32	

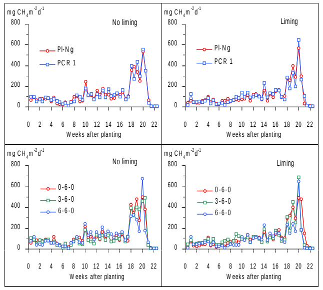
Mitigation





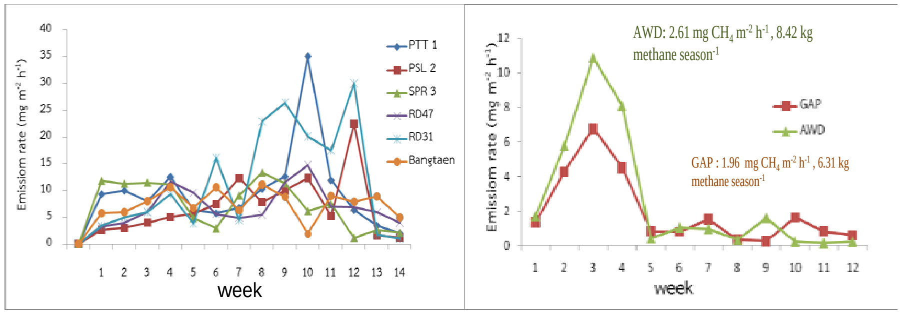


Fertilizer management



DWR variety and chemical fertilizer management

Mitigation



Methane emission from irrigated rice production system

Mitigation

CH_4 emission rate from various irrigated rice variety

Variety	CH_4 emission rate		Carbon Footprint
	mg m^2 h^{-1}	kg ha^{-1} $season^{-1}$	kg CO_2 e/kg of rough rice
PTT1	10.64	40.06	6.05
PSL2	7.67	28.87	5.41
SPR3	8.07	30.36	5.50
RD47	7.45	28.04	5.37
RD31	12.84	48.30	6.52
BT	12.00	29.47	5.45
Average	9.08	43.42	5.79

Adaptation

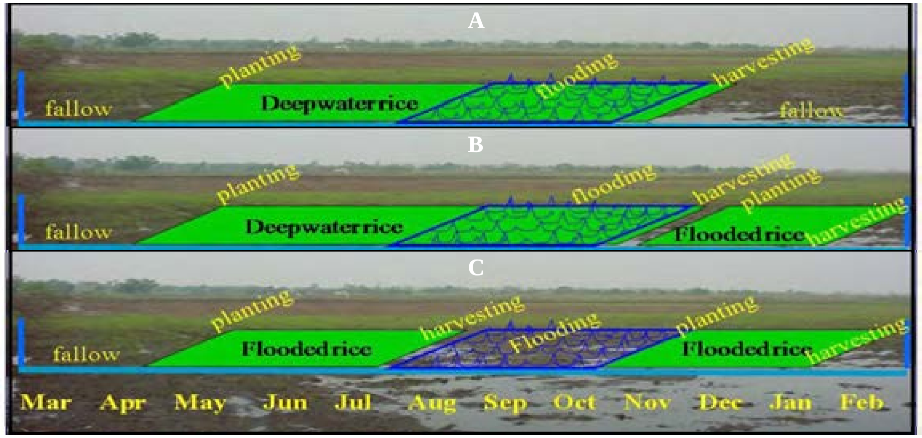
Rice production adaptation to climate change

Adaptation strategy	*Rainfed rice*	*Irrigated rice*
Variety	Early mature variety, deep root system, submergence tolerance, low CH_4 emission variety	Short growth duration with high growth rate, low CH_4 emission variety
Agronomic management	Suitable planting technology depending on area and precipitation pattern, e.g. dry seeding, pre-germinated seed, and transplanting	Technology for CH_4 reduction without effect on yield/ farmers' net income
Water management	Improve water management system to prevent flood in the rainy season and drought in the dry season	Improve water use efficiency

- In order to improve yield, reduce GHGs emission with out effect on farmer way of life

Adaptation

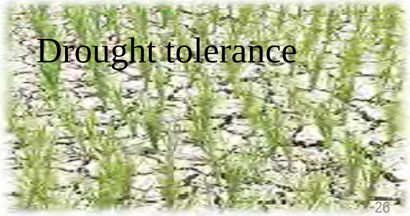
Cropping system



A: conventional deepwater rice production system B: deepwater rice – flooded rice production
C: flooded rice – flooded rice production

Adaptation

Rice variety



Adaptation

Fertilizer management

Adaptation

Planting method

Adaptation

Summary

- Rice production system has been affected by climate change, and will be affected in the future. Base on A2 scenario and recent technology, rainfed rice yield will be slightly increase, but some area will be affected climate variability. On the other hand, irrigated rice yield will be decreased due to shorter growth duration. Rice production system is a GHGs source, even it is a small proportion as compare to other sector, but it's needed to be concerned

Summary

- Mitigation, The effective methodology for methane emission reduction are: 1) rice variety selection in term of emission rate, and growth duration, 2) fertilizer management (both organic and inorganic), and 3) water management
- Adaptation, under future climate, suitable rice varieties with appropriate plating date, planting method, and water management could be able to adapt rice cultivation system to the future climate.

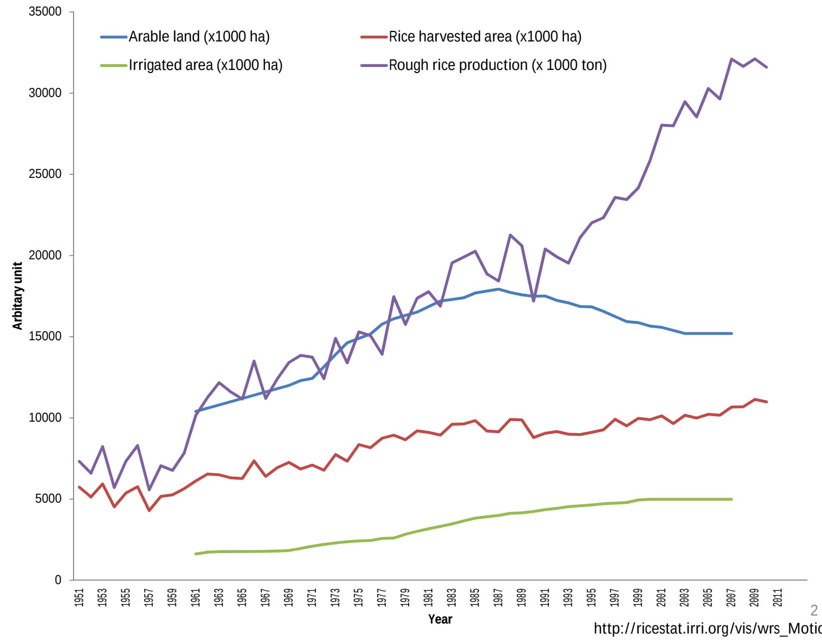
CEE-PERDO Center for Energy Technology and Environment
APN
JGSEE The Joint Graduate School of Energy and Environment

"Sustainable agricultural production – Focus on rice production in (Thailand)"

Amnat Chidthaisong
Joint Graduate School of Energy & Environment
King Mongkut's University of Technology Thonburi

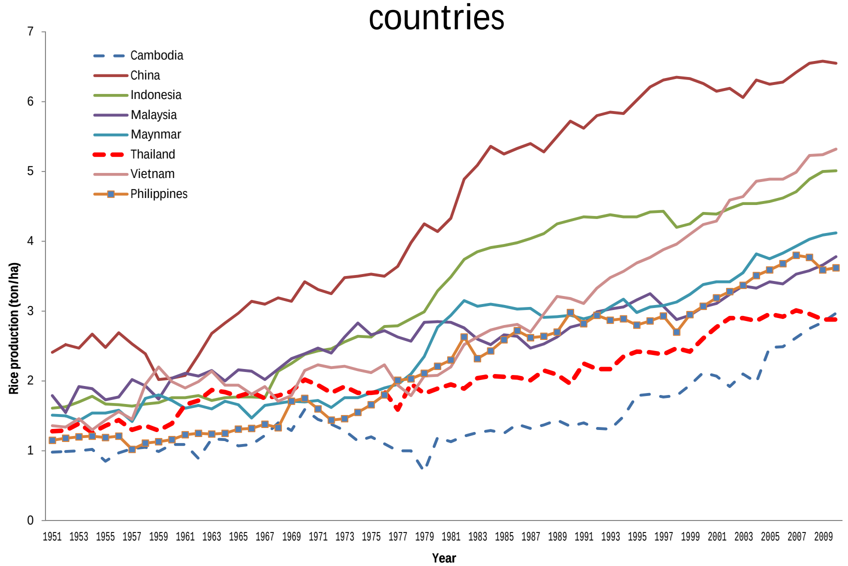
Capacity Building Workshop on:
"Strategic rice cultivation with energy crop rotation in Southeast Asia – A path toward climate change mitigation in the agricultural sector"
29-31 May 2013
Bangkok, Thailand

Current situation



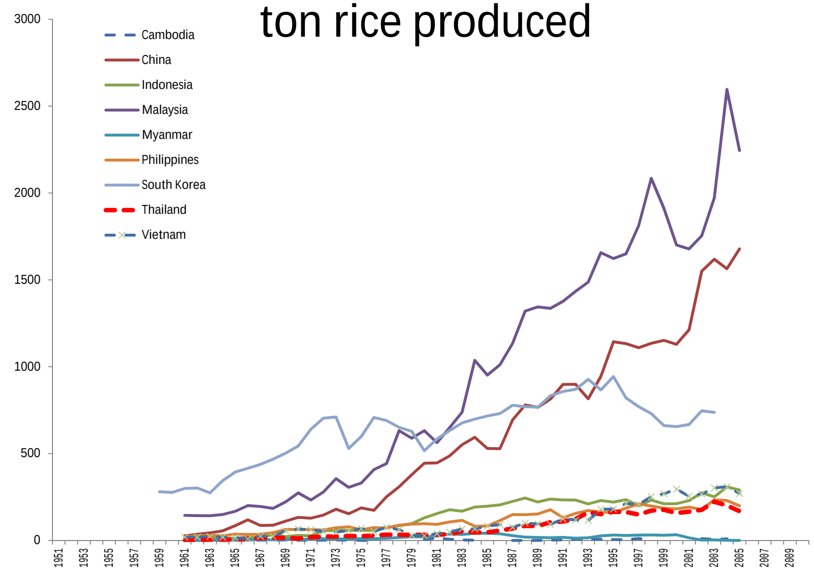
http://ricestat.irri.org/vis/wrs_Motion.php

Current situation: Productivity compared with other countries



http://ricestat.irri.org/vis/wrs_Motion.php

Current situation: Chemical fertilizer use per ton rice produced

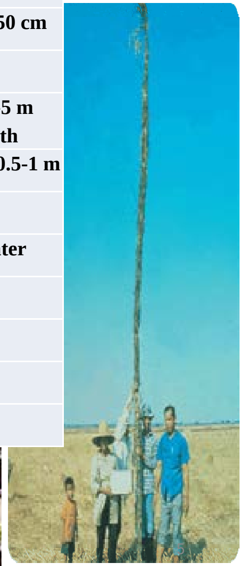


http://ricestat.irri.org/vis/wrs_Motion.php

Current situation: Variety

Rice Ecosystem	No. of Variety	Remark
Lowland: Photosensitive	44	Water depth≤ 50 cm
Lowland: Non-photosensitive	38	
Floating rice:PS	6	Water depth 1-5 m for at least 1 mth
Deep-water: PS	6	Water depth >0.5-1 m
Deep-water: NPS	1	
Upland:PS	9	No flooding water
Upland: NPS	1	
Red hawm rice:PS	2	
Red hawm rice:NPS	1	
Japanica rice	2	

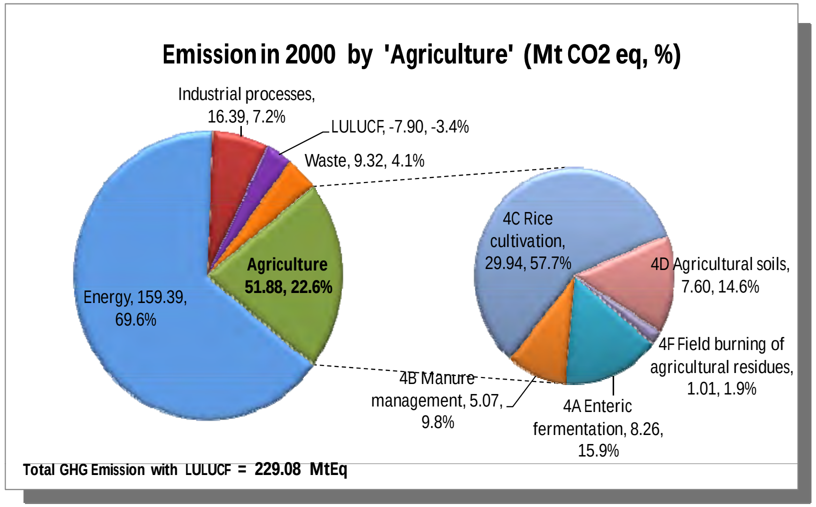


Research topics

- Paddy fields as the important greenhouse gas source and sink in Thailand
- Results from field experiments
  - Emissions and mitigation of greenhouse gas by using food-energy crop rotations
- Conclusions

Emission in 2000 of 'Agriculture' (Mt CO_2 eq,%)



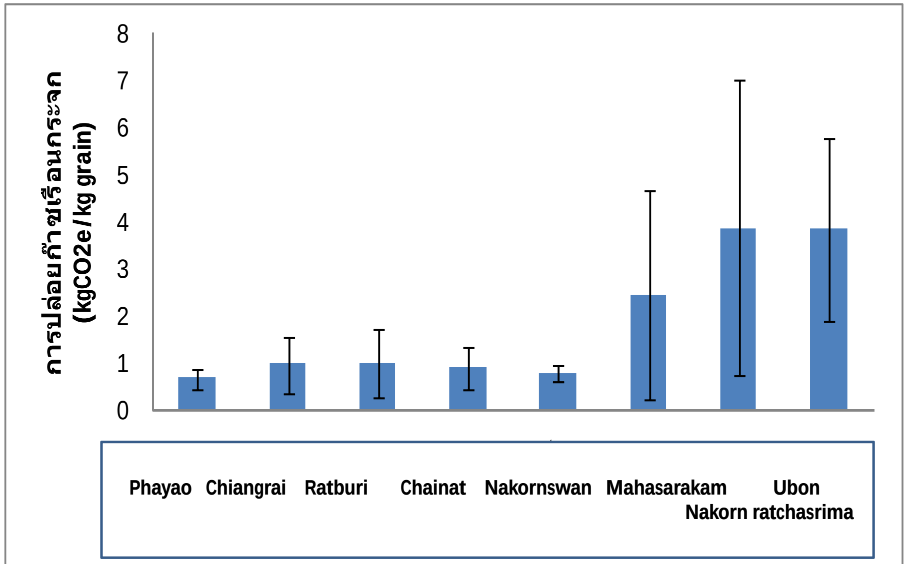
Remark# I: Greenhouse gas emission from Agricultural sector:

- Contributes ~ 20-24% to country total emission during 1994-2005
- Major source of methane (~70%), most from rice cultivation
- Major source of N_2O (~80%), most from soil emission

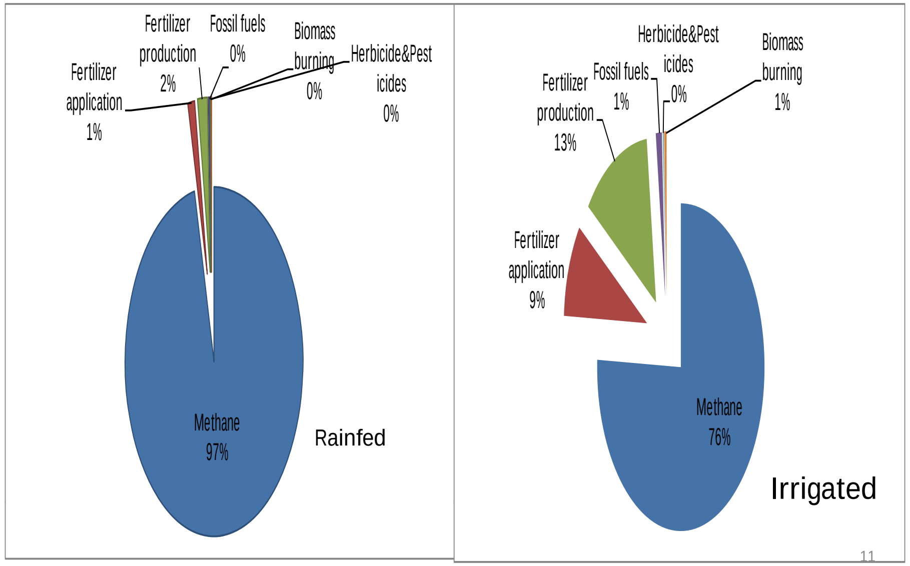
Issues arising from GHG inventory

- Mitigation need to be considered carefully;
  - Sustainable development (including maintaining/increasing yields under climate change pressure)
  - No drastic changes in/affect to local ways of life
  - Cost-benefit analysis

Emission vs. yield: an example of rice production



Specific sources of emissions

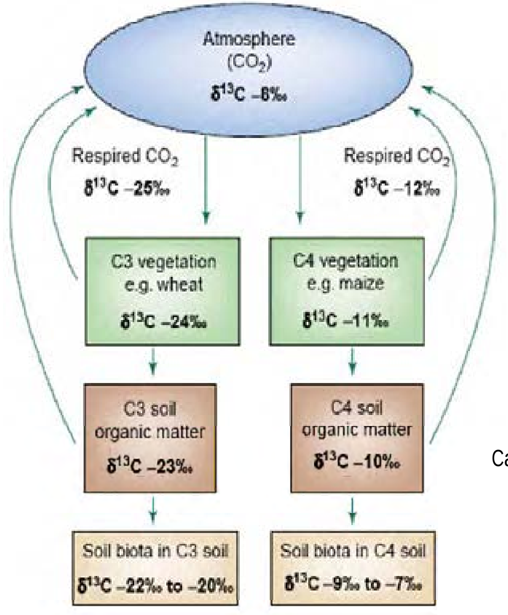


Approaches

- **Mitigation aims: lowering the ratio between emissions and yield;**
  - **Increasing yield and reducing emission/keep emission low--mitigation should not affect yield**
  - **Increase land productivity through enhancing land use usability while maintaining its fertility**

Investigation on crop rotation

- **Two case studies**
  - **Clay soil originally planted to maize—then rotated with lowland and upland rice**
  - **Sandy loam soil originally cultivated with lowland rice---then rotated with energy crop (maize and sweet sorghum)**



Case I: Main-rice system

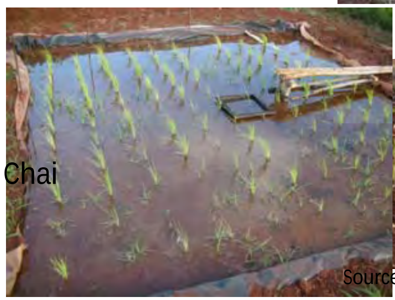
Plot preparation

Maize: 4901 variety

Upland rice: Sakon Nakhon variety

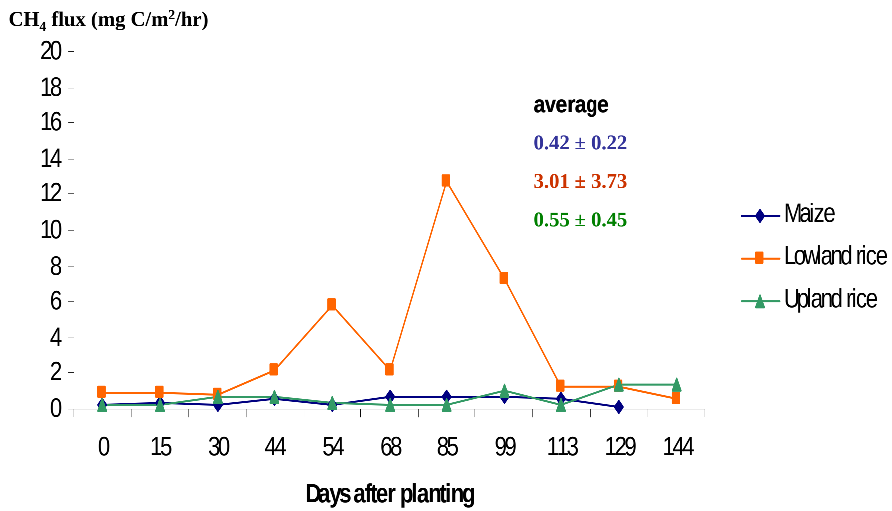
Plantation

Lowland rice: Chai Nat 1 variety



Source: P. Ponpang-nga & A. Chidthaisong, 2012

Methane emission flux (1st crop)



Source: P. Ponpang-nga & A. Chidthaisong, 2012

	Carbon stock (ton C/ha)		
	M treatment	R treatment	RM treatment
1st	17.32 ± 0.34[a]	18.20 ± 0.45[a]	
	17.29 ± 0.49[a]	18.20 ± 0.51[a]	
	17.98 ± 0.43[a]	20.79 ± 0.63[b]	
2nd	17.76 ± 0.56[a]	18.27 ± 0.50[a]	18.39 ± 0.47[a]
	16.87 ± 0.53[a]	21.35 ± 0.63[b]	17.73 ± 0.45[c]
	16.50 ± 0.48[a]	20.88 ± 0.52[b]	19.35 ± 0.44[c]

Source: P. Ponpang-nga & A. Chidthaisong, 2012

Where carbon is accumulated?--The $\delta^{13}C$ values of SOC in different aggregate size fractions at the end of 2nd crop (± S.D. of 3 replications).

Aggregate	$\delta^{13}C$ values ((‰)		
	M treatment	R treatment	RM treatment
< 250 µm	-18.94±0.08[a]	-20.72±0.48[b]	-20.20±0.19[b]
250-500 µm	-18.62±0.17[a]	-20.79±0.57[b]	-20.08±0.31[b]
500-1000 µm	-18.94±0.29[a]	-20.29±0.93[b]	-20.10±0.44b
Bulk soil	-18.70±0.09[a]	-20.98±0.38[b]	-20.31±0.16[c]

Source: P. Ponpang-nga & A. Chidthaisong, 2012

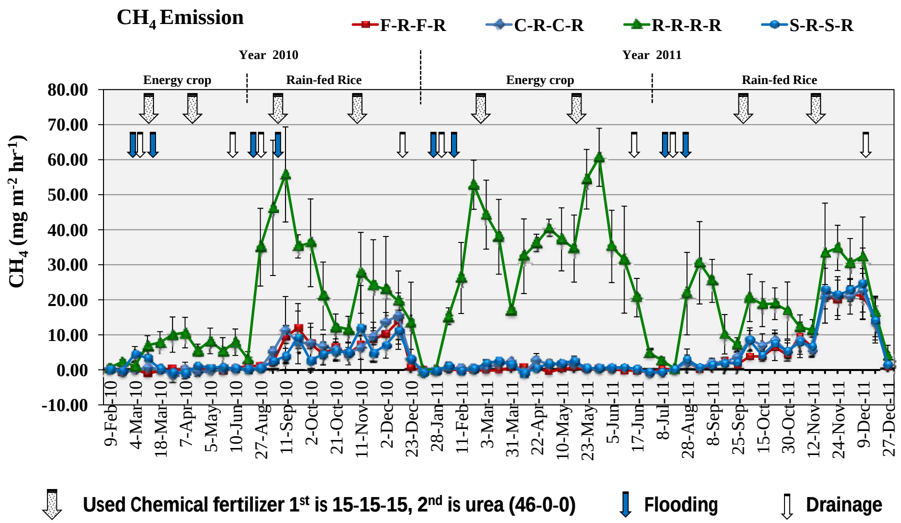
Case study II: lowland rice rotated with energy crop (maize and sweet sorghum)

4 treatments

- F-R-F-R: fallow-rice-fallow-rice
- R-R-R-R:rice-rice-rice-rice
- C-R-C-R: Maize-Rice-maize-rice
- S-R-S-R: sweet sorghum-rice-sweet sorghum-rice

Source: N. Cha-un & S. Towprayoon, 2011

Seasonal of CH_4 fluxes in different crop management



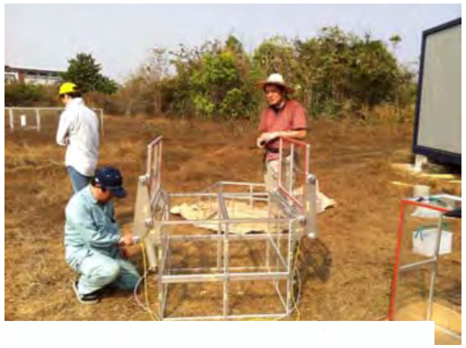
Source: N. Cha-un & S. Towprayoon, 2011

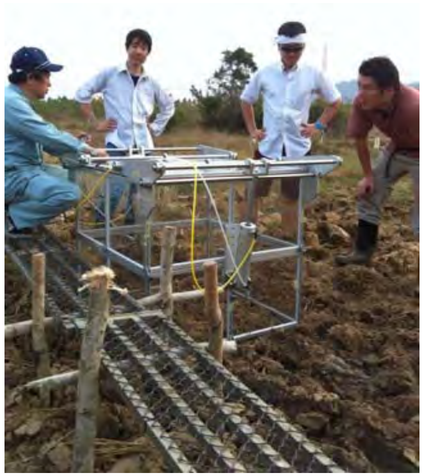
Crop/Treatment	Cumulative flux (mg CH_4 m^{-2} crop^{-1})
1st crop in 2010	
RF (fallow)	-6.090
RC (Corn)	-0.380
RI (Rice)	762.260
RS (Sorghum)	125.420
2nd crop in 2010	
RF (fallow→Rice)	784.900
RC (Corn→Rice)	849.655
RI (Rice→Rice)	2,960.600
RS (Sorghum→Rice)	610.730
3rd crop in 2011	
RF (fallow→Rice→fallow)	6.370
RC (Corn→Rice→Corn)	99.190
RI (Rice→Rice→Rice)	7,043.820
RS (Sorghum→Rice→Sorghum)	105.735
4th crop in 2011	
RF (fallow→Rice→fallow→Rice)	1,003.006
RC (Corn→Rice→Corn→Rice)	1,105.523
RI (Rice→Rice→Rice→Rice)	2,433.576
RS (Sorghum→Rice→Sorghum→Rice)	1,104.599

Source: N. Cha-un & S. Towprayoon, 2011

Remark # II:

- Cropping shift from upland maize to flooded rice could enhance soil carbon sequestration (but needs to consider CH_4)
- Decomposition and incorporation of organic materials (maize and rice straw) into SOC was detectable within a short time period.

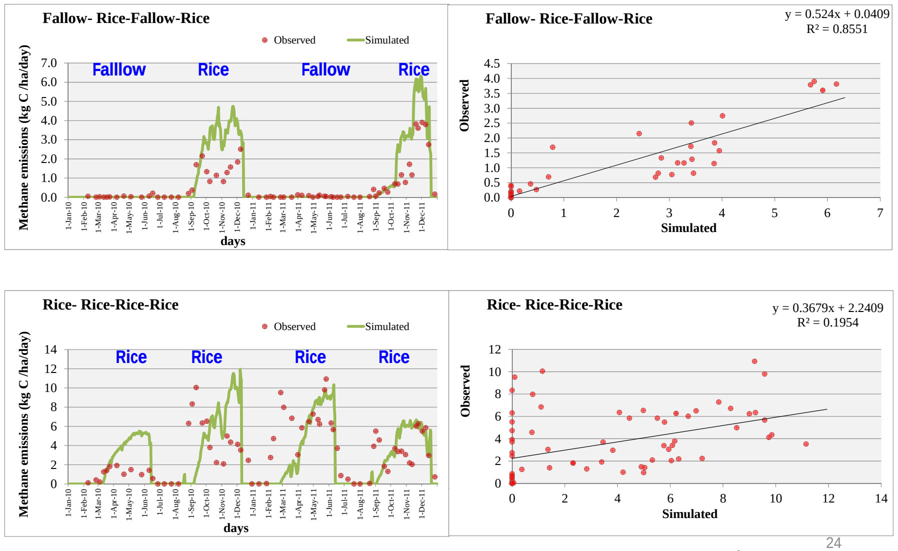




Activity and results under GRENE—mitigation and modeling

Modeling by DNDC (site mode)

Comparison between observed and DNDC simulation of daily pattern of CH_4 emission from crop rotation system



Source: N. Cha-un, pers. Com.

Concluding remarks

Main findings:

- **Rice yield per area is still low**
- **Rice cultivation contributes relatively large to country total GHG emission**
- **Emission reduction is possibly achieved by;**
  - **Managing soil carbon through cultivation practices/diversification such as rotation with energy crops (reduce methane emission and maintain SOC).**

•Next step:

- **Modeling approach will help improve relationship between yields and GHG mitigation associated with crop managements**

Thank you

http://ricestat.irri.org/vis/wrs_Motion.php

CEE-PERDO Center for Energy Technology and Environment | APN | JGSEE The Joint Graduate School of Energy and Environment

"Sustainable agricultural production – Focus on rice production in (Cambodia)"

Seng Vang
Cambodian Agricultural Research & Development Institute (CARDI)

Capacity Building Workshop on:
"Strategic rice cultivation with energy crop rotation in Southeast Asia – A path toward climate change mitigation in the agricultural sector"
29-31 May 2013
Bangkok, Thailand

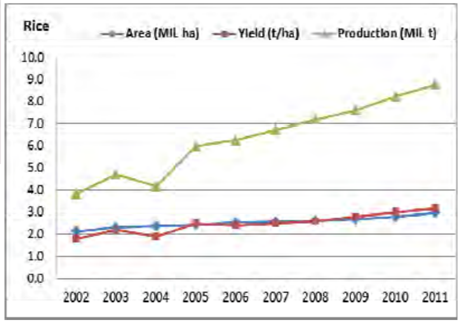
Current situation

- Plantation area
- Cultivation practice
- Water regime
- Rice varieties
- Organic and Chemical fertilizer used

Current Situation of rice production in Cambodia

- **Rainfed Lowland: 79.3% ↓**
- **Upland: 1.7%↓**
- **Deepwater/Floating: 3.1% ↓**
- **Irrigated/Dry Season: 15.9%↑**

Fact:
- Total production (Paddy): 8.78 mil t
- Per capita consumption: 143 kg/year
- Demand per annum: 2.11 mil t
- Population growth per annum: 1.5%
- Surplus (Paddy): 4.34 mil t

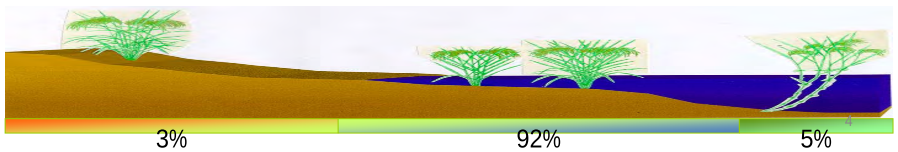


Data source: MAFF (2012)

Last 2-year statistics of rice

Year	Wet season			Dry season			Total (WS+DS)		
	Har. area (mil ha)	Yield (t/ha)	Prod. (mil t)	Har. area (mil ha)	Yield (t/ha)	Prod. (mil t)	**Har. area (mil ha)**	**Yield (t/ha)**	**Prod. (mil t)**
2011	2.29	2.92	6.70	0.47	4.41	2.08	**2.77**	**3.17**	**8.78**
2012	2.48	2.87	7.14	0.50	4.35	2.15	**2.98**	**3.11**	**9.29**
Cultivation practice	Mostly transplanting			Direct seeding/Broadcasting					
Water regime	Rainfed			Irrigated/Recession/Supplementary irrigation					

Source: MAFF Department of Statistics (2012, 2013)



Rice varieties released: 38

9 Early maturing, insensitive to photoperiod, irrigated & rainfed
16 Intermediate maturing, rainfed lowland
8 Late maturing, rainfed lowland
2 Rainfed upland
3 Deepwater

10 Recommended Varieties:

Early maturity
1. Sen Pidao
2. Chul'sa
3. IR66

Intermediate maturity
1. Phka Rumdoul
2. Phka Romeat
3. Phka Romdeng
4. Phka Chan Sen Sar

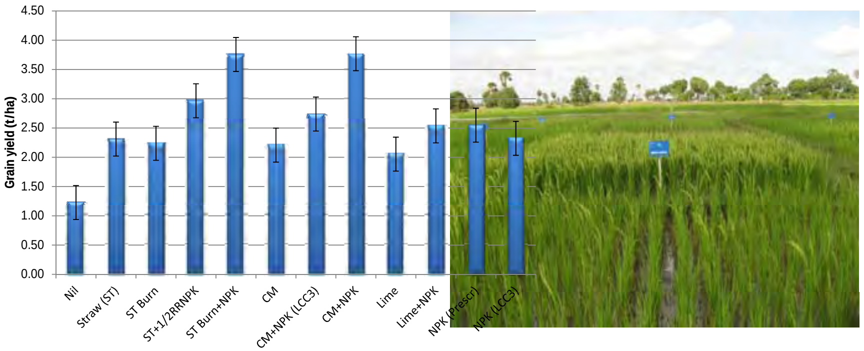
Late maturity
1. Riang Chey
2. CAR4
3. CAR6

Nutrient requirement for rice

Major soil types	Recommended rate of nutrients (kg/ha)		
	N	P_2O_5	K_2O
Prey Khmer (Psamments)	28	10	40
Prateah Lang (Plinthustalfs)	50	23	30
Bakan (Alfisol/Ultisol)	75	30	30
Koktrap (Kandic Plinthaquult)	73	35	30
Toul Samroung (Vertisol/Alfisol)	98	35	0
Krakor (Entisol/Inceptisol)	120	25	0

Common fertilizers used:
- Urea (46-0-0), DAP (18-46-0), MAP (16-20-0), NPK+TE (20-15-15+TE) from different countries such as Thailand, Philippines, China, Vietnam, etc.
- Composed cattle manure, FYM

Effect of Organic and Inorganic Fertilizers



The effect of organic and inorganic fertilizers management on grain yield of rice, *cv.* Sen Pidao grown on Prateah Lang soil in 2012 wet season. CARDI Experimental Station, Phnom Penh, Cambodia.

Fertilizer rates:
Straw: 5 t/ha
CM (cow manure): 5 t/ha
Lime: 1 t/ha
NPK: 50-23-30 kg/ha

Fertilizer effectiveness on farmer fields

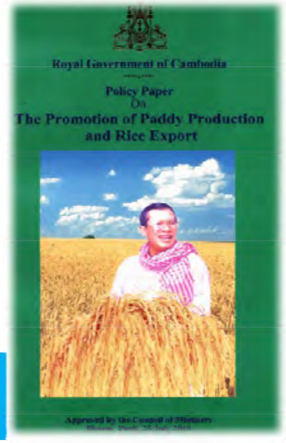
Treatments	Amount of applied fertilizers (kg/ha)	Cost of fertilizers (USD/ha)	Grain yield (t/ha)	Income (USD/ha)	Profit (USD/ha)
No fertilizer	0	0	2.35	765	765
Farmer fertilizer practice	211	126	2.69	874	748
Recommendation rate	231	127	3.36	1093	966

Source: CARDI Annual Report in 2012.

Plan to improve rice plantation in the future

- For examples
  - Yield
  - Market
  - Irrigation
  - Breeding
  - Cultivation practices
  - Others……

The RGC policy on the promotion of paddy production and rice export
"**Rice = White Gold**" (as of July 25, 2010)



Early maturity	Intermediate maturity	Late maturity
1. Sen Pidao	1. Phka Rumdoul	1. Riang Chey
2. Chul'sa	2. Phka Romeat	2. CAR4
3. IR66	3. Phka Romdeng	3. CAR6
		4. Phka Chansensar

4 Interventions:
- Enhanced production of rice crops
- Purchasing and processing
- Improved enabling factors
- Marketing

2015 Milestones:
- Paddy surplus : 4 million tons
- Milled rice for export: 1 million tons
- Cambodian rice: Recognized internationally

Current research and research institute involved

- For examples
  - genetic improvement- University
  - Rotation crop- Rice research
  - Organic farming- Internal funding agency
  - Others…

Current research and institutes involved

Organizations	Project Title	Duration	Notes
CARDI, RCD/GDA, RUA	Improved rice establishment and Productivity (CSE2009/037)	2010-2013	Completion Sept 2013
CARDI, DAE/GDA, IDE/NGO	Developing Multi-Scale Climate Change adaptation strategies for farming communities In Cambodia, Lao PDR, Bangladesh and India (LWR2009/019)	2010-2014	Completion June 2014
CARDI, RCD/GDA, IRRI	Improved rice germplasm for Cambodia and Australia (CSE2009/005)	2010-2014	Completion Feb 2014
CARDI, TSC, ITC, IDE	Improved irrigation water management to increase rice productivity in Cambodia (LWR2009/046)	2011-2014	Completion June 2015
CARDI, IRRI	Remote-sensing-based information and insurance for crops in emerging economies (RIICE)	2012-2015	Completion June 2015

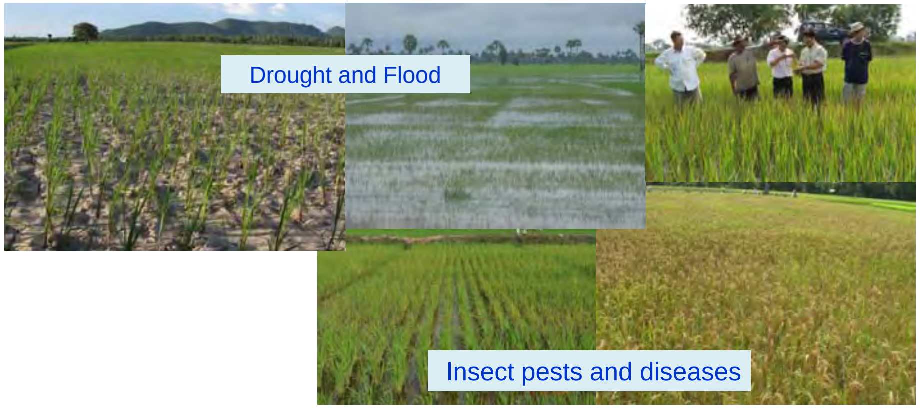
RCD/GDA: Rice Crop Dept, GDA: General Directorate of Agriculture, DAE: Dept of Agr Extension, IDE: International Dev. Enterprise-Cambodia, TSC: Technical Service Centre, ITC: Institute of Technology of Cambodia

Adaptation and mitigation of rice cultivation

For examples
- Effect from drought/flood
- Water stress
- Less water consumption rice
-High temperature resistance
- GHG emission
- F foot print
- Data base collection
-Others.....

Effects of flood, drought, and pests

Factors	Damaged area (ha)			Production losses (t)*		
	2010	2011	Total	2010	2011	Total
Drought	2,934	53	2,987	8,802	168	8,970
Insect pests	298		298	894	-	894
Flood	17,357	267,184	284,541	52,071	846,973	899,044
Sum total	20,589	267,237	287,826	61,767	847,141	908,908



Identified elite aerobic rice lines
CARDI, 2011WS

Designation	Duration (days)	Height (cm)	Yield (t/ha)	
IR 04A305	101	111	6.0	29%
IR 80013-B-141-4-1	99	112	5.7	23%
IR 81040-B-78-U 2-1	96	117	5.7	23%
IR 06L164	99	109	5.5	20%
IR 04A393	101	101	5.5	18%
IR 05A235	100	110	5.3	16%
IR 05A139	108	108	5.3	16%
IR 03L146	112	102	5.3	15%
IR 06L129	97	112	5.2	12%
Rumpe (Check)	101	91	4.6	0%

Identified early-maturing lowland rice
Takeo (Bati), 2011WS

Designation	Duration (d)	Height (cm)	Yield (t/ha)
IR 07L167	106	111	5.4
IR 06L136	108	96	5.1
IRRI 148	103	103	5.0
BP 223 E-MR-5	105	115	5.0
IRRI 123	108	94	4.9
Chul'sa (Check)	106	85	4.9

Identified medium-duration lowland rice Takeo (Bati), 2011WS

Designation	Duration (d)	Height (cm)	Yield (t/ha)
IR 06L141	113	87	5.3
IR 04A421	117	84	5.3
ZX117	113	88	5.1
IR 04A428	118	88	5.1
OM 6049	116	80	5.0
IRRI 150	115	86	5.0
IR 73459-120-2-2-3	117	85	4.9
IR 79195-42-1-3-1	120	88	4.9
IR 06M142	112	99	4.9
Sen Pidao (CK)	112	87	4.7
IR 66 (CK)	113	80	4.5

Policies

- Are there any policies on the topics below about rice cultivation in your country and what are the detail and how to implement
  - Increase rice yield
  - Irrigation system
  - Residue
  - Rotation crop
  - Other.....

Related policies and legal documents

- **Implementing:**
  - Rice export policy (White Gold for Export)
  - Strategy for agriculture and water
  - Law on the management of pesticides and fertilizers
  - Seed law
- **On-going development:**
  - Agricultural land law (On going preparation by MAFF): Manage the use of the country's agricultural lands (Unproductive, conversion of land, conservation, food production vs. bioenergy)
  - National Action Program to Combat Land Degradation (Final draft being reviewed by MAFF)
  - National Strategy on Adaptation to CC in Agricultural Sectors (On going preparation by MAFF)

Rice and energy/biofuel

- What are the situation
- What are the policies involved
- Trend and direction

- Annual production of rice waste: about 47 million tones equivalent to about 1 million tones of fuel production (JICA, 2005).
- Biochar (National Working Group on Biochar; Biocharm Project, UK Biochar Research Centre)
- Biomass for energy (Rice husks used for brick kiln, rice mill, and for cooking in poor-forest areas)
- Biofuel (Ethanol, jatropha)

As of March 2013, the RGC launched:

- The national policy for green growth 2013-2030 aims to
  - balance between economic development and environment, society, culture and sustainable consumption of natural resources in order to enhance people's well-being and living conditions.
- The national strategic plan for green growth 2013-2030 aims to
  - promote Cambodian economy towards the green economy, focusing on effective use of natural resources, environmental sustainability, green jobs, green technologies, green finance, green credit, and green investment.

Rice and sustainability

What are the activities in your country that lead to rice and sustainability.

On-going breeding program at CARDI

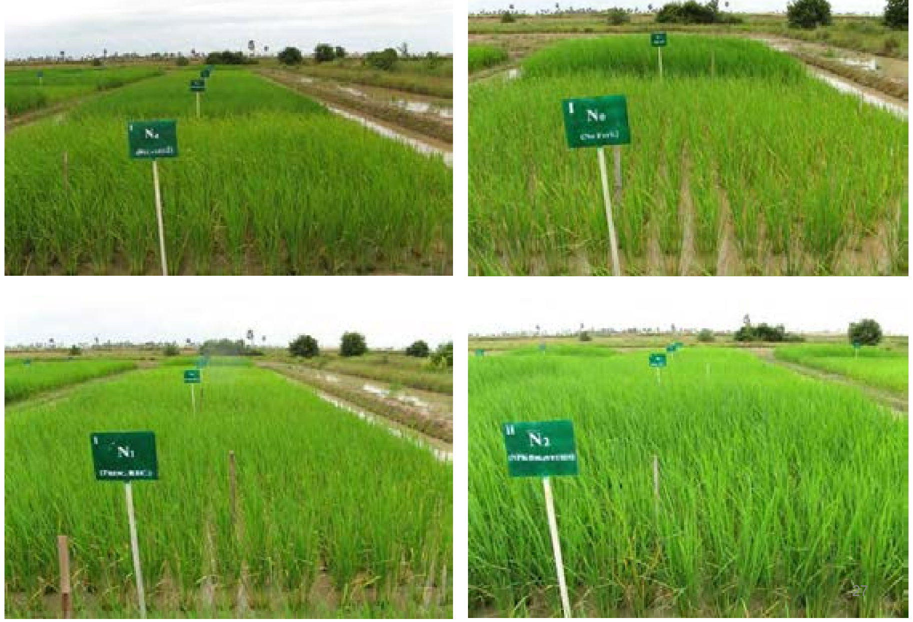
Dry season rice	**Wet season rice**		
Earliness Drought tolerance Quality	Drought tolerance	Submergence tolerance	Lodging resistance
10 crosses F1	PRD x CAR3 BC5F3	(PRD, PRM, CAR3, Riang Chey) x IR64Sub1 BC1F1	(PRD, Phka Chansensar) x Riang Chey F1

Plant protection program develops technologies and strategies that will assist farmers to increase yields and profit by protecting agricultural crop losses from pests in a safe and sustainable manner

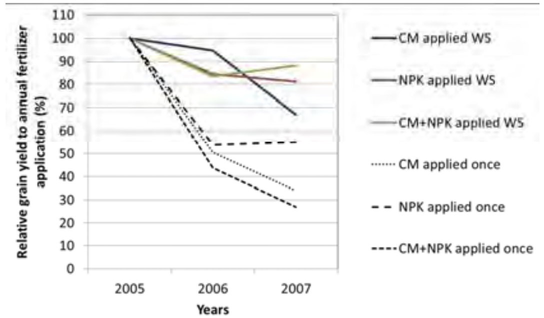
Soil fertility improvement program develops cost effective, simple and reliable nutrient management systems to help farmers increase and stabilize crop yields through improving knowledge of soil, plant nutrition, water quality, and crop water use

Optimizing nutrient use efficiency by various crops
Reaching yield potential in irrigated areas
Improving crop water productivity
Management of organic and inorganic matters (Medium and long term trends)

Improving fertilizer use efficiency



Missed applications of fertilizers resulted in rice production decline



Agricultural engineering research program develops technologies, related to production means, that would help farmers improve the efficiency and security of agricultural production

- Pre-Harvest Technology
- Post-Harvest Technology
- Prototype Development and Testing

- Thanks,....

CEE-PERDO Center for Energy Technology and Environment — APN — JGSEE The Joint Graduate School of Energy and Environment

"Sustainable agricultural production – Focus on rice production in Indonesia"

Dr. Iman Rusmana

Department of Biology

Bogor Agricultural University

Capacity Building Workshop on:

"Strategic rice cultivation with energy crop rotation in Southeast Asia – A path toward climate change mitigation in the agricultural sector"

29-31 May 2013

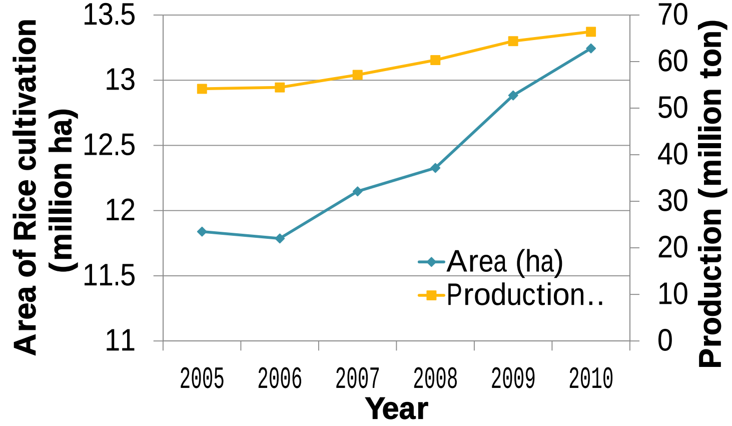
Bangkok, Thailand

Figure of Indonesia

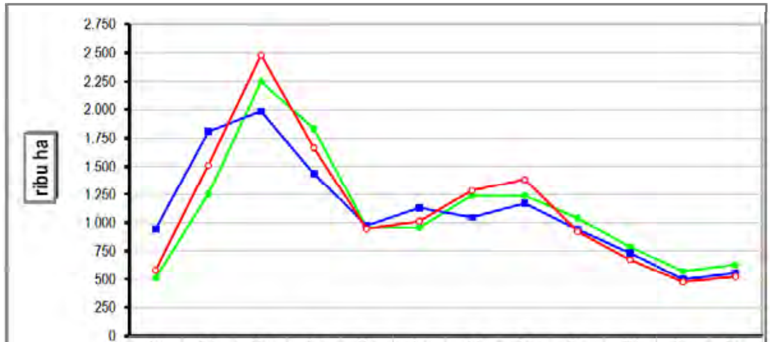
- **Population : 230 million**
- **Pop growth rate : 1.35%/year**
- **Total land area : 190 million ha**

  - **Rice productivity : 5.01 ton/ha**
  - **Rice consumption : 137 kg/cap/year**

Area of Rice Cultivation and Production in 2005-2010



Rice harvesting profiles in 2010-2012



	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Agt	Sep	Okt	Nov	Des
2010 (ha)	509 181	1 252 719	2 246 741	1 830 866	958 790	955 141	1 239 591	1 238 371	1 039 816	785 400	569 636	627 198
2011 (ha)	941 759	1 806 090	1 983 625	1 435 401	973 504	1 128 595	1 046 364	1 166 493	939 609	731 681	497 502	553 020
2012 (ha)	579 094	1 510 868	2 478 077	1 663 920	944 248	1 010 903	1 284 231	1 382 740	921 047	671 753	474 299	522 263

Rice cultivation area, productivity and production in 2010-2012

	2010	2011	2012 (ASEM)
(1)	(2)	(3)	(4)
1. **Area (ha)**			
- Jawa	6 358 521	6 165 079	6 185 521
- Outside of Java	6 894 929	7 038 564	7 257 922
- Indonesia	**13 253 450**	**13 203 643**	**13 443 443**
2. **Productivity** (ku/ha)			
- Jawa	57,21	55,81	59,05
- Outside of Java	43,65	44,54	44,80
- Indonesia	**50,15**	**49,80**	**51,36**
3 **Production (ton)**			
- Jawa	36 374 771	34 404 557	36 526 663
- Outside of Java	30 094 623	31 352 347	32 518 478
- Indonesia	**66 469 394**	**65 756 904**	**69 045 141**

Rice Cultivation Practices

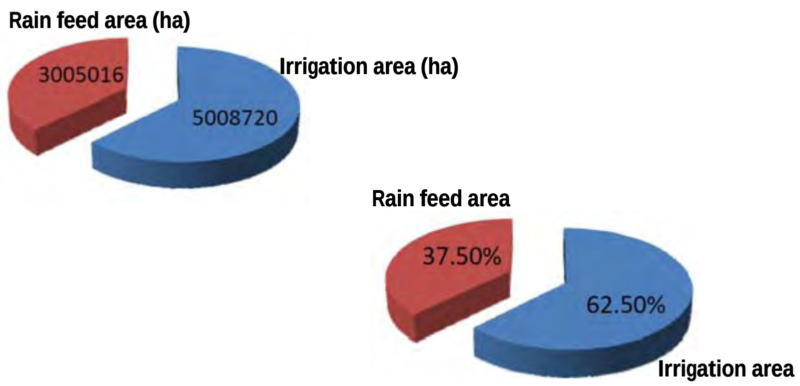
Conventional practices (Flooded) are still the dominant of rice cultivation practices in Indonesia

SRI (System of Rice Intensification):

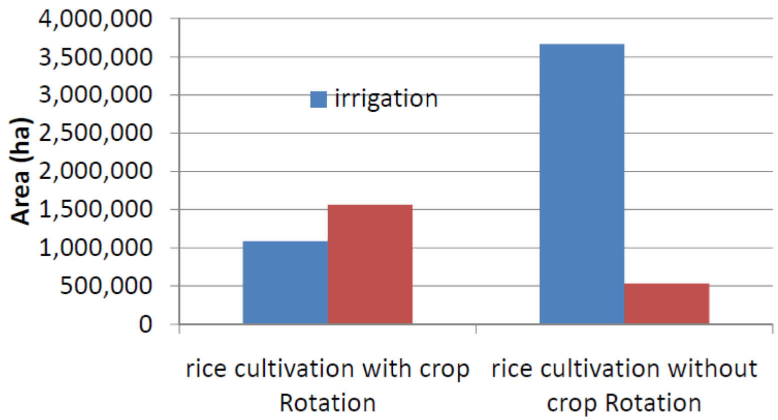
The Agriculture ministry of Indonesia plans to increase the use of the SRI:

- 2011 : 100.000 ha
- 2012 : 200.000 ha
- 2015 : 1,5 million ha

Rice cultivation of rain feed and Irrigation area



Total area of rice cultivation with and without rotation crops in Indonesia



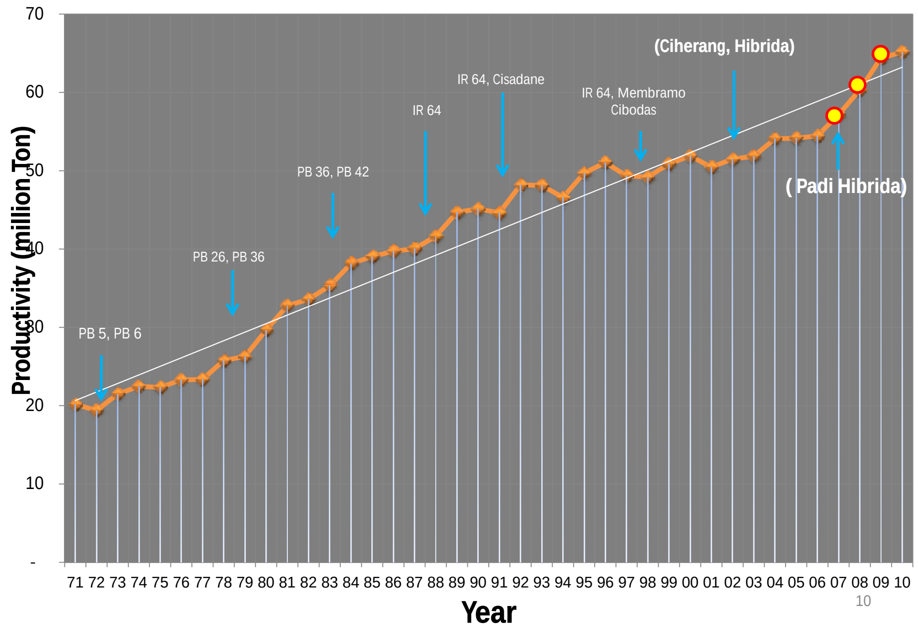
Rice Variety

Form 1943 up to 2007:
- → 190 rice varieties of wetland were released
- → 30 rice varieties of dryland were released

Mostly cultivated:

IR-64	**Ciherang**	**Ciliwung**
Way Apo Buru	IR 42	Widas
Memberamo	Cisadane	IR 66
Cisokan	Cibogo	

Development of Rice productivity and variety in Indonesia (1971 - 2010)



SEED VARIETY DISTRIBUTION OF RICE IN 2010 (NATIONAL)

NO	AREA	COMMON VARIETY: CIHERANG	IR 64	CIGEULIS	MEKONGGA	CIBOGO	CILIWUNG	SITUBAGENDIT	MEMBRAMO
1	SUMATERA								
	- Luas Tanam (Ha)	1.393.195	363.094	266.506	239.856	88.405	115.090	18.434	3.950
	- Persentase (%)	10.50	2.74	2.01	1.81	0.67	0.87	0.14	0.03
2	JAWA								
	- Luas Tanam (Ha)	3.081.381	1.624.653	582.305	477.319	258.731	4.918	132.895	78.932
	- Persentase (%)	23.22	12.24	4.39	3.60	1.95	0.04	1.00	0.59
3	KALIMANTAN								
	- Luas Tanam (Ha)	391.016	18.377	1.221	38.921	22.607	31.566	15.172	-
	- Persentase (%)	2.95	0.14	0.01	0.29	0.17	0.24	0.11	-
4	BALI & NUSRA								
	- Luas Tanam (Ha)	333.450	53.410	133.090	56.328	21.394	7.338	5.012	14.378
	- Persentase (%)	2.51	0.40	1.00	0.42	0.16	0.06	0.04	0.11
5	SULAWESI								
	- Luas Tanam (Ha)	222.934	84.222	223.340	190.418	3.208	197.761	10.447	75.634
	- Persentase (%)	1.68	0.63	1.68	1.44	0.02	1.49	0.08	0.57
6	MALUKU & PAPUA								
	- Luas Tanam (Ha)	13.496	6.367	12.403	11.677	3.617	1.386	190	1.305
	- Persentase (%)	0.10	0.05	0.09	0.09	0.03	0.01	0.00	0.01
	TOTAL								
	- Luas Tanam (Ha)	5.435.472	2.150.123	1.218.865	1.014.519	397.962	358.059	182.150	174.199
	- Persentase (%)	40.97	16.20	9.19	7.65	3.00	2.70	1.37	1.31

Research and startegy to improve rice productivity

- **Improve seed quality → rice variety development**
- **Improve technologies**
  - **Land preparation**
  - **Fertilizer recommendation & application**
  - **Water management**
  - **Pest and disease control**
  - **Post harvest handling**
- **Improved dissemination and communication of technology**
- **Policy to maintain price stabilization**
- **Research and Development**

Rice Fertilizer Recommendation

- Blanket recommendation (before 1990):
  - fixed rate
  - under package
- Gradually improved based on soil test
- Balanced fertilization based on soil testing was applied (experiment, on-farm trial, training, socialization)
- Implementation:
  - using soil P and K map
  - soil analysis by paddy soil test kit in the field

Criteria of soil P and K status in intensified lowland areas and its fertilizer recommendation

Soil status	P and K extracted by HCl 25%		Fertilizer recommendation (kg/ha)		
	P(mg P_2O_5/100g)	K(mg K_2O/100g)	SP-36	KCl –Straw	KCl +Straw
Low	< 20	< 10	100	100	50
Medium	20 – 40	10 – 20	75	50	0
High	> 40	> 20	50	50	0

14

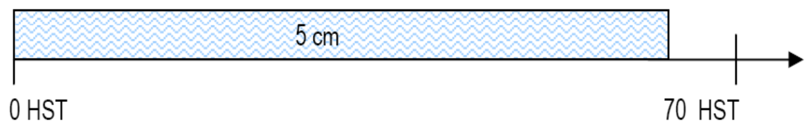
Water management

- Soil submersion allows methanogenesis
- Reduces methanotrophy
- Short periods of drainage decreases methanogenesis in ricefields dramatically (Fe, SO_4)

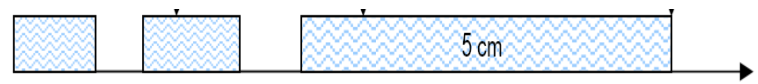
1. Conventional (flooded)
2. Intermittent
3. System of Rice Intensification (SRI)

Water Management:

1. Conventional

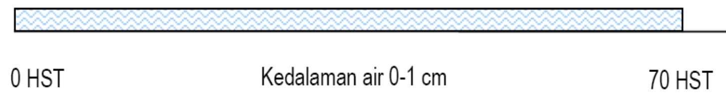


2. Intermittent



2 x dried periode: 15-20 and 30-35 HST

3. SRI



Metabolisms : → Redoks potential

Reaction	Redoks potential (mV)
Hilangnya O_2	
$O_2 + 4e^- + 4H^+ \rightarrow H_2O$	600 – 400
Hilangnya NO_3^-	
$NO_3 + 2e^- + 2H^+ \rightarrow NO_2^- + H_2O$	500 – 200
Pembentukan Mn^{2+}	
$MnO_2 + 2e^- + 4H^+ \rightarrow Mn^{2+} + 2H_2$	400 – 200
Pembentukan Fe^{2+}	
$FeOOH + e^- + 3H^+ \rightarrow Fe^{2+} + 2H_2$	300 – 100
Pembentukan HS^-	
$SO_4^- + 9H^+ + 6e^- \rightarrow HS^-$	0 – -150
Pembentukan CH_4	
$(CH_2O)n \rightarrow n/2\ CO_2 + n/2\ CH_4$	-150 – -220
Pembentukan H_2	
$2H^+ + 2e^- \rightarrow H_2$	-150 – -220

Rice production and methane emission from different water management

Water management	Cara pengelolaan					
	OTS, tapin		OTS, tabela		TOT, tabela	
	CH4 emission	Rice yield	CH4 emission	Rice yield	CH4 emission	Rice yield
	kg ha^{-1}	t ha^{-1}	kg ha^{-1}	t ha^{-1}	kg ha^{-1}	t ha^{-1}
Conventional	164	5,1	91	5,21	66	5,1
Intermittent	77	4,8	57	4,7	37	4,9
SRI	70	4,5				

Sumber: Suharsih *et al.*, 1998 dan Suharsih *et al.*, 1999

OTS= olah tanah sempurna; tapin= tanah pindah; tabela= tanam bening lahan

-**SRI (System of Rice Intensification):**

--> Increase productivity with lower methane emission

The Agriculture ministry of Indonesia plans to increase the use of the SRI:

- 2011 : 100.000 ha
- 2012 : 200.000 ha
- 2015 : 1,5 million ha

Organic Agriculture

The total area of organic farming in Indonesia in 2010 was 238,846.14 hectares, an increase of 10% from the previous year. This includes:

- the certified (organic and conversion) - 103,908.09 hectares
- in certification Process - 14.50 hectares
- PAMOR-certified (PGS) - 5.89 hectares
- uncertified organic agriculture areas - 134,917.66 hectares

(*source: Indonesia Organic Alliance, 2010*).

- The organic agriculture area in Indonesia in 2010 is managed by thousands of producers, including the small farmers who are generally participated in farmer group and who are certified by various certification system.
- Export has also been established.
- Trends are welcomed by rice farmers, they shift gradually from the chemicals-intensive conventional farming to the environmentally-friendly (organic) farming which promotes the health of the producers (farmers), consumers, and the environment alike.

Pictures: women take the lead in organic practices in Central Java ("Istiqomah group").

Study of Methane emission from rice fields in several area and rice varieties in Indonesia

City	Type of soil	Rice variety	CH4 emission
			kg ha-1
Kebumen	Eutrudepts, Hapludalfs	IR 64	798,6
Semarang	Endoaquepts, Dystrudepts	IR 64	775,1
Boyolali	Haplustepts, Haplustalf	Memberamo	682,4
Magelang	Dystrudepts, Endoaquepts	IR 64	599,4
Sragen	Haplustepts, Dystrudepts	IR 64	543,2
Blora	Haplustepts, Haplustalf	IR 64	409,5
Kendal	Endoaquepts	IR 64	338,2
Purworejo	Eutrudepts, Undorthents	IR 64	331,1
Cilacap	Udipsamments, Endoaquents	IR 64	323,0
Pekalongan	Endoaquepts	IR 64/Way Seputih	300,5
Pati	Haplustent, Haplustalfs	IR 64	155,2
Pemalang	Hapludults	IR 64	147,6
Temanggung	Hapludults	IR 64	107,1

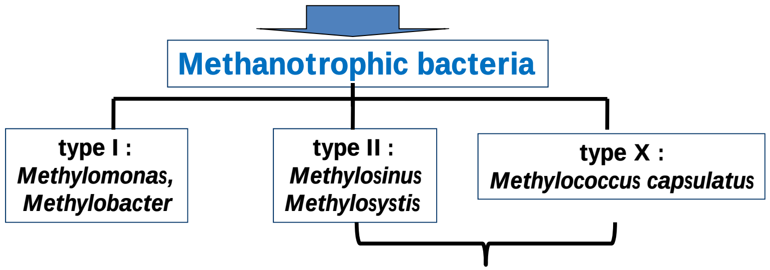
Setyanto et al. 2004

Methane emission and rice productivity of several rice varieties in Indonesia

Rice Variety	CH4 emission (kg/ha)	productivity (t/ha)
Lahan sawah irigasi dan sawah tadah hujan[1]		
Dodokan	74	3,3
Tukad Balian	115	5,1
Maros	117	4,3
Cisantana	124	5,4
Muncul	127	4,6
Way Apoburu	154	7,4
Memberamo	173	7,4
Ciherang	175	5,8
IR64	176	6,7
Tukad Unda	185	5,3
Batang Anai*	196	4,5
Cisadane	218	6,4
IR36	112	4,9
Lahan sawah pasang surut[2]		
Martapura	171	5,99
Sei Lalan	153	6,75
Indragiri	141	6,03
Punggur	105	5,65

Biofertilizer using Methanotrophs

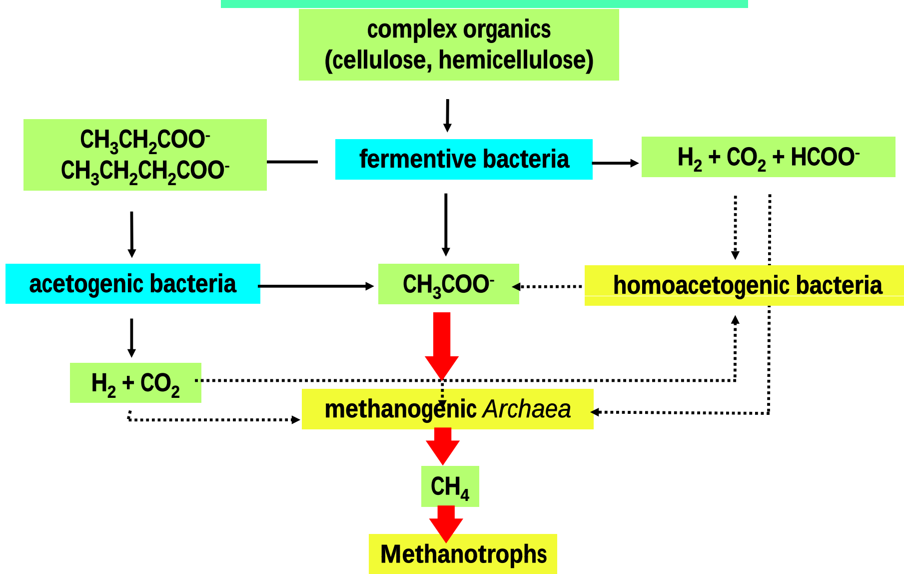
→oxidized methane in oxygenic layer of sediment
→Some of them can fix N2
→Methane oxidation was also found in rhizosphere area



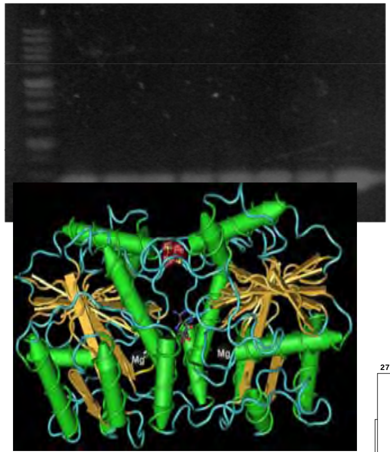
→able to degrade halogenated hydrocarbon:
- TCE (trichloroethylene)
- methyl bromide and methyl fluoride
- 2- and 4-chloro-biphenyl
- 4-hydrroxy-2-chlorobiphenyl

→ able to fix N_2

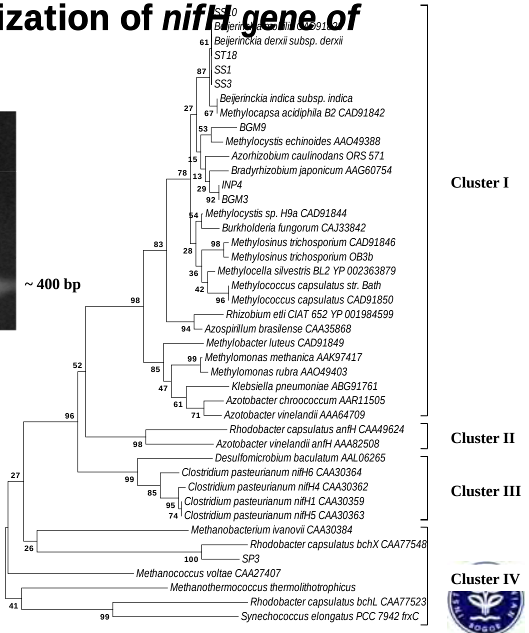
Role of Microbes on methane



Molecular Characterization of *nifH gene of Methanotrophs*

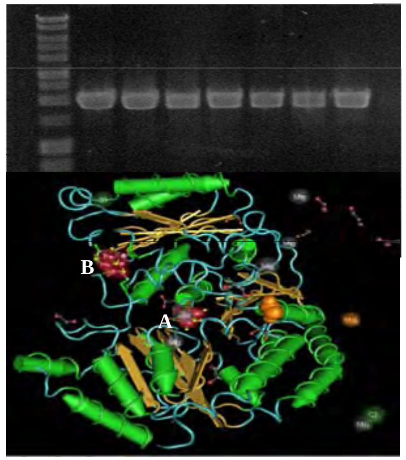


Putative structure of NifH protein : yellow= beta sheet, green= alfa helix, red= 4Fe-4S cluster

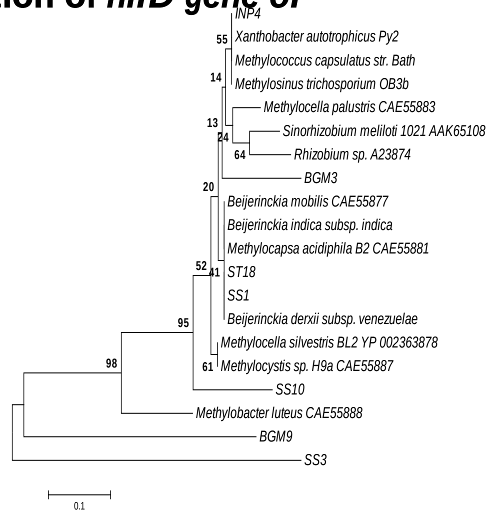


Phylogenetic based on amino acid sequences of NifDHprotein

Molecular Characterization of *nifD gene of methanotrophs*



Putative structure of NifD protein : yellow= beta sheet, green= alfa helix, red= 4Fe-4S cluster

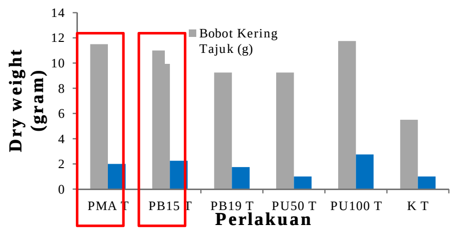


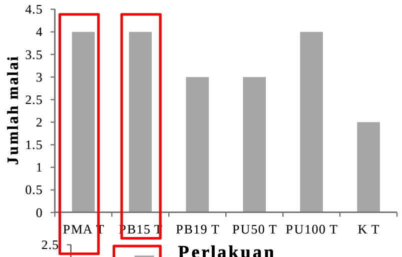
Phylogenetic based on amino acid sequences of NifD protein

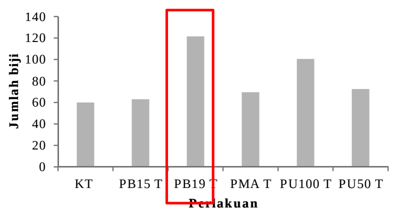
Experiment:

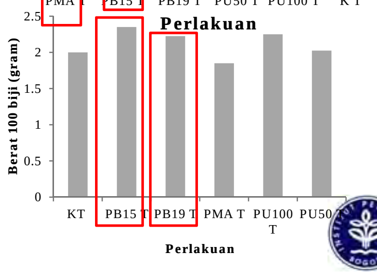
→ Could substitute N fertilizer up to 50 %

→Number and weight of seed the same as 100% N fertilizer application



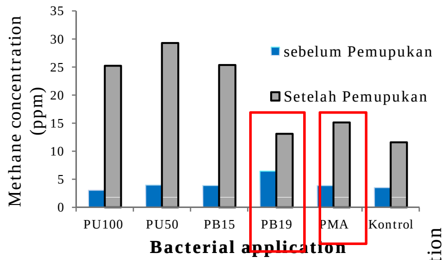


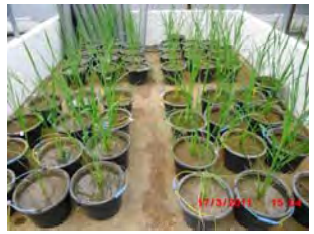


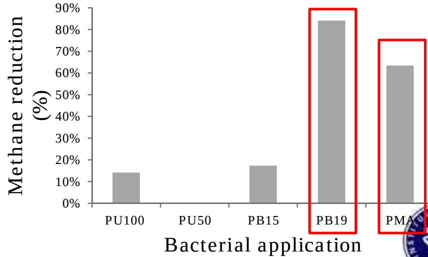


Reduction of Methane Emission:

Mixed culture of BGM 1 & BGM 9 isolated could reduce up to 84%







Food and energy/biofuel

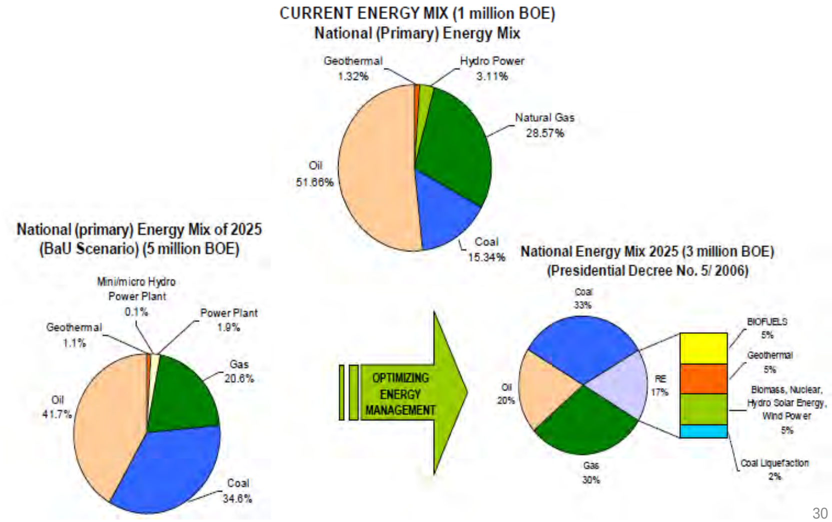
- Ministry of Energy (2008):
  - Indonesia's share of non-renewable energy source is more than 95%, consisting of Oil (51.7%), Natural Gas (28.6%), and Coal (15.3%).
  - Whereas the share of renewable energy source is less than 5%: Hydropower (3.1%) and Geothermal (1.3%).

Indonesia : production ↓ Consuption ↑ → Imports Oil

→ Indonesia's subsidy for Oil

- Thus, renewable energy is needed: **Bio fuel**.
- Indonesia has the production potentials, primarily from palm oil and soybean for biodiesel; and maize, sugarcane, and cassava for bio ethanol. ⇒ Demand for these crops and land do increase. This may lead to a competition between bio fuel development and food security.

National Energy policy: Presidenntial decree No. 5/2006



Oktaviani et.al (2011)

→ analyse impacts of policy options (productivity, land extention and intermediate demand increases) and the global food and mining price changes on bio fuel and the Indonesian economy performance

↓

database structure of the model:

- Industries and Commodities: 68 goods and services produced by 68 corresponding industries (New disaggregation on **Bio fuel and Cassava)**
- Regional: JavaBali, Sumatera, Others
-Factors of Production:
1. Labor: Farmer, operator, administrator, manager.
2. Capital
3. Households: 7 rural and 3 urban

↓

Using 5 simulation models

-5 simulation models (*Oktaviani et.al 2011)*

Sim1. escalating prices agricultural (Sugarcane, Rice, Maize and PalmOil) and mining (Petrolium and Coal), which is considered as various external shocks to Indonesian economy

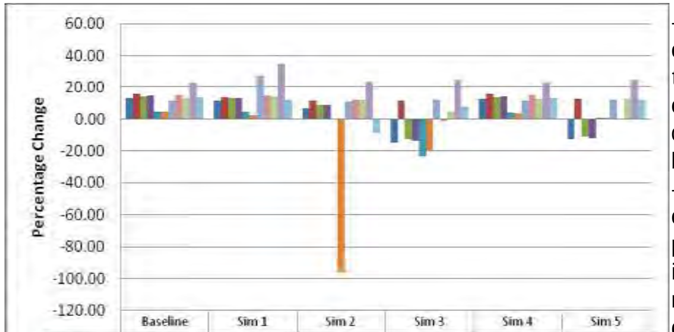
Sim 2. increasing demand for CPO as the main intermediate inputs for bio fuel with 15 per cent shock to baseline (Indonesian Biofuel Mandate by 2015)

Sim 3. increasing Total Productivity (TFP) , which is computed from Bank Indonesia (2011). -rice 13.14 %; -maize 13.14 %; -cassava 13.14 %; - sugarcane 16.07 %; - palm oil 16.07 %

Sim 4. Biofuelmandate by increasing the demand for land.
- Paddy (34 %/ year); maize (1,86 %/ year), CPO (10.82 %/ year), sugarcane (1.69%/year), cassava (0.95 %/year)

Sim 5. Combination Sim 3 and Sim 4

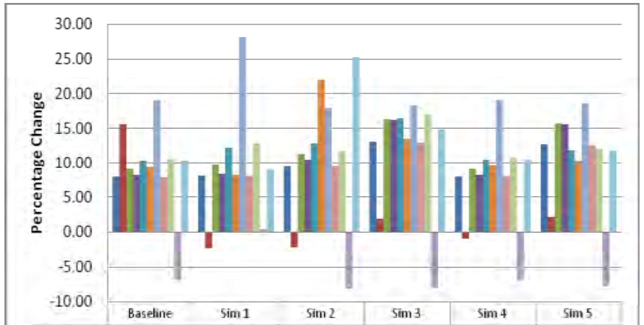
Impact on prices (Octaviani *et al*, 2011)



	Baseline	Sim 1	Sim 2	Sim 3	Sim 4	Sim 5
Paddy	12.86	11.40	6.52	-14.49	12.73	-12.67
Soybean	15.54	13.65	11.23	11.44	15.50	12.64
Maize	14.19	13.25	8.59	-12.62	13.80	-11.01
Cassava	14.55	13.21	8.66	-13.90	14.29	-12.18
Sugarcane	4.50	4.40	-0.45	-23.22	4.22	0.39
CPO	4.73	2.61	-95.81	-19.97	3.42	0.06
Coal	11.23	27.65	10.99	12.16	11.23	12.17
Rice	15.16	14.61	11.97	-1.15	15.09	-0.19
Sugarcane	12.81	14.14	11.79	4.66	12.73	12.27
Petroleum	23.44	34.98	23.46	24.78	23.45	24.72
Biofuel	13.36	12.12	-8.81	7.61	13.07	12.04

-Biofuel and majority of sectors experience the decreasing of output price compared to baseline.
- Increasing demand of palm Oil and productivity of intermediate good more sensitive to decrease biofuel price
- However, it is compansated by a decrease on Palm Oil price

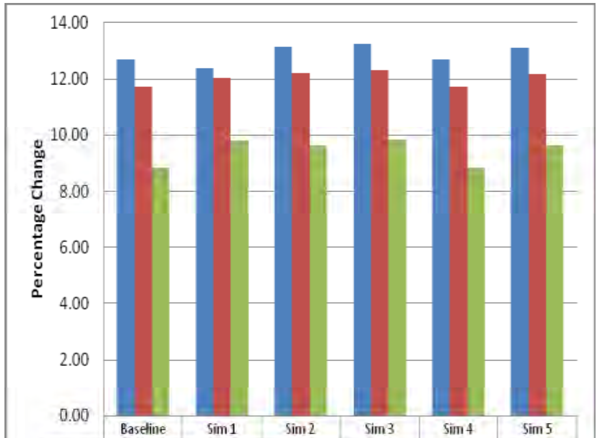
Impact on productivity (Octaviani *et al*, 2011)



	Baseline	Sim 1	Sim 2	Sim 3	Sim 4	Sim 5
Paddy	7.94	8.14	9.52	13.05	7.97	12.65
Soybean	15.54	-2.42	-2.22	1.84	-1.02	2.07
Maize	9.05	9.67	11.36	16.27	9.15	15.64
Cassava	8.21	8.40	10.41	16.16	8.28	15.55
Sugarcane	10.34	12.22	12.82	16.43	10.41	11.86
CPO	9.33	8.24	21.92	13.46	9.54	10.31
Coal	19.05	28.10	17.90	18.29	19.04	18.57
Rice	7.90	8.10	9.48	13.02	7.93	12.62
Sugarcane	10.60	12.84	11.66	16.91	10.65	12.12
Petroleum	-6.88	0.41	-8.11	-8.00	-6.90	-7.69
Biofuel	10.28	8.98	25.28	14.86	10.48	11.79

The impacts on outputs vary among sectors
- Strong demands for palm oil increase the highest bio fuel output
- Simulation 5 caused an improved performance on biofuel and other sectoral output , but not as big as productivity increase (simulation 3).

Biofuel Impact on Indonesian's Regional GDP (Octaviani *et al*, 2011)



	Baseline	Sim 1	Sim 2	Sim 3	Sim 4	Sim 5
JavaBali	12.68	12.38	13.15	13.25	12.68	13.11
Sumatra	11.73	12.02	12.20	12.32	11.74	12.18
Others	8.84	9.79	9.63	9.84	8.85	9.62

- There is a substantial decrease in GRDP of Java-Bali which is the main producer of agricultural commodities and increases in GRDP of Sumatra due to Global price increases (Sim 1)
- Increasing the demand of CPO as intermediate good for biofuel lead to increases in GRDP of Java-Bali and Sumatra (sim 2)
- Increased productivity (sim 3) would increase GRDP of all regions more than that caused by expansion of feed stock land (sim 4).

- Major challenges facing biofuel development in Indonesia include :

1. Further research needed to increase feed stock productivity without causing substantial trade-offs between food, fuels, feed, and forest.
2. The need for capacity building for policy makers, researchers and academic community, private sectors and academic agencies to improve efficiency and productivity especially of labor

Research institutes involved in rice cultivation development

→ Many Indonesian institution/university involved in rice research development such as :

→ **Indonesian Agency for Agricultural Research and Development (Ministry of Agriculture):**

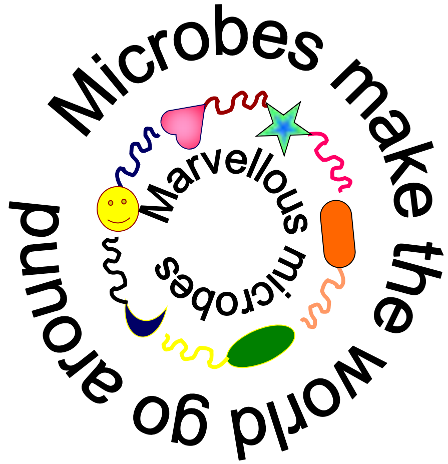
- Indonesian Center for rice research
- Indonesian Center for Agricultural Biotechnology & Genetic Resources
- Indonesian soil research institute
- Indonesian Center for Food Crops Research and Development

Universities (Ministry of Education):

- Bogor Agricultural University
- University of Gajah Mada
- University of Padjajaran
- University of Lampung
- And other institutions

Research on Rice variety development, Genetic improvement, Organic farming, Precision farming, Biofertilizer, Crop rotation, etc.

Thank You



CEE-PERDO Center for Energy Technology and Environment

APN

JGSEE The Joint Graduate School of Energy and Environment

"Sustainable agricultural production – Focus on rice production in (Myanmar)"

Khin Lay Swe

Yezin Agricultural University

Capacity Building Workshop on:
"Strategic rice cultivation with energy crop rotation in Southeast Asia – A path toward climate change mitigation in the agricultural sector"
29-31 May 2013
Bangkok, Thailand

Sown Area and Production by Different Crop Groups in Myanmar (2010-11)

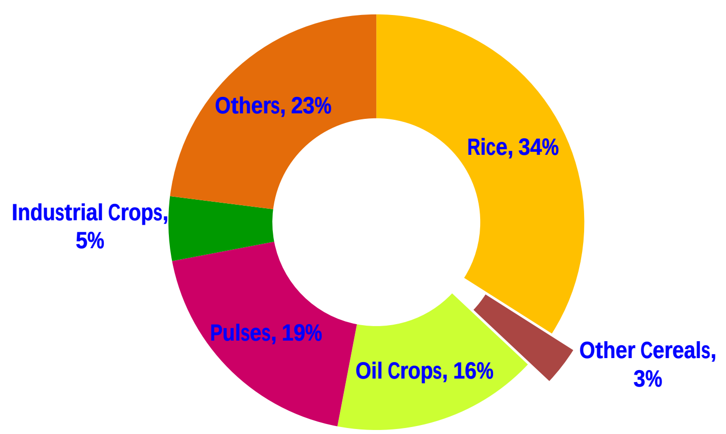
Crops	Sown Area (,000 ha)	Production (,000 mt)	Sown area %
Paddy	8047	32579	34.13
a. Monsoon Rice	6793	26769	28.81
Summer Rice	1254	5810	5.32
b. Wheat	101	184	0.43
c. Sorghum	221	192	0.94
d. Maize(seed)	389	1376	1.65
Oil Seed Crops	3814	3132	16.18
a. Groundnut	877	1392	3.72
b. Sesame	1585	861	6.72
c. Sunflower	859	790	3.64
d. Mustard	102	89	0.44

Source: Settlement and Land Records Department

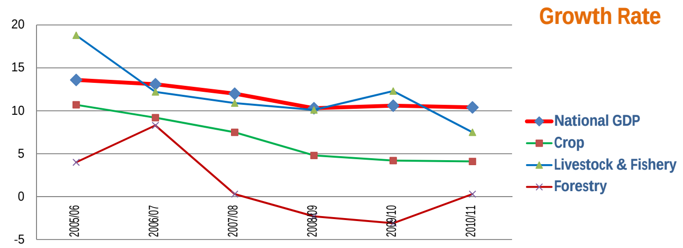
Sown Area and Production by Different Crop Groups in Myanmar (2010-11)

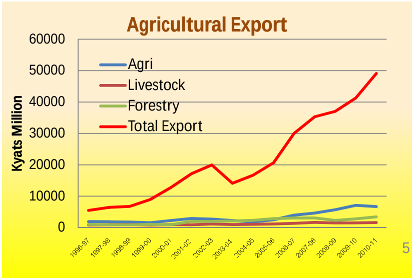
Crops	Sown Area (,000 ha)	Production (,000 mt)	Sown area %
Pulses	4501	5912	19.10
a. Black gram	1055	1603	4.48
b. Green gram	1121	1410	4.75
c. Chick pea	332	467	1.41
d. Pigeon pea	633	837	2.68
Industrial crops	1016	684	4.31
a. Cotton	351	550	1.49
b. Sugarcane	155		0.66
c. Rubber	504	128	2.14
Plantation crops (Tea, Coffee, Coconut)	213	1180	0.90
Vegetables	542		2.30
Fruit tree	553		2.34

Sown Area and Production by Different Crop Groups in Myanmar (2010-11)



Agriculture Sector





Different Rice Environment in Myanmar

Rice Environment	Sown Area (ha)	%
Favorable Rain-fed	4,267,954	63
Flooded	581,198	9
Deep water	357,483	5
Upland	1,115,605	16
Taung-yar	295,993	4
Saline	114,350	2
Others	63,079	1
Total	6,795,662	100

Rice Sown Areas by Varieties, 2011

States/Regions	Special HYV	HYV	Quality Rice	Local Rice	Total (ha)
Kachin	2,301	34,916	15,398	64.788	260,402
Kayah		18,579	843	22.038	41,461
Kayin		166,228	4,869	47.438	218,535
Chin		9,102	19	47.062	56,184
Sagaing		447,716	263,695	28.554	739,9645
Tanintharyi		95,798	1843	45.565	143,206
Bago		908,765	157,579	166.591	1,232,935
Magway		342,257	12,316	6.622	361,194
Mandalay	2	245,914	22,780	39.228	307,924
Mon		172,960	32,294	152.667	357,921
Rakhine		376,768	18,696	97.809	493,273
Yangon	19	292,272	39,592	153.948	485,832
Shan States	75916	135,766	42,389	340.425	594,497
Ayeyarwady		836,682	235,351	430,301	1,502,334
Total	78239	4,083,725	990,662.75	1,643,035.63	6,795,662
%	1	60	15	24	100

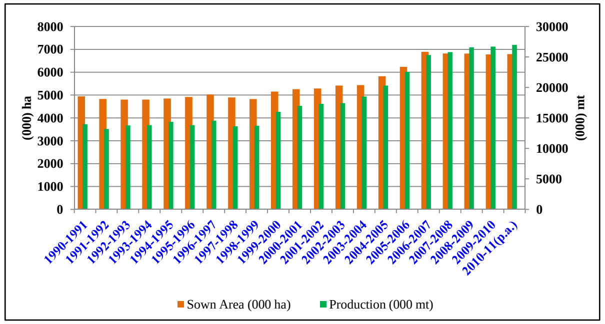
Rice Cultivation Practices

Type of sowing	Area (ha)	%
Transplanting	4,351,321	64
Broadcasting	1,593,311	23
Direct Seeding	851,031	13
Total	6,795,662	100

Paddy Production

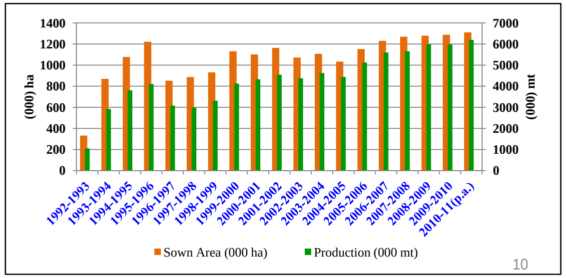
Year	Sown Area (Million ha)	Yield (MT/ha)	Production (Million MT)
1996 - 97	5.88	3.06	17.68
1998 - 99	5.76	3.13	17.08
2001 - 02	6.45	3.42	21.92
2002 - 03	6.49	3.42	21.81
2003 - 04	6.54	3.54	23.14
2004 - 05	6.86	3.64	24.75
2005 - 06	7.39	3.75	27.68
2006 - 07	8.12	3.83	30.92
2007 - 08	8.09	3.93	31.45
2008 - 09	8.09	4.03	32.57
2009 - 10	8.07	4.06	32.68

Agriculture sector is contributing 33% (2009-2010) of the GDP leading to 17.5% of total export earnings and employing more than 61.2% of the labor force.



Sown Area and Production of Monsoon Rice in Myanmar

Sown Area and Production of Summer Rice in Myanmar



Source: Myanmar Agriculture Service (2011)

Irrigation Facilities (Irrigation Department, MOAI)

Year	Number	Beneficial Area(Ha)
Myanmar Kings Era to 1961-62	69	540,752
1961-62 to 1988-89	69	
1988-89 to 2011 August	233	1,144,174
Total	371	1,684,926
Irrigation coverage (1987-1988)		12.5%
Irrigation coverage (2009-2010)		17.1% of the sown area

Irrigation Facilities

Project	Number	Beneficial area (ha)
Pump Irrigation from river	**327**	**201095**
• Electric pumping	136	155132
• Diesel pumping	191	45963
Groundwater for agriculture	**8279**	**41537**
▪ Deep Tube wells	5212	
▪ Shallow Tube wells	3067	

Source: Water Resource Utilization Department, MOAI

Department of Agricultural Research (DAR)

- ✓ DAR has 18 outreach research stations: Specific adaptive research activities for main crops
- ✓ Rice Division, introduction of new lines : Rice varietal improvement for different ecological zones
- ✓ Conventional Plant breeding/ Mutation breeding
- ✓ 28 HYV released; widely grown in Myanmar

Distribution of PGR (2009) in National Seed Bank

Crop	Short-term (10°C)	Medium-term (-5°C)
Rice	6421	6366
Wild rice	141	141
Cereals	2079	1945
Legumes	1052	1045
Oil seeds	638	631
Industrial crop	42	42
Total	10373	10170

Varietal Improvement: Research on Local Rice Varieties

Wild Rice,O. Rufipogon, in **Ayeyarwady Region, seems to be peak flowering time**

Local Rice Varieties for Deepwater Area: Tadaung Po, Sitpwa, Yoesein

Flooded/ Submergence Rice

Rice Research at DAR

Cropping Patterns/ Water Management

- ✓ Effects of Long-term “Rice-Fallow-Rice” and “Rice-Pulses-Rice” on Rice yield and soil properties (2001 – 2010): Black gram fixed 18-73kg N2/ha; 9- 23% yield increase
- ✓ Effects Of Crop Residues on “Rice-Fallow-Rice” cropping system: Early tillage and Late tillage (without straw, with straw, with straw burn): Treatment of incorporating rice straw soon after rice harvest gave the best yield
- ✓ Effects of Water Management systems on rice yields / Drought screening methods: Continuous flooding, Alternate Wet and Dry, Irrigation 2-week intervals ; Irrigation at 2 wk interval--reduced water requirement 26-39% less than the AWD, not yield affected

Rice Research at Yezin Agricultural University

- ✓**Sustainability Assessment of Rice-based Cropping Systems in Central Dry Zone**
- ✓**Screening Methods for Drought Tolerance of Rice Varieties**
- ✓**Diversity of Rice (*Oryza sativa* L.) germplasm from rainfed lowland ecosystem of Bago Division, Myanmar**

High Yielding and Quality Seed Production

Current Policy of MOAI

- Adoption of 14 points Good Agricultural Practices in paddy cultivation and production of good high yield seeds have been undertaken in 2011
- A hybrid seed variety, namely "Pa-le-thwe", was produced in 40 h each of YAU, Shwetaung Farm, Wundwin Township in 2011 with the cooperation of Chinese technicians
- The hybrid seeds were distributed to cultivate 1892 ha in States and Regions for summer paddy cultivation in 2012.

Major Cropping Patterns in Central Dry Zone

First crop	Second crop	Third crop
Low land		
1. M Rice (Irri.)	Pulse	Summer rice
2.Cotton (Pre-mon soon)	Rice (Irri.)	Pulses
3. M Rice (Irri.)	Summer rice (Irri.)	Pulses
4 Sesame	Cotton + Groundnut	
5. Sesame	Cotton + Pulses	
6. M Rice	Onion	
7. Sesame	Cotton (Long Staple)	
8. Cotton	Rice	
9. M Rice	Oilseeds / Pulses / Wheat	
10. Sesame	Rice	
11. Oilseeds	M Rice	Summer rice

Major Cropping Patterns in Central Dry Zone

First crop	Second crop
Upland	
1. Sesame	Maize / Lablab bean
2. Sesame+ Pigeon pea	Cotton
3. Sesame/ Peanut + Pigeon pea	Green gram
4. Sesame/ Peanut	Green gram + Cotton
5. Sesame	Chilli / Cotton(Pre-Monsoon)
6. Sesame/ Peanut	Sesame (Post Monsoon)
7. Sesame	Groundnut
8. Sesame	Green gram + Pigeon pea
9. Sesame	Wheat/ Chick pea
10. Maize (seed)	Pulses
11. Peanut	Sesame
12. Pulses (Green gram)	Sesame

Source: Agricultural Extension Division, MAS (2011)

Major Cropping Patterns in Lower Myanmar

First crop	Second crop	Third crop
Low land		
1. M Rice	Pulses	
1. Jute	M Rice	Pulses
1. M Rice	Summer rice	
1. M Rice	Pulses	Summer rice
1. M Rice	Pulses	Vegetables
1. M Rice	Vegetables	
1. M Rice	Oilseeds	
1. Oilseeds	M Rice	
1. Oilseeds	Oilseeds / Pulses	
1. Jute	Chilli / Vegetable	Pulses+ Cotton

Source: Agricultural Extension Division, Myanmar Agriculture Service (2011)

Major Cropping Patterns in Hilly Regions

Land Class	First Crop	Second Crop
Low Land	M Rice	Summer Rice
	M Rice	Pulses
	M Rice	Vegetables/ Oil seed crops
	Potato	Wheat/ Niger
Upland	M Rice	Pulses
	Pulses (Soybean)	Pulses
	Maize	Pulses
	Peanut	Potato

Rice after Rice;
Garlic after Rice harvest

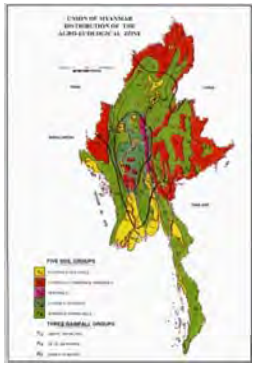
Reforms in Agriculture Sector: : Crop Policy, Pricing and Trade

Rice Policy

- National crop: Production-oriented
- Rice Reserve Program (100,000 mt)
- Guaranteed price
- Diversified crops policy depending on the market demand.
- Peas and beans, oilseed crops fetch more earnings

Agro-Chemical Policy

✓Subsidize for selected target groups
✓Use on requirement and soil fertility
✓Vary the usage depending on crop and fertilizer prices
✓Enforcement of law and regulations: Fertilizer Law, Pesticide Law



Land Use Policy

- Co-ordination among line ministries
- Concrete land use policy
- Farmland law
- Agro-ecological zoning
- Remote sensing & GIS

Rural Credit Policy

- Myanmar Agriculture Development Bank
- Extend loan coverage (rice, sugarcane, cotton, etc)
- Micro-credit systems
- Private sector involvement
- Special loan for very poor and crop losers

- **Pricing policy - balanced between farmers and consumers. When setting the price of output, it should take account of input price.**
- **Government should establish instruments such as: reserve or buffer stock,, and taxation system.**
- **Trade policy. Maximizing the interest of the state and the people, following the market-oriented system and sustainable development should be considered in trading.**

Export Value (mil. USD)

Year	Rice	Pulses
2008/09	198.2	744.5
2009/10	254.2	929.9
2010/11	198.1	799.8
2011/12	267.2	986.1
2012/13	568.9	912.0

Source: CSO (2012), Commerce (2013)

Trade related services: like banking system, market development, port facilities, transport system, lab testing, tariff rates, exchange rate, trade services, trade barriers, and foreign direct investment (FDI).

Trade Data

Foreign Trade

Year	Export	Import	Total (mil USD)
2008-09	6,779.1	4,543.3	11,322.4
2009-10	7,586.9	4,181.4	11,768.3
2010-11	8,861.0	6,412.7	15,273.7
2011-12	9,135.6	9,035.1	18,170.7

Rice Export

Year	Normal	Border	Total (MT)
2009-10	81,8464	77,448	89,5912
2010-11	53,6840	-	53,6840
2011-12	65,4974	13,6113	79,1087
2012-13	54,7637	72,3615	1,271,252

Agricultural Export

Year	Agri	L&F	Forestry	Total (mil USD)
2008-09	1,035.0	273.7	429.0	1,737.7
2009-10	1,302.7	277.2	512.9	2,092.8
2010-11	1,209.8	288.0	615.3	2,113.1
2011-12	1,497.6	446.8	625.4	2,569.8

Policy Changes Related to Crop Production

- Myanmar launched "the whole township special high yielding production program in 1977 with the introduction of high yielding rice varieties and improved technologies
- 1992: A summer rice program was introduced in high yielding varieties together with proper irrigation system and high input technology.
- Since 1988, removal of state procurement policy on rice, cotton, sugarcane and rubber, and pricing at market rate substantially increased the production and farmers' income.
- Great impact on agricultural sector. Farmers have grown much more land under pulses, cotton

Policy Changes Related to Crop Production

A comprehensive reforms: Deregulation - liberalizing agriculture and trade

- Market-oriented economic and agricultural reforms, since 1988, free trade was allowed within country for all crops, some crops were permitted to export except rice
- Subsidy of chemical fertilizer and pesticide for rice farmers was eliminated in 1993-94,
- Procurement of rice at low price was totally abolished in 2003, and rice ration system for civil servants was abolished in 2003.
- An export ban for private sector was imposed in rice until 2007

Water Management Practices

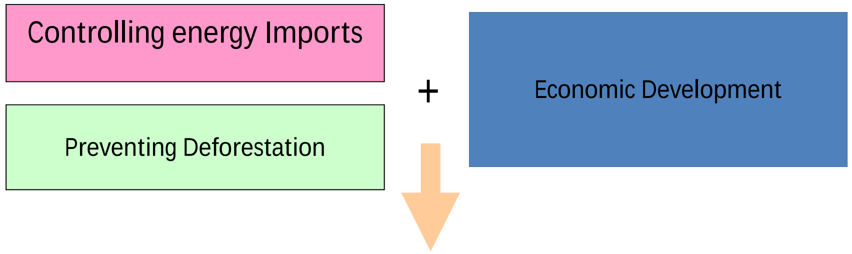
Irrigation water mostly to the rice fields

- The crop choice -- an important factor to be considered for sustainable crop production.
- In water-scarce areas, the land-use system should prioritize the cultivation of crops of high value and requiring less water, such as pulses and oilseeds
- Eg, for the similar soil type and weather condition, rice needs irrigated water of 750-1440 mm per hectare,
- Other crops such as wheat need 375 mm, maize, sorghum, and groundnut need 510 mm, 150 mm, and 360 mm per hectare respectively (Chandy, 2004).
- Due to the high production cost of rice, it is not so profitable and price competitive anymore. Additionally, it requires more irrigated water than any other crop.

Water Management Practices

- Water productivity: to increase yield production per hectare per unit of water used, both under rain-fed and irrigated conditions
- The maintenance of irrigation system and irrigation water management activities, including efficient water use technologies -- successfully conducted through the formation and empowerment of water user groups.

Myanmar Energy Policy



1. Increase energy self-sufficiency
2. Promote the utilization of renewable energy
3. Enhance energy efficiency and promote energy conservation
4. Prevent deforestation caused by excessive use of fuel wood and charcoal
5. Promote use of alternative fuels in household
6. Develop hydroelectric power as a core power source

Rural Energy Policy

"National Energy Policy" and "Energy Regulation" are currently under processing

MOAI: Development of *bio-fuel industry & appropriate regulatory measures;*

Policy of Ministry of Industry

No specific rural energy policy was observed, however, aim/ objectives of " *Rural Energy Development support Committee"* headed by Union Minister of Ministry of Industry stated as follows:__

> To improve the socio-economic development of rural populace, by harmoniously implementing the activities/ plan of rural energy development, that may support the Rural Development & Poverty Alleviation.

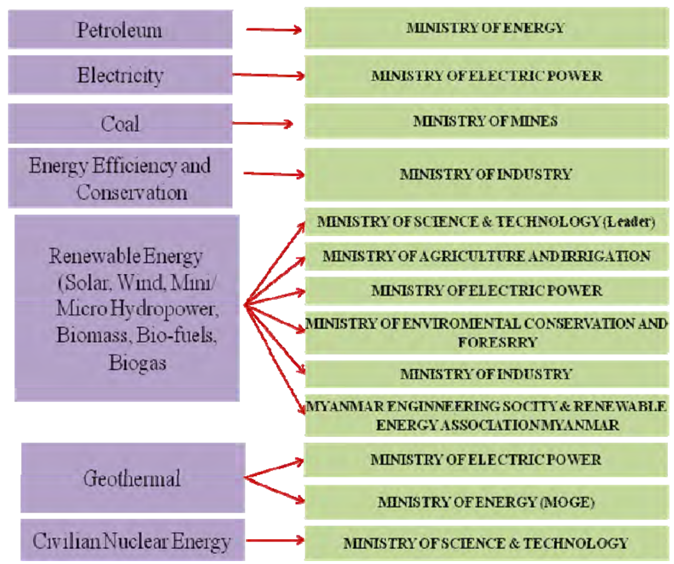
Policy of Ministry of Border affairs

The Department of Rural Development (DRD)

One of the major tasks "*Undertaking rural electrification works through renewable sources*"

Institutional Framework for Myanmar Energy Sector by MOE

- **All energy sectors under the umbrella of National Energy Management Committee**



Estimated Rice Husk Production and Usage

		No. of rice mill	Capacity (ton/24hrs)	Estimated paddy production ('000 ton/year)	Estimated Husk volume ('000 ton/year)	Rice husk for power plant ('000 ton/year)
Large scale rice mills	State	68	5,113	1,637	307	32
	Private	1,158	26,626	8,002	1,600	320
	Total	1,226	31,738	9,539	1,907	352
Small scale rice mill		10,469	41,341	12,424	2,485	-
Total		11,695	73,079	21,963	4,392	352

Source: Myanmar Rice Millers' Association

ASEAN Energy Award 2006, Kaung Kyaw Say Engineering Co. *Ltd*, Gasifier Models

Rural Electrification with rice husk gasifier at "Lin-thar Village, Thandwe Township, Rakhine State

ASEAN Energy Award from ASEAN Centre for Energy in 2006

Village Electrification with Rice-husk Gasifier

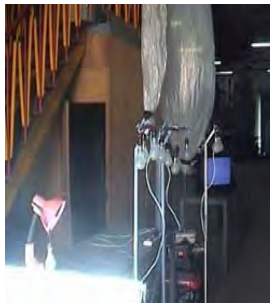
Ywa Htaung Gon village,
Thegon Township, Pago Region

The total cost amounted to Kyats 10,146,640

- Beneficiaries: 100 households and 500 people
- Year: 2010-2011

Low Cost Plastic Biogas Plant

✓Myanmar Agricultural Produce Trade Department of the Ministry of Commerce
✓32 Kg of Cow manure are fed in daily mixing with water equality to produce 1 m^3 of gas for continuous use
✓Biogas digester built with bamboo mats coated rubber compound liquid



Applications

- Lighting
- Engines
- Cooking
- Heating

Biogas from Cow Dung Manure

Biogas from biomass for electrification in rural area
Kyauk-se Township, built by Ministry of Science & Technology

Electricity from Biogas Shwepay Village in Pyinmana Township

Biogas plants installed in different States and Divisions; Ministry of Sciences and Technology from 2003 to 2009

State / Regions	Capacity of biogas, m^3	Number
Mandalay	100	1
	50	107
	25	1
	20	1
	8	2
	Subtotal	109
Sagaing	50	23
	10	1
	Subtotal	24
Magway	50	8
Shan North	50	1
Shan South	10	1
Kayah	50	1
Kachin	10	1
Ayarwaddy	10	2
Bago	8	1
Naypyitaw	8	8
	Total	156

Present and Future Ethanol Producing Plants and Production Capacity In Myanmar

Name of plant	Gallon/day	Status
Ethanol Distillery No.2 Sugar mill (MSE)	500	Operating
Kantbalu Distillery (MEC)	3000	Operating
Taungsinaye Distillery (MEC)	3000	Under construction
Mattaya Distillary	15,000	Operating

Source: Ministry of Energy, 2011

"Sustainable agricultural production – Focus on rice production in Vietnam "

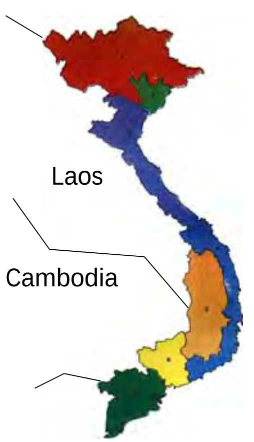
Assoc.Prof. Dr. Nguyen Thi Phuong Thao
Faculty of Biotechnology, Hanoi University of Agriculture

Capacity Building Workshop on:
"Strategic rice cultivation with energy crop rotation in Southeast Asia – A path toward climate change mitigation in the agricultural sector"
29-31 May 2013
Bangkok, Thailand

Outline

- General Information
- Plantation area
- Cultivation practice
- Rice varieties
- Fertilizer used
- Plan to improve of rice plantation in the future
- Adaptation and mitigation of rice cultivation for sustainability development
- Solutions for rice production stability & development

General Information



Vietnam:

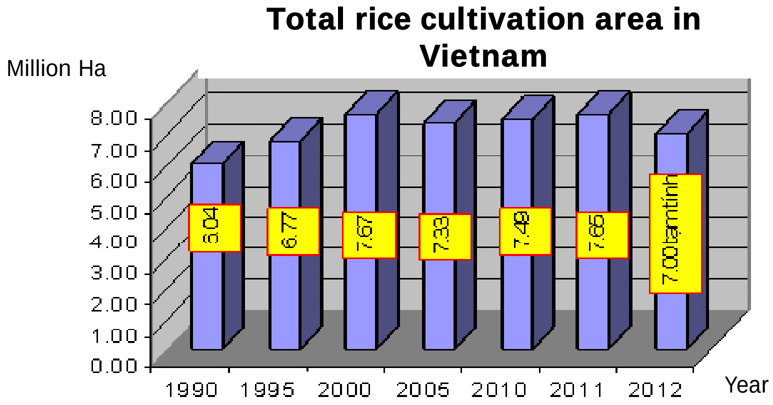
- \- **Population: 86 mil.people**
- **Total area: 331.000 km2**
- **¾ of area is mountains**
- **Cultivation land occupies ~ 28%**

- **Cultivation Land per capita:**

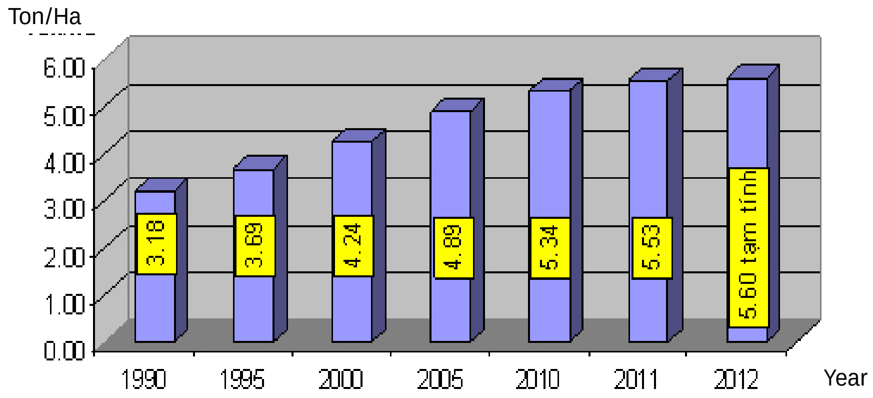
In Mekong Delta and East-Southern regions: 1,000m2/person

In other regions: 400 m2/person

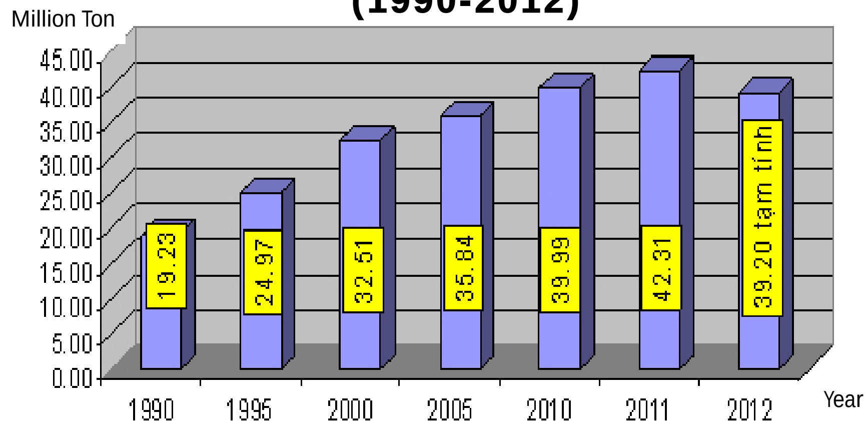
Rice plantation area



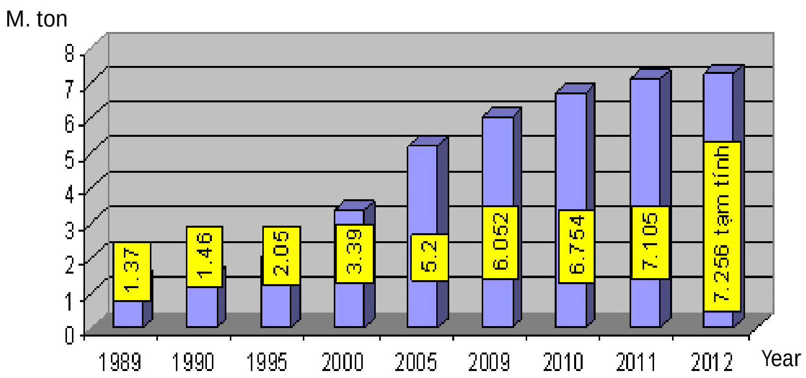
Average yield



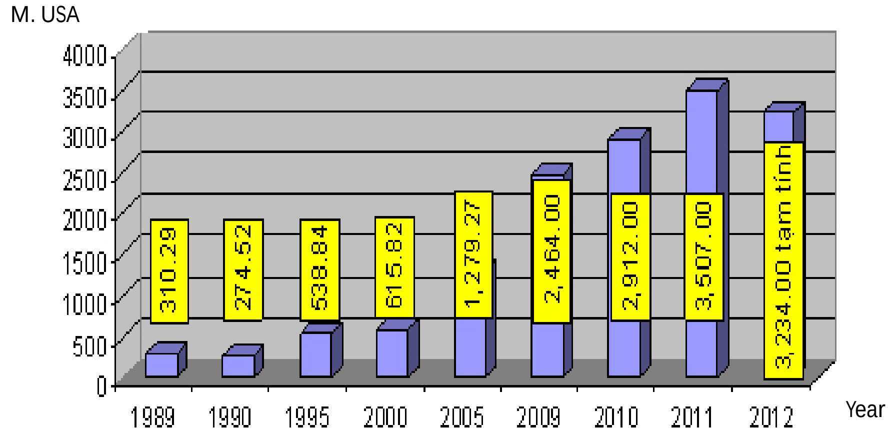
Total rice productivity of Vietnam (1990-2012)



VIETNAM RICE EXPORT (1989-2012)



Rice export value (1989-2012)



Main Rice production regions

- Rice productions are differently distributed in the country:
  - **Red river Delta** & **Mekong Delta**: main country Rice Production areas
  - **Other regions**: Self-sufficient rice production

Water regime

	% DT	DT (1.000 ha)
Irrigated	80.0	3,440
Rainfed	5.0	217
Deepwater	4.5	193
Upland	10.5	450

Areas, Productivity and Yield distributed by Regions

Region	Area (Million ha)	Productivity (tons/ha)	Yield (Mil.tons)
Total the Country	**7.44**	**5.23**	**38.89**
1.RedRiver Delta	**1.16**	**5.88**	**6.80**
2. Northern Mountain	**0.67**	**4.55**	**3.05**
3.Northern Central	**1.22**	**5.12**	**6.25**
4.Central HighLand	**0.21**	**4.65**	**0.99**
5.East Southern	**0.31**	**4.31**	**1.32**
6.MekongDelta	**3.87**	**5.29**	**20.48**

Rice Cultivation Practices

- **In Northern Mountainous (region 1):**

- **"Milpa" cultivation**: Depends on raining water, using dry varieties, without fertilizers & insecticide/Plant protection – Very Low productivity.
- **Terraced fields:** Depends on raining water, using dry varieties, without chemical fertilizers & insecticide/Plant protection, Very few compost - Very Low productivity.

Rice Cultivation Practices

- **Red River Delta (Region 2)**
- ✓ **Paddy rice cultivation: Based on active irrigation water provision; High intensification; Using high productive varieties; Overuse of chemical fertilizers & Pesticide : High productivity.**
- ✓ **Almost 90% of growing time: the rice plants are in 10-15cm of field water.**
- ✓ **Some recent new practices, applied for mitigating Climate change:**
- In the Period of rice seedling transplanting growth: keeps rice filed dry/damp in 2 periods:
  - First period: during 7-10 days after 10 days from rice transplantation.
  - Second period: during 7-10 days after 30 days from rice transplantation.
- In the Period of rice seedling Reproducting growth:
  Keeps rice filed in 4-5cm water in the period of time from 45 days after transpantation until 15-20 days before the harvest.

Rice Cultivation Practices

- **The Central/Coastal region (Region 3):**
- **In Mountainous areas:**
  Depends on raining water, using dry varieties, without chemical fertilizers & insecticide/Plant protection, Very few compost - Very Low productivity.
- **In coastal plain areas: Paddy rice cultivation Based on active irrigation water provision; High intensification; Using high productive varieties; Overuse of chemical fertilizers & Pesticide: Main & High productivity**

Rice Cultivation Practices

- **Mekong Delta region (Region 6):**
- 75% cultivation area in Active irrigation water provision: **High intensification; Using short-term & high productive varieties; Overuse of chemical fertilizers & Pesticide: High & very high productivity;**
  During most of growing time rice plants are filled with water.
- 25% cultivation area depends on raining water (Cultivation during March-April to Nov.-Dec.) ; Main intensification; Extremely Short-term varieties; Main level of use of **Overuse of chemical fertilizers & Pesticide: High productivity**
  During 100% growing time rice plants are filled with water.

Rice Variety

- **Rice seeds are important.**
  Improvement of Rice seeds have been achieved through different periods:
- **In '60s -'70s:** The criteria on selection of rice seeds have been based on outward aspect (physical) of rice plants.
- **In '80s:** Change on research objective by stabilization of productivity towards seeds having good resistance to pestilent insect.
- **In '90s:** Concentration of efforts on Improving Productivity and Quality of rice seeds.
- **In 2000s:** Research on rice seeds based on improved rice seed quality in combination with improved resistant capacity .

Rice Variety

- **Depending on Local Specific Climates, Soils & Traditions: Different areas – Different rice varieties**.

1. In the North (Red River Delta, Mountainous & Northern Central) mainly used the following varieties:

- **Local varieties:** Tam Xuan Đai, Tam Xoan Thai Binh, Tam Den Hai Phong, Tam bang Phu Tho, Du Huong, Nep cai Hoa vang, Tep lai...
- **Imported Chinese or Originated Chinese varieties**: Short Moc Tuyen, Short Bao Thai, M90, Bac Yu 64, Cross-Breeding 5, Nhi Yu 63, Khang Dan 18, Short Ay 32...
- **Originated IRRI' varieties**: Selected or Cross-Breeded from: IR24, IR 17494, IR 1820, IR 36, IR 46, IR 2053-26-3-5-2, IR 2588, IR 19746-11-33, IR 8423-132-622,...

Rice Variety

2. In the South (East-Southern, Mekong Delta, Central HighLand) there're following varieties:

- **Local varieties**: Early Thom, Nang Thom Nha Be, Thom Binh Chanh, Nang thom Đuc Hoa, Nang thom cho Dao, Nang Huong, LC90-4, ...
- **Varieties originated from IRRI**: Selected or Cross-Breeded from: **IR 49517-23**, **IR 59606**, **IR 64**, **IR 68**, **IR 66**, **IR 66707**, **IR 56279**, **IR 32893**, **IR 48**, **IR 8423**, **IR 50401**, **IR 44592**, **IR 9729-6-7-3**, **IR 62032**...

Hybrid rice varieties

No	Developer	Female parent lines	Male parent lines	Hybrids
1	Hanoi University of	T47S, T1S-96, 103S, T70S, 135S, T23S, P5S, T8S, T9S, T10S	R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, R12, R15, R16, R18, R20, R50, R75	- VL20, VL24, TH3-3, TH3-4, TH3-5, TH5-1, TH7-2, TH8-3, VL50, TH7-5, TH3-7 (2 dòng) - CT16, TH17, TH18
2.	Trung tâm Nghiên cứu và PT lúa lai Viện KHNN Việt Nam	- CMS: AMS72A, AMS 6A - TGMS: AMS 35S-1, AMS 35S-2, AMS 36S-7, AMS 34S-10, AMS 35S-11, AMS 37S-76. - TGMS (gene WC): D51S, D52S, D59S, D60S, D116S	RTQ5, R527, Q99, PM3, R242, GR10, R108.	HYT83, HYT100, HYT92, HYT102, HYT103, HYT108, HYT106.
3	TT Giống nông lâm nghiệp Lào Cai	136A; 137A.	100 dòng bố	LC25, LC212, LC270
4.	TT WD KHKT nông lâm nghiệp Thanh Hóa	TX1A	10 dòng bố	Thanh ưu 3, Thanh ưu 4
5	Công ty Giống cây trồng miền Nam	: II32A, Bo A, Kim 23A	R998	903KBL, Nhị ưu 838 KBL, Nam ưu 603, NƯ 604, NƯ 605, HR182

Rotation Crops

- ***Northern Mountains (region 1)***
  - ✓ 2 rice crop: 50% area
  - ✓ 1 rice crop + 1 subsidiary/vegetable crop: 20% area
  - ✓ 1 rice crop: 30% area (Terraced field & "Milpa cultivation")
- ***Red River Delta (region 2):***
  - ✓ 2 rice crops: 50% cultivation area
  - ✓ 2 rice crops + 1 subsidiary/vegetable crop: 40% area
  - ✓ 1 rice crop + 1-2 subsidiary/vegetable crops: 10% area
- ***Northern Central (region 3)***
  - ✓ 2 rice crops: 50% cultivation area
  - ✓ 1 rice crop + 1 subsidiary/vegetable crops: 30% area
  - ✓ 1 rice crop: 20% area

Rotation Crops

- ***Central Highlands (Region 4)***
- ✓ 2 rice crops: 30% cultivation area
- ✓ 1 rice crop + 1 subsidiary/vegetable crop: 30% area
- ✓ 1 rice crop: 40% cultivation area

- ***East-Southern region (region 5):***
- ✓ 2 rice crops: 60% cultivation area
- ✓ 2 rice crops + 1 subsidiary/vegetable crop: 30% area
- ✓ 1 rice crop + 1 subsidiary/vegetable crop: 10% area

Rotation Crops

- ***Mekong Delta region (region 6)***

In Alluvial soil & freshwater: 40-45% area

- ✓ 2-3 rice crops
- ✓ 2 rice crops + 1 subsidiary/vegetable crop
- ✓ 2 rice crops + fish/shrimp integration

In raining water with salty contamination: 55-60% area

- ✓ 2 rice crops
- ✓ 1 rice crops + fish/shrimp integration
- ✓ 1 rice crop

Estimates of fertilizer use in rice cultivation in Viet Nam

Region	Urea	NPK	SP	Potash	DAP
			(kilograms/hectare)		
Red River Delta	170–200	30–35	196–274	30	0
Mekong River Delta	131–165	88–91	5–34	6–14	40–100

Source: IFPRI 1996.

Notes: The range refers to averages for different seasons. NPK refers to compound fertillizer with nitrogen, phosphorous, and potassium. SP is superphosphate, and DAP is diammonium phosphate.

Farmers are applying around 170 to 182 kilograms of plant nutrients per sown hectare of paddy (IFPRI, 2000).

Chemical fertilizer application for Vietnan rice production, 1976-1994

Year	Total fertilizer use (1000 mt)	Fertilizer use in rice (1000 mt)	Rice area (1000 mt)	Rice production (1000 mt)	Fertilizer use in rice (kg/ha)	Paddy per kg fertilizer (kg)
1976	416	217	5,297	11,827	41	55
1977	432	249	5,469	10,597	46	43
1978	377	183	5,463	9,790	33	53
1979	396	184	5,485	11,363	34	62
1980	436	195	5,600	11,647	35	60
1981	484	221	5,652	12,415	39	56
1982	726	407	5,711	14,390	71	35
1983	931	622	5,611	14,743	111	24
1984	897	595	5,675	15,506	105	26
1985	932	622	5,704	15,875	109	26
1986	1142	796	5,689	16,003	140	20
1987	921	623	5,589	15,103	111	24
1988	1266	865	5,726	17,000	151	20
1989	1040	727	5,896	18,996	123	26
1990	1092	815	6,028	19,225	135	24
1991	1174	884	6,301	19,427	140	22
1992	1306	968	6,423	21,500	151	22
1993	1371	1131	6,559	22,836	172	20
1994	1772	1205	6,598	23,528	182	20

Source: Agricultural Statistics, General Statistics Office, Hanoi

Plan to improve of rice plantation in the future

Three Reductions, Three Gains (3R3G) Program

- To reduce seed rates, fertilizer rates, and pesticide use
- To improve yield, quality and farmers' income and protect the environment

A poster (left) and a billboard used to motivate farmers to adopt "Three Reductions, Three Gains" practices.

"One Must Do, Five Reductions" program

- The one "must do" is to use certified rice seeds;
- The five reductions are to reduce the amount of seeds, pesticides, fertilizer, water, and postharvest losses.

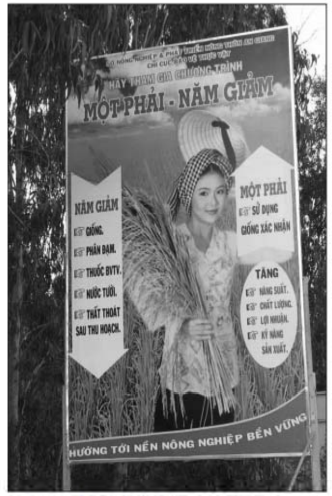


Fig. 5. Billboard used by An Giang Province to promote "Five reductions, one must do," a further modification of the "*Ba Giam, Ba Tang*" campaign.

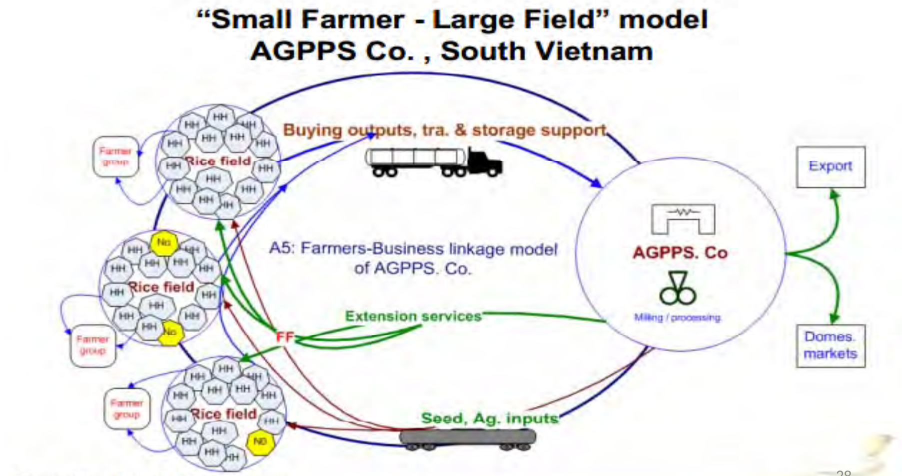
System Rice Intensification -SRI

- Increased rice yield without increasing chemical inputs (benefit for poor farmers)
- Reduced costs of seeds, by 60% (suitable for poor, especially for any using hybrid varieties)
- Reducing labor for transplantation, by 50% (a benefit for women)
- Saving of water by 40% (making SRI more suitable for upland areas)
- Reducing pests and diseases (support for environment)
- Reducing methane emission (support for environment)

the number of SRI farmers increased five-fold from 2009 to 1.3 million in 2012.

New business models for smallholder farmers

LARGE RICE FIELD MODEL



AGPPS. Co: An Giang Plant Protection Joint Stock

Current research and research institute involved

Some of the key institutions involved in rice research specific to Vietnam under the MARD:

- Cuu long delta rice research institute,
- Agricultural Genetic Institute,
- Institute for Food Crop Research,
- Institute for Soils and Fertilizers,
- Institute for Science and Technology,
- Vietnam Agricultural Sciences and Technology Institute,
- Southern Institute for Food Crops,
- Vietnam Agricultural Sciences and Technology Institute,
- University of Agriculture and Forestry,
- **Hanoi university of Agriculture (belongs to MOET)**

Current national & international research projects

- Rice breeding projects by MARD, MOST: to improve submergence, drought, heat, salinity tolerance; simultaneously to mention the resistance to brown plant hopper and blast, the grain properties as chalkiness and amylose content.
- CLUES project by ACIAR and IRRI / rice based farming system in Mekong Delta (salinity, submergence)
- DANIDA project: Improving rice tolerance of submergence and salinity to cope with climate change in coastal areas of Vietnamese Deltas (phase II & III)
- Water management projects by MARD: Mekong Delta and Red River Delta are mainly concerned, the High Plateau and Central Coast.

Rice Research Approaches

- Traditional breeding (hybridization)
- Molecular breeding
- Rice functional genomics
- Next generation sequencing
- GM techniques (research level)

Adaptation and mitigation of rice cultivation for sustainability development

Many factors that affect rice production stability

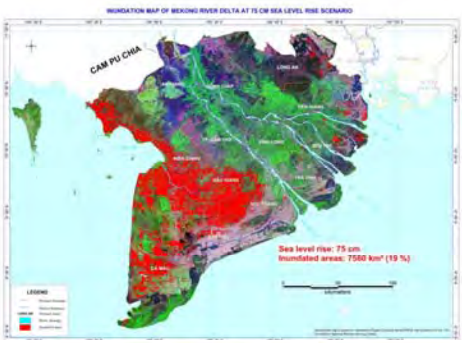
- Rising / fluctuated food prices
- Crop competition (due to low profit/high risk…)
- Poor infrastructure, especially irrigation and transport in mountainous area; storage facility for rice in the Mekong delta
- Harvest by machine: Applying the rice harvest by machine that adapted only 26% rice area in the region of Mekong delta
- High production cost, less sustainable agricultural practices
- Impact of climate change/Natural disaster
  - Shortage of water, submergence, salinization
  - More pest & diseases …

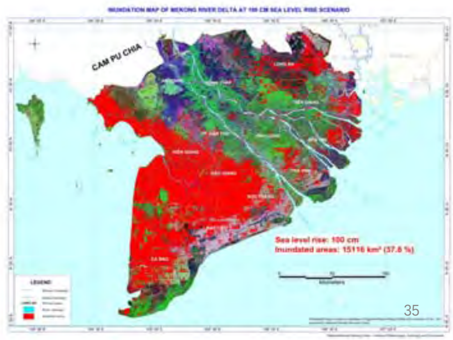
Impact of climate change

Temperature increase at the 2020's scenario

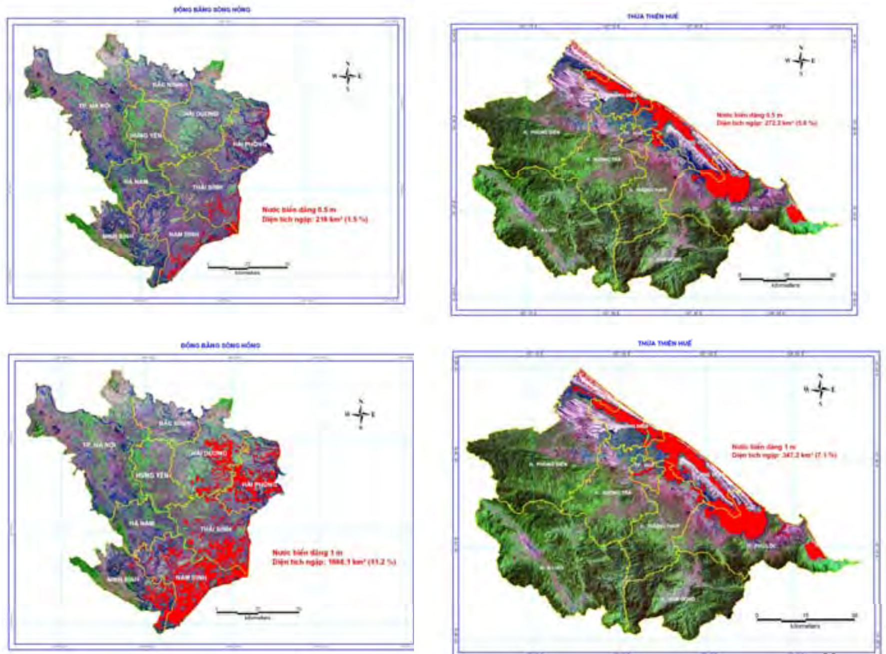
- In 2020 scenario, the average temperature will increase (as compared to 1980 – 1999)
- 2.60C in North-West;
- 2.50C in North-East;
- 2.80C in North Central Coastal Region;
- 1.90C in South Central Coastal Region;
- 1.60C in High Plateau;
- 2.00C in Southern part.

Impact of climate change





Climate Change Scenario, 2009



Climate Change Scenario, 2009

NATIONAL TARGET PROGRAM TO RESPOND TO CLIMATE CHANGE

(Decision No. 158/2008/QĐ-TTg dated 2nd December 2008)

Breeding for resistances of pest & diseases

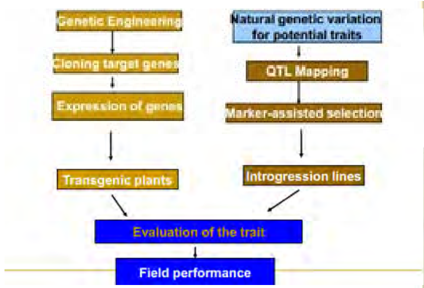
Rice blast fungus Magnaporthe grisea

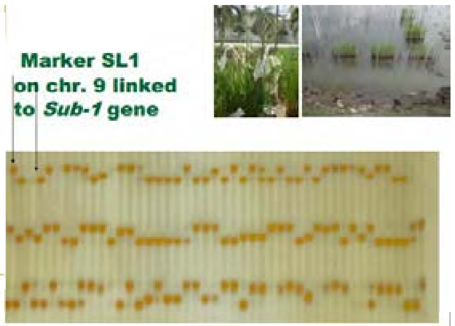
TO TRANSMIT VIRUS DISEASES

BROWN PLANT HOPPER: CURRENT CHALLENGE

DEVELOPMENT SUBMERGENCE TOLERANT RICE VARIETIES

- Strategies for Improving the submergence tolerance in rice





Heat tolerance breeding

Heat tolerance breeding

Salt tolerance breeding

Solutions for rice production stability & development

Policy for strictly protect and manage rice land.

- surveys on rice cultivated land to map growing areas for rice
- to make a "red line" border in reality for specialized paddy rice areas.
- Degree 42/2012/NĐ-CP for the management and use of land for rice cultivation in the rice-growing areas in the country

Policy for rice farmers &

- Support to rice producers in disadvantaged regions, lacking of food
- Continue to apply reduction fee of free irrgation
- Insurance policy for food producing farmer

Solutions for rice production stability & development

Policies for improving rice yield and rice production are also concerned issues.

- Bigger investment in researches on new and better varieties, especially diseases and flood resistant varieties.
- Carry out researches to find out suitable crop structures taking into account the ecological balance, ensuring production efficiency and suitability.
- Develop large-scale rice production in Mekong and Red River Delta by supporting land accumulation and consolidation, expanding or removing land limits and improving agricultural services.

Policies on infrastructure for agriculture

- Speed up the process of building rice storages to enhance the current storage capacity and quality.
- Promoting mechanization in the production, harvesting, processing and storage of rice.
- Providing more and better facilities for rice trading such as construction of Can Tho Port for rice export in the Mekong Delta.
- Strengthening the rice distribution system and trading network such as food retail outlets and warehouse systems.

Rice and energy/biofuel

- Nation plan on biofuel development to 2015 with a vision to 2025,

→ Viet Nam will produce 1.8 million tonnes of ethanol and vegetable oils as biofuels each year.

Potential biofuel from rice biomass

+ Estimatedly in 2011, Vietnam had 110 millions tons of biomass, of which, 70% came from agriculture by products, 30% from wood residues.
+ rice straw: 60 mil tons, rice husk: 10 mil tons

→ With about 4 million ha of rice → to produce 20 million ton of oil

Rice husk: Using rice husk as fuel, paving material for raising chicken/poultry, energy for burning bricks or pottery and porcelain…

Rice straw: using rice straw as fuel, food for cattle or burning on the field. Some areas: Using rice straw for production of bio-fertilizer.

Summary

- Rice production in Viet Nam is still characterized by multiple cropping, small irrigated farms, labor-intensive practices, and widespread use of fertilizer & pesticides
- Many efforts have been done to improve rice production in country including: policies, infrastructure, education, research, production practices.....
- Weather and climate are still key factors in agricultural productivity despite technological advances such as improved crop varieties and irrigation systems

Thank you for your attention!

Contact: ntpthao@hua.edu.vn

Introduction to DNDC model

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Nakornpathom province
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DNDC

- **DNDC: DeNitrification DeComposition Model**
- **DNDC is a comprehensive biogeochemistry model that simulates crop growth and soil C and dynamics based on input data on soil properties, climate, and farming practices (e.g. Li et al., 1992, 1994)**
- **The model was expanded to simulate the emission of trace gases such as NO, N_2O, NH_4 , and CH_4 from agricultural ecosystems and natural wetlands (Zhang et al., 2002; Li et al ., 2004)**

De-Nitrification De-Composition model

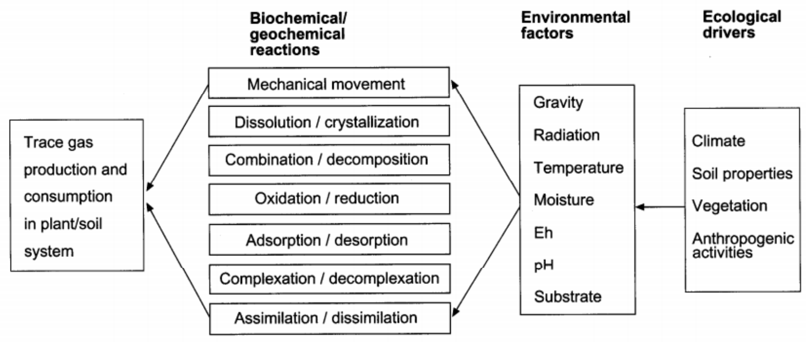


Figure 1. A biogeochemical model is a mathematical expression of biogeochemical field which consists of spatially and temporally differentiated environmental forces driving a series of biogeochemical reactions in ecosystems. Fluxes of NO, N_2O, CH_4, and NH_3 are regulated by directions and rates of the relevant biogeochemical reactions

C.S. Li 2000

DNDC

- **The DNDC model predicts C and N biogeochemistry in agricultural ecosystems at site and regional scales.**
- **The accuracy of prediction depends on the input data on four drivers.**
- **Four major ecological drivers, namely climate, soil physical properties, vegetation, and anthropogenic activities, drive the entire model.**

DNDC

All the impacts in the system can be categorized into 2 groups.

- The first group includes impacts of ecological drivers on soil environmental variables,
- The second groups includes the impacts of the soil environmental variables on trace gas-related geochemical or biochemical reactions.

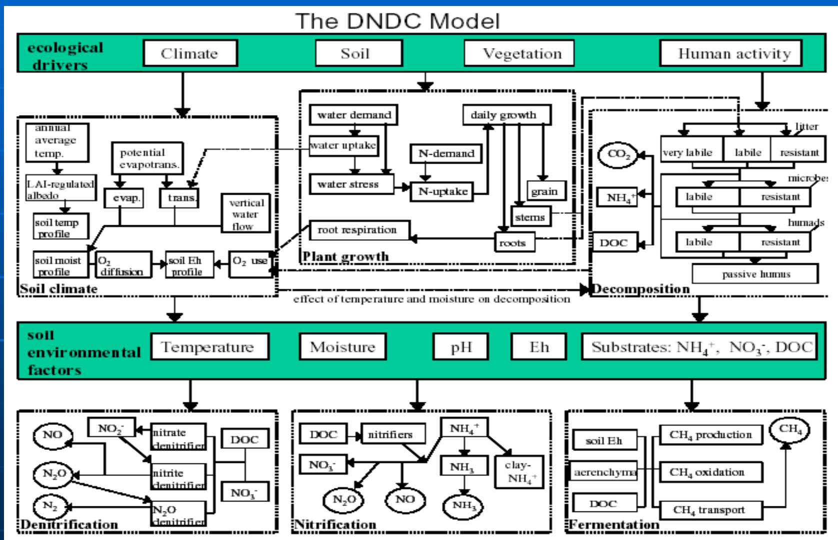
DNDC components

DNDC consisted of 2 components

- The first component consisting of the soil climate submodel, crop growth, and decomposition submodes, predicts soil temperature, moisture, pH, Eh, and substrates component

- The second component consisting of nitrification, denitrification, and fermentation submodels, predicts NH_3, NO, N_2O, CH_4 fluxes

De-Nitrification De-Composition model



Source: University of New Hampshire, 2003

Linking ecological drivers to soil environmental variables

- DNDC needs site-specific input data of climate, soil, vegetation, and farming practices for the simulated agricultural land.

- DNDC integrates the ecological drivers in the three submodels to generate their collective effects on soil temperature, moisture, pH, Eh, and substrate concentrations.

Linking ecological drivers to soil environmental variables

- The soil climate submodel calculates soil temperature, moisture, pH, Eh profiles by integrating air temperature, precipitation, soil thermal and hydraulic properties, and oxygen status.
- By integrating crop characters, climate, soil properties, and farming practices, the plant growth submodel simulates plant growth and its effects on soil temperature, moisture, pH, Eh, dissolved DOC, and available N concentration.

Linking ecological drivers to soil environmental variables

- The decomposition submodel simulates concentrations of substrates (e.g., DOC, NH_4^+, and NO_3^-) by integrating climate, soil properties, plant effect, and farming practices.
- The three submodels interact with each other to finally determine soil temperature, moisture, pH, Eh, and substrate concentrations in the soil profiles at a daily time step.

Linking ecological drivers to trace gases

- The links were set up based on either the basic physical, chemical, or biological laws, or equations obtained from the experiments under controlled conditions so that effect of each soil variable could be distinguished.

Linking ecological drivers to trace gases

- Biological oxidation/reduction dominates NO and N_2O evolution in soils.
- Nitrification (i.e., microbial oxidation of ammonium) has been observed to be the main source of NO and N_2O under aerobic conditions.

$$\text{Nitrification: } \begin{array}{ccccccccc} NH_4^+ & \rightarrow & H_2NOH & \rightarrow & NOH & \rightarrow & NO_2^- & \rightarrow & NO_3^- \\ & & \downarrow & & \downarrow & & & & \\ & & NO & & N_2O & & & & \end{array} \qquad (1)$$

- The factors controlling nitrification have been determined to be soil temperature, moisture, pH, and NH_4^+ concentration.

Linking ecological drivers to trace gases

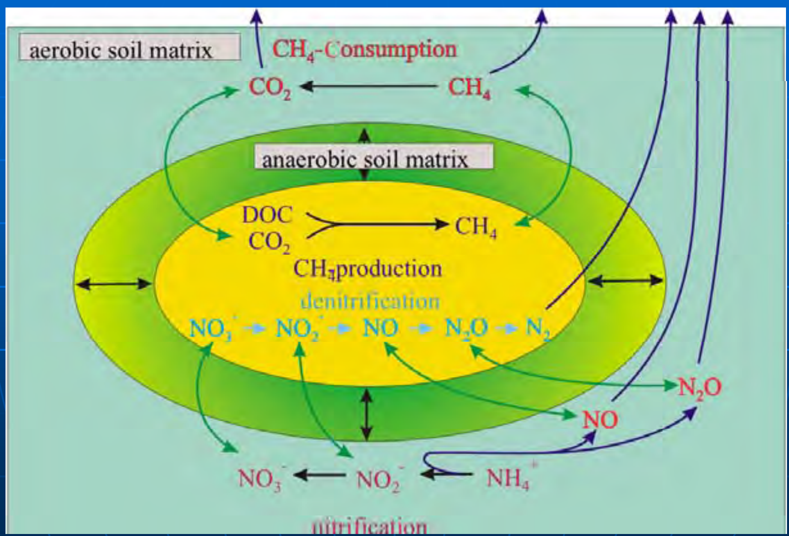
- Denitrification is another main source of N_2O and NO from soil.
- Denitrification includes a sequential reduction of nitrate to dinitrogen (N_2) driven by denitrifying bacteria under anaerobic conditions.

$$\text{Denitrification: } NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 \quad (2)$$

- Denitrification controlled by soil moisture and Eh.

Linking ecological drivers to trace gases

- The DNDC model simulates relative growth rates of nitrate, nitrite, NO, and N_2O denitrifiers based on soi Eh, concentrations of DOC, and nitrogen oxides.
- A simple scheme of anaerobic balloon was developed in the model to divide the soil matrix in to aerobic and anaerobic parts.
- DNDC simulated swelling and shrinking of the anaerobic balloon.
- Only the substrates allocated in the anaerobic part are involved in denitrification.



http://imk-ifu.fzk.de/823.php

Linking ecological drivers to trace gases

- Methane is an end product of the biological reduction of CO_2 or organic carbon under anaerobic conditions.

$$\text{Methane production: } CO_2 + 8\,H^+ \rightarrow CH_4 + 2\,H_2O \quad (3)$$
or
$$\text{Organic C} + 4\,H^+ \rightarrow CH_4$$

- Methane fluxes were strongly controlled by soil available carbon (i.e., DOC) content, and soil temperature.
- The reduction of available carbon to methane is mediated by anaerobic microbes (e.g., methanogens) that are only active when the soil Eh is low enough.

Linking ecological drivers to trace gases

- DNDC calculates methane production rate as a function of DOC content and temperature as soon as the predicted soil Eh reaches -150 mV or lower.
- Methane is oxidized by aerobic methanotrophs in the soil. A highly simplified scheme was employed in DNDC to model methane diffusion between soil layers based on methane concentration gradients, temperature, and porosity in the soil.

Function 3.5. CH_4 diffusion rate (kg C/ha/d)
$Rd = 0.01 * (CH_4[l] - CH_4[l+1]) * T[l] * PORO;$
AC – Available C concentration, kg C/ha;
T – soil temperature, °C;
l – soil layer number;
AERE – plant aerenchyma;
FloodDay – flooding days;
PORO – soil porosity;
$CH_4[l]$ – CH_4 concentration at layer l, kg C/ha.

Linking ecological drivers to trace gases

- DNDC predicts plant-transported methane flux as a function of methane concentration and plant aerenchyma.

Equation 3.3. CH_4 flux through plant aerenchyma (kg C/ha/d)
$CH_{4(aere)} = 0.5 * CH_4[l] * AERE;$
$AERE = -0.0009*PGI^5+0.0047*PGI^4-0.883*PGI^3+1.9863*PGI^2-0.3795*PGI+0.0251;$
PGI = (days since planting) / (season days); (plant growth index)

- DNDC assume that ebullition only occurs at the surface layer, and ebullition rate is regulated by soil methane concentration, temperature, porosity, and plant aerenchyma.

Function 3.4. CH_4 flux through ebullition (kg C/ha/d)
$CH_{4(ebullition)} = 0.025 * CH_4[l] * PORO * Ft * (1 - AERE);$
$Ft = -0.1687*(0.1*T[l])^3 +1.167*(0.1*T[l])^2 -2.0303*(0.1*T[l])+1.042;$

Linking ecological drivers to trace gases

- Soil NH_3 concentration is directly regulated by a chemical reaction occurring in the soil liquid phase:

$$[NH_4^+] + [OH^-] = [NH_{3\,(liquid)}] + H_2O \qquad (4)$$

where $[NH_4^+]$ is ammonium concentration, $[OH^-]$ is hydroxide ion concentration, and $[NH_{3\,(liquid)}]$ is ammonia concentration in soil water.

- DNDC calculate $NH_{3(liq)}$ concentration base on NH_4^+ and OH^- concentration, and NH_4^+ concentration in the soil profile is calculated by the decomposition submodel.

Linking ecological drivers to trace gases

- The equations describing the effects of soil environmental factors on NO, N_2O, CH_4, and NH_3 were organized into three submodels.

1. The fermentation submodel contains all the methane related equation. This submodel calculates production, oxidation, and transport of methane under submerged conditions.
2. The denitrification submodel contains all the denitrification equations. This submodel calculates production, consumption, and diffusion of N_2O and NO during rainfall, irrigation, or flooding events.

Linking ecological drivers to trace gases

3. Nitrification related equations are included in the nitrification submodel. As a logical extension of the NH_4^+ / $NH_{3(liq)}$ /$NH_{3(gas)}$ equilibrium, functions for NH_3 production and volatilization are also included in the nitrification submodel.

- The three submodels compose the second component of the DNDC model. *(Biogeochemistry reaction)*

Input and output

- Daily temperature
- Precipitation
- Soil bulk density
- Texture
- Soil organic carbon content
- pH
- Farming (e.g., crop type and rotation, flooding, grazing, and weeding)

Input and output

When the DNDC is used for regional estimates of trace gases emissions, the model needs the spatially and temporally differentiated input data stored in geographical information system type database in advance.

Base on the input parameters of the ecological drivers, DNDC first predicts daily soil temperature, moisture, Eh, pH, and substrate concentration, and then uses the environmental parameters to drive nitrification, denitrification, methane production/oxidations.

Daily emissions of trace gases are finally calculated as their daily net fluxes.

Input and output

Most parts of the model run at a daily time step except the soil climate and denitrification submodels which run at an hourly time step.

Output parameters from the model runs are daily soil profiles of temperature, moisture, Eh, pH, and concentrations of total soil organic carbon, nitrate, nitrite, ammonium, urea, ammonia, as well as daily fluxes of trace gases emission.

For the regional version of DNDC, the simulated results are recorded as geographically explicit data in a GIS database.

DNDC Site mode

Figure 2. Main menu of DNDC

DNDC Site mode

III Model Operation

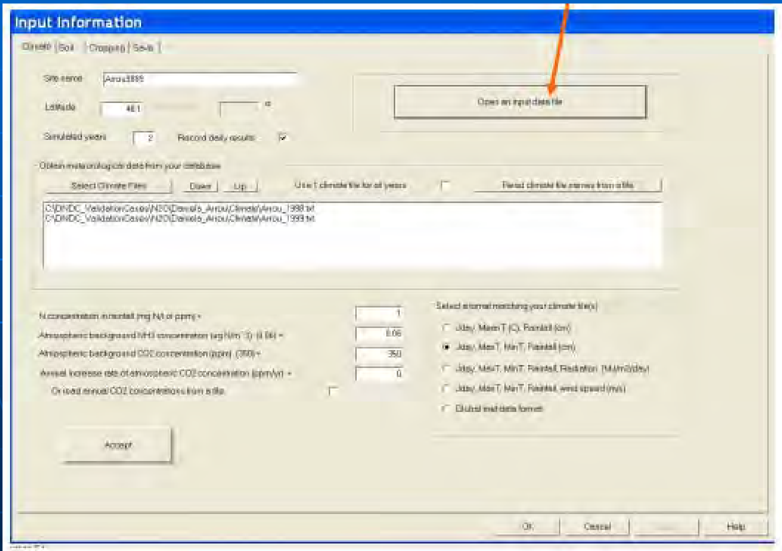
1. Site Mode

1.1. Input Parameters

- Page 1: Site and climate
- Page 2: Soil
- Page 3: Farming management
- Page 4: Crop
- Page 5: Tillage
- Page 6: Fertilization
- Page 7: Manure amendment
- Page 8: Weeding
- Page 9: Flooding
- Page 10: Irrigation
- Page 11: Grazing and cutting

1.2. Save and Open Input File
1.3. Run DNDC at Site Scale
1.4. A Quick View of Modeled Results
1.5. Batch Run

Open an input data file



Run model at site mode

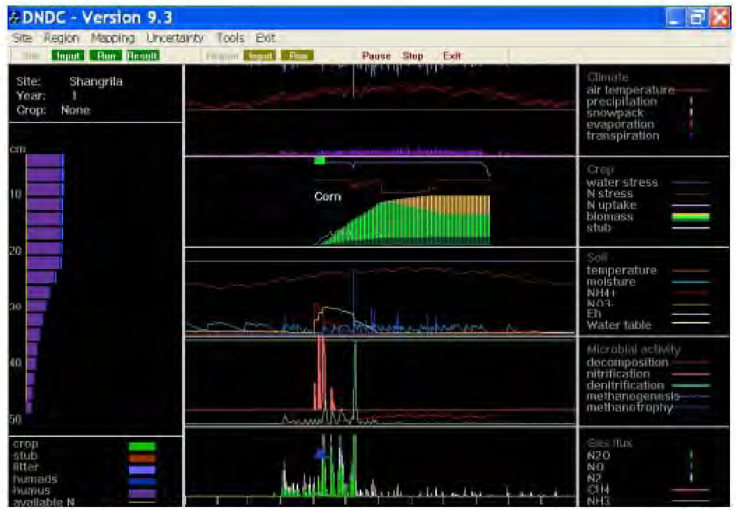
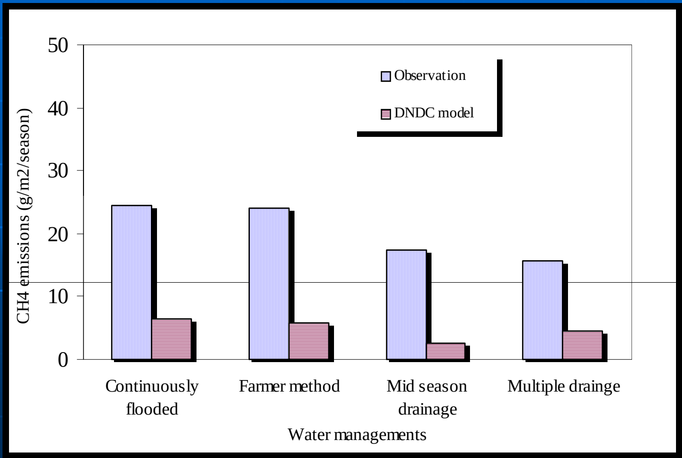


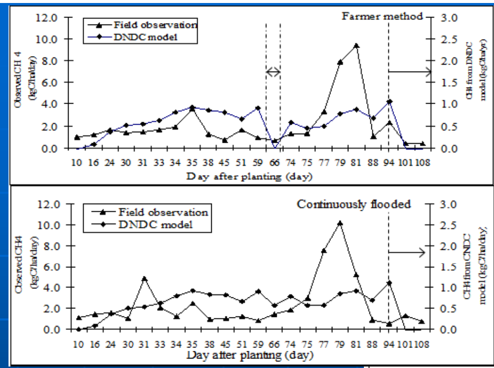
Figure 15. The seven windows allow users to monitor daily dynamics of several major simulated factors during the model run.

Case study: CH_4 emissions

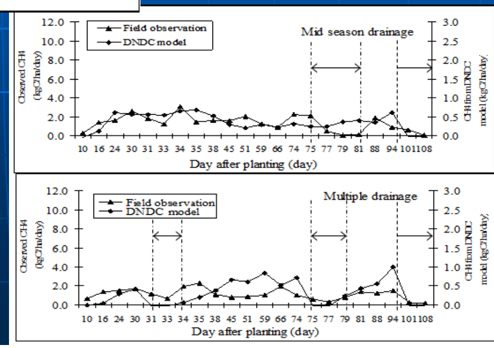


K.Smakgahn, 2003

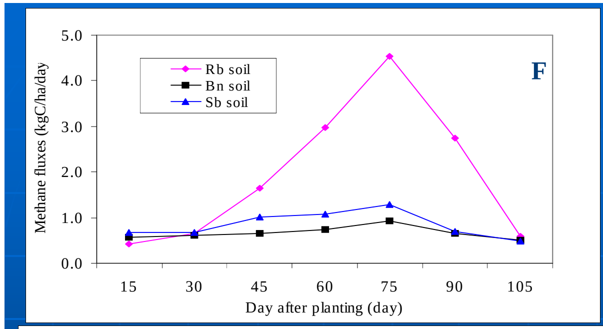
Case study: CH_4 emissions

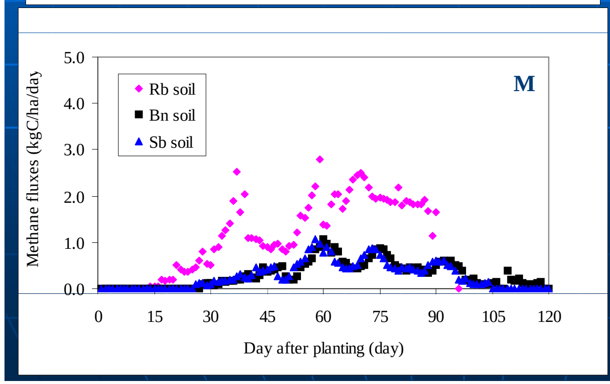


- *Water Management



K.Smakgahn, 2003

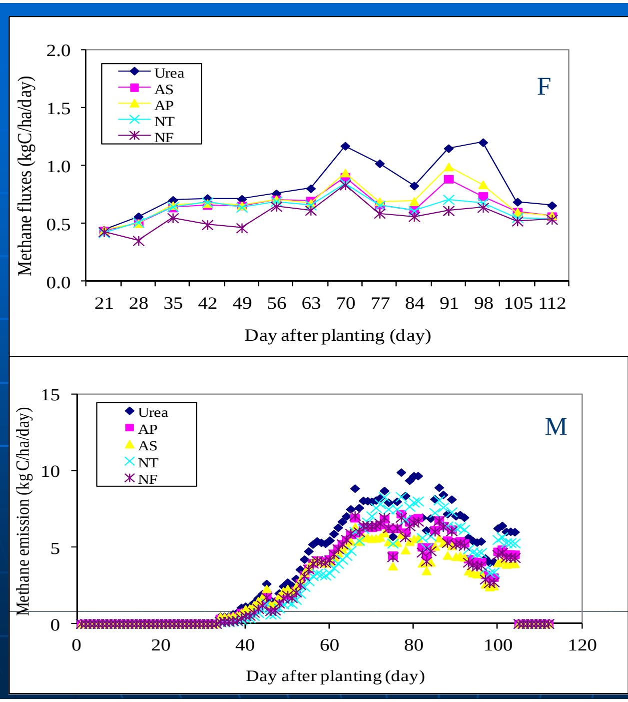




Case study: CH_4 emissions

* Soil

K.Smakgahn, 2003



Case study: CH_4 emissions

- Fertilizer

K.Smakgahn, 2003

Case study: CH_4 emissions

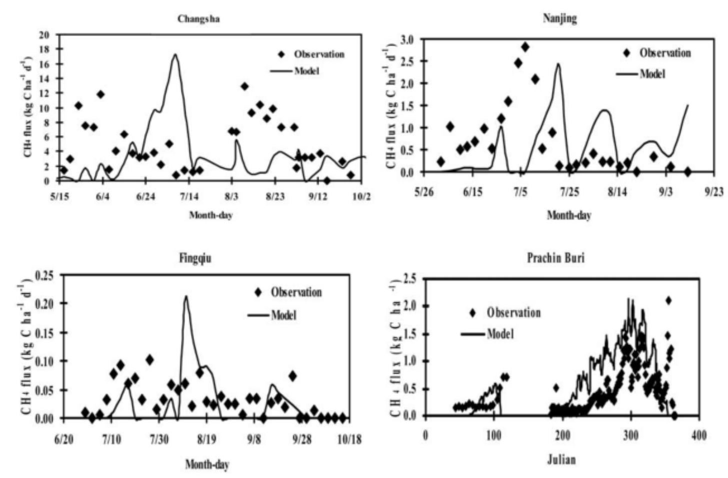
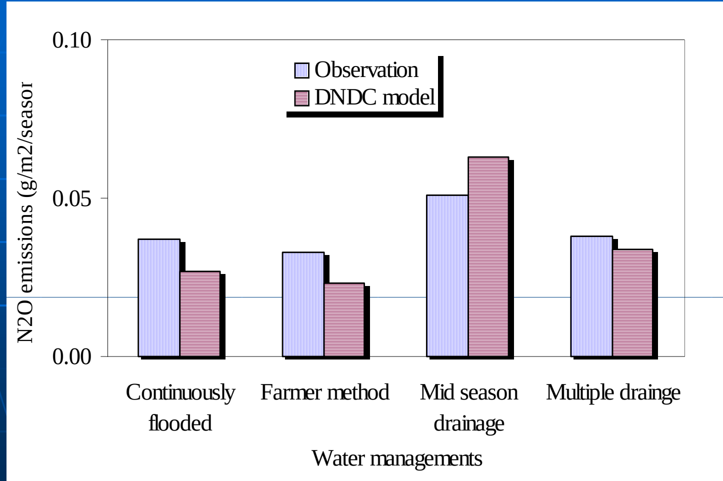


Figure 5. Comparison between observation and DNDC-simulation of seasonal patterns of CH_4 emissions from rice fields in China and Thailand.

33

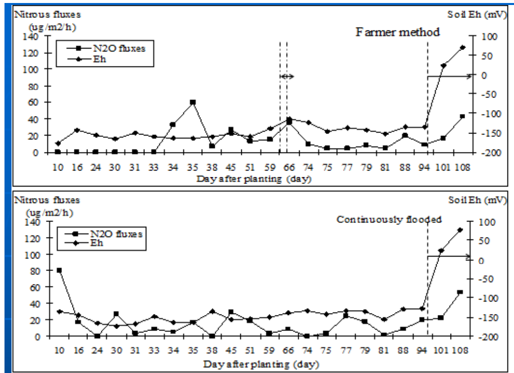
Source: Cai et al. 2003

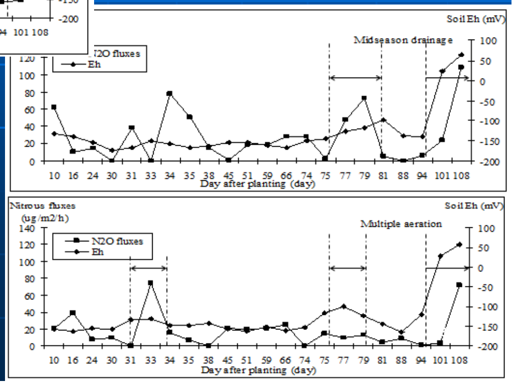
Case study: predicts N_2O



K.Smakgahn, 2003

Case study: predicts N_2O





- **Water management**

K.Smakgahn, 2003

Regional mode: predicts CH_4

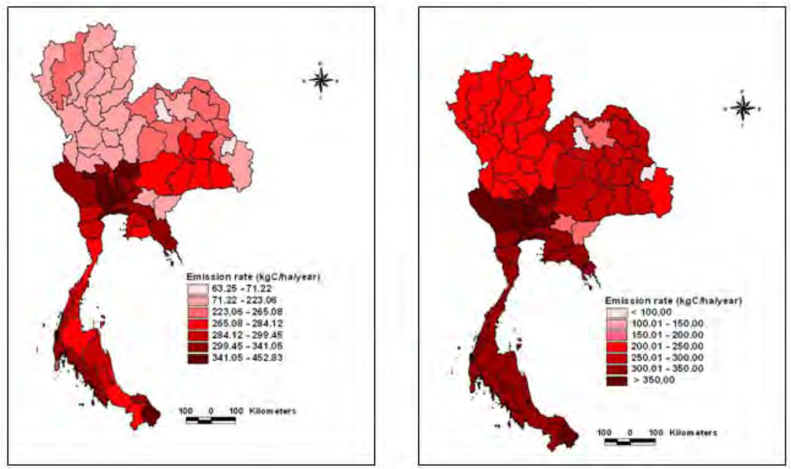


Figure 5.25 Estimated methane emission rates (minimum scenario) at the provincial level from single rice cultivations

Figure 5.26 Estimated methane emission rates (maximum scenario) at the provincial level from single rice cultivations

K.Smakgahn, 2003

Regional mode: predicts N_2O

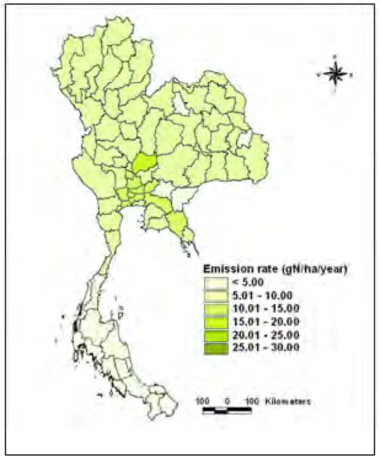


Figure 5.27 Estimated nitrous oxide emission rates (minimum scenario) at the provincial level from single rice cultivations

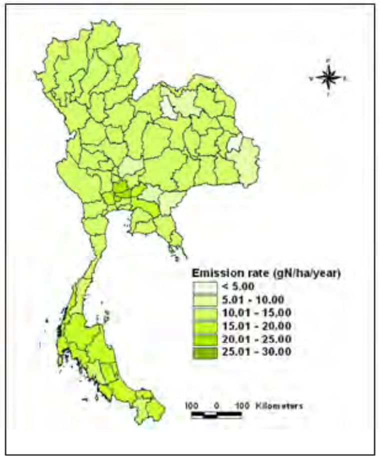


Figure 5.28 Estimated nitrous oxide emission rates (maximum scenario) at the provincial level from single rice cultivations

K.Smakgahn, 2003

Case study: predicts SOC

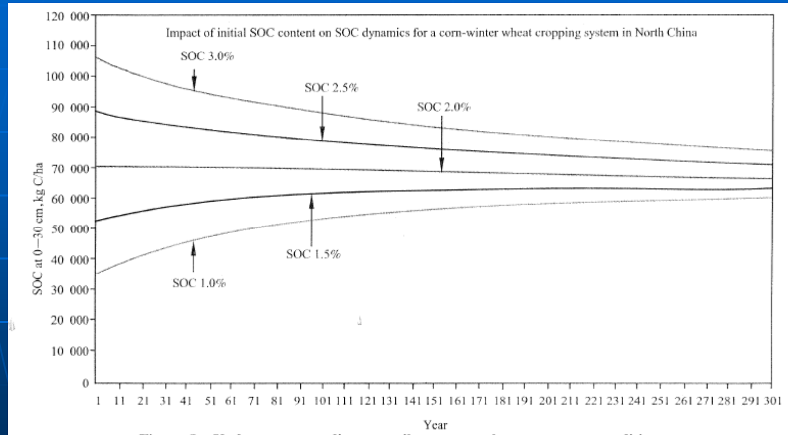
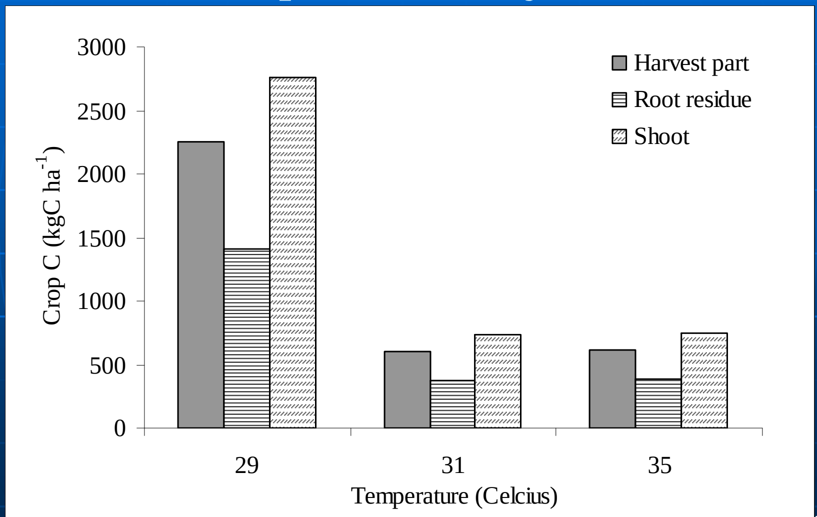


Figure 5 Under constant climate, soil texture and management conditions, the modeled SOC contents approached to an identical equilibrium level, which is independent of the initial SOC contents of the soils

CS. Li, Quantifying SOC sequestration potential with modeling approach

Case study: predicts effect of air temperature on yield



K.Smakgahn, unpublicized work

Capacity Building Workshop on:
"Strategic rice cultivation with energy crop rotation in Southeast Asia
– A path toward climate change mitigation in the agricultural sector"

Experience in using DNDC-Rice model: Case of Japan

National Institute for Agro-Environmental Sciences, Japan

Kazunori Minamikawa

NIAES

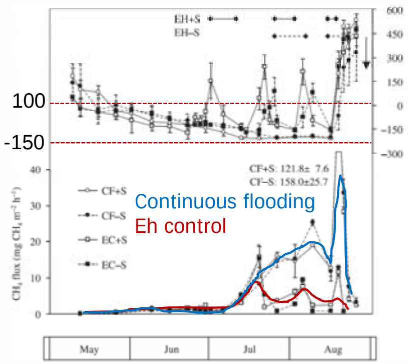
30 May 2013, Bangkok, Thailand

Today's contents

- Self-introduction
- Difference between original DNDC and DNDC-Rice
- Water management reduces CH_4 emissions from rice paddies: a modeling study in Japan
  - ✓ Introduction
  - ✓ Methods
  - ✓ Results 1: model validation
  - ✓ Results 2: long-term simulation

PhD study (2000~2005 @ Tsukuba Univ.)

Water management base on soil redox potential (Eh) can effectively reduces paddy CH_4



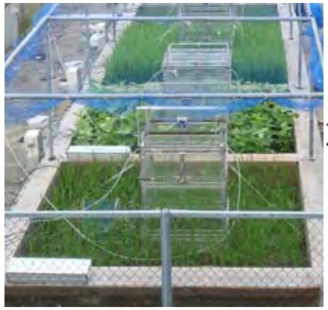
(Agric. Ecosyst. Environ., 2006)

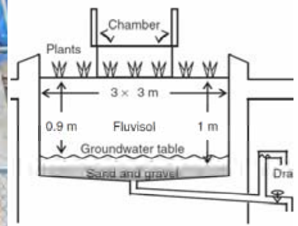
Estimation of soil C budget in a rice paddy by ecological method (g C m^{-2} yr^{-1})

Components and budget	First year			
	CF+S	CF–S	EH+S	EH–S
CO_2 Fallow period				
Straw incorporation A	–229	0	–229	0
Ratoon B	–24.7	–24.7	–24.7	–24.7
Weed C	–2.9	–2.9	–2.9	–2.9
Soil respiration D	166	162	166	162
Fallow sub-budget E	–91	134	–91	134
Growing period				
Grain F	–199	–208	–212	–193
Straw G	–179	–209	–219	–202
Root H	–58.1	–64.1	–66.2	–60.5
Stubble† I	–17.3	–20.2	–21.2	–19.5
Dead straw† J	–23.8	–26.4	–27.3	–25.0
Exudates K	–14.7	–16.3	–16.9	–15.4
Algae‡ L	–25.7	–25.7	–16.3	–16.7
Weed M	–0.04	–0.04	–0.04	–0.04
Flush N	42	25	134	65
Diffusion‡ O	180	132	114	86
Water§ P	17.5	17.5	17.5	17.5
Growing sub-budget Q	100	22	118	31
CO_2 budget of soil R	9	156	27	165
	(33)	(572)	(99)	(605)
CH_4 Growing period S	10.66	10.33	5.48	4.88
	(327)	(317)	(168)	(150)
Soil carbon budget T	20	166	32	170
	(360)	(889)	(267)	(755)

(Soil Sci. Plant Nutr., 2007)

Postdoc study (2006~2010 @ NIAES)





Monitoring indirect GHG emissions through groundwater

	Paddy rice		Soybean and wheat		Upland rice	
	1	2	1	2	1	2
Aboveground emission*						
CH_4 (mg C m^{-2} yr^{-1})	4647	2893	–47.9	–73.0	–52.1	–48.5
N_2O (mg N m^{-2} yr^{-1})	47.7	30.8	197	292	398	173
Dissolved emission						
CO_2 (g C m^{-2} yr^{-1})	33.4	36.7	7.62	8.01	11.7	10.5
CH_4 (mg C m^{-2} yr^{-1})	2.20	0.964	0.145	0.159	0.238	1.28
N_2O (mg N m^{-2} yr^{-1})	130	105	114	147	268	113

*Negative values represent the net uptake.

(Global Change Biol., 2010)

Current study (2011~present)

Mitigation of GHG emissions from agriculture in Monsoon Asia

- China
- Indonesia
- Japan
- Philippines
- Thailand
- Vietnam

Ex.
- Modeling province-scale estimation of potential of plastic mulching film on reducing paddy GHG emissions in China
- Estimating national-scale of paddy CH_4 emissions in Thailand by model simulation
- Developing improved water management for reducing paddy GHG emissions in four Asian countries (monitoring and social science)

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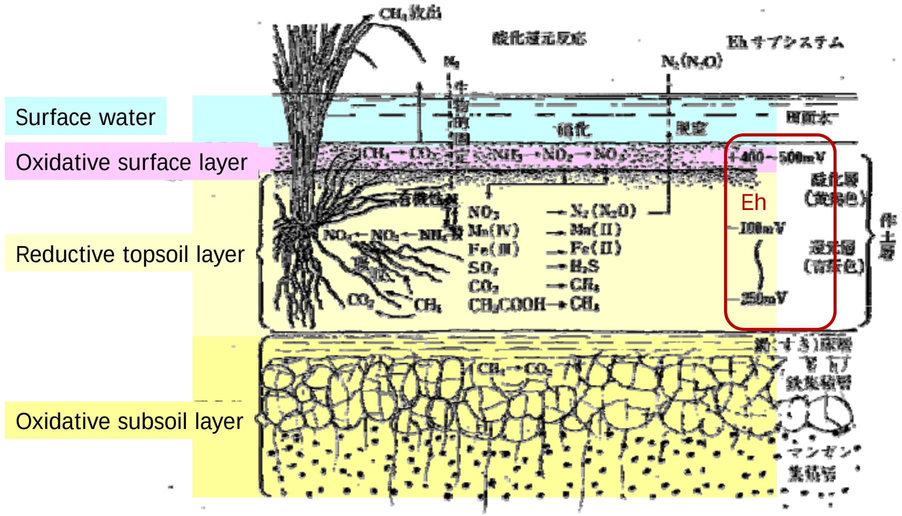
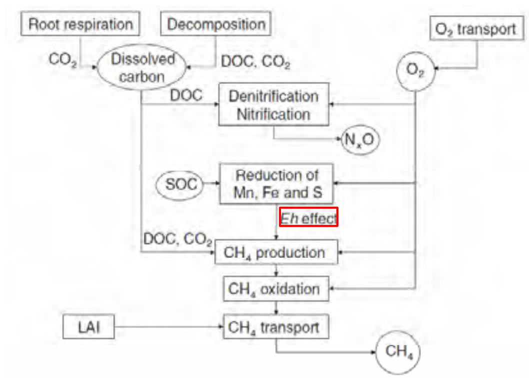
Development of reductive conditions in a flooded paddy soil



(Wakatsuki, 1997)

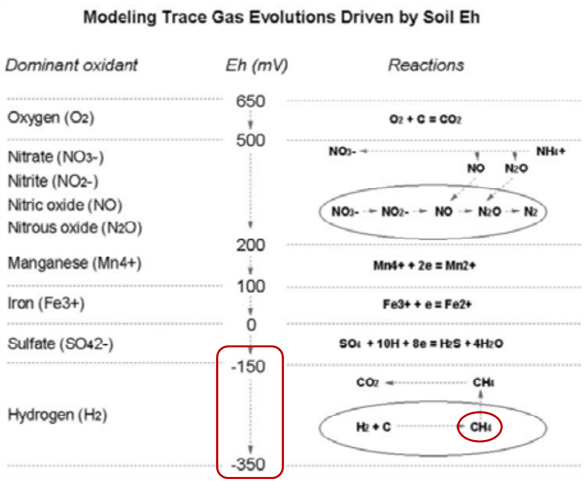
A limitation of the original DNDC model



- One of the limitations of the original DNDC model is the model's dependence on empirical simulation of changes in a soil Eh, which acts as a major driver for CH_4 production but does not account for changes in the availabilities of electron donors (e.g. DOC and H_2) and acceptors (e.g. Fe^{3+}).
- Therefore, the original DNDC model's simulation of soil Eh is insensitive to the amounts of various oxidants, which should have a significant influence on changes in soil Eh.

(Fumoto et al., GCB, 2008)

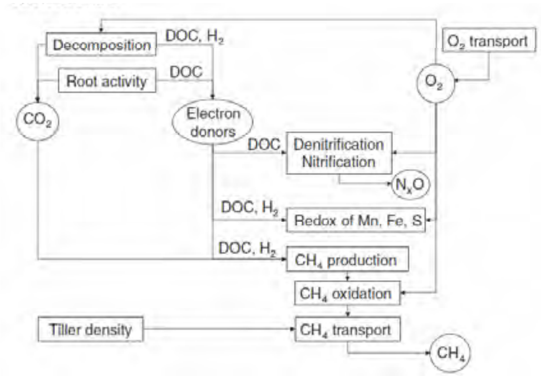
Anaerobic balloon and soil Eh: original DNDC



By tracking the formation and deflation of a series of anaerobic balloons driven by depletions of O_2, NO_3^-, Mn^{4+}, Fe^{3+}, and SO_4^{2-}, DNDC estimates soil Eh dynamics as well as production and consumption of CO_2, N_2O and CH_4 from the redox reactions. With the anaerobic balloons, DNDC links soil Eh to GHG emissions for paddy soils.

(Li et al., JGR, 2000; GBC, 2004)

Major revision for developing DNDC-Rice

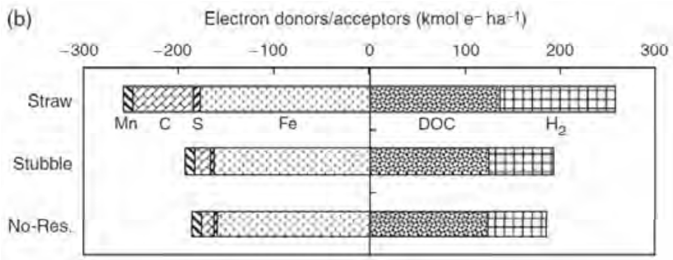


- The goal of the revision was to quantitatively track electron transfer in each reduction and oxidation process in a soil.
- H_2 and DOC are the immediate electron donors for the series of reductive reactions (reduction of NO_3^-, Mn^{4+}, Fe^{3+}, SO_4^{2-}; and CH_4 production).
- The rates of these reactions are limited by the availability of H_2 and DOC in the soil.

- The DNDC-Rice model calculates the production of H_2 and DOC, and then calculates the rates of reductive reactions by means of kinetic equations that depend on the concentrations of electron donors and acceptors.

(Fumoto et al., GCB, 2008)

Electron budget: DNDC-Rice

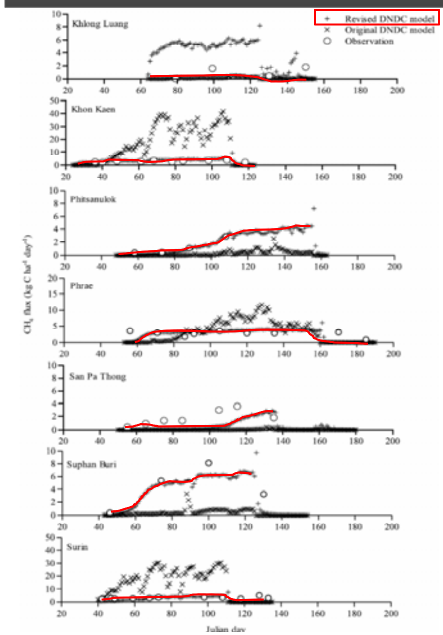


Calculated electron budgets for the flooded soils [i.e. the production of H_2 and DOC (electron donors) as a result of organic matter decomposition and root exudation, and consumption of these electron donors by reduction of NO_3^-, Mn^{4+}, Fe^{3+}, SO_4^{2-}, and C].

=> Reduction of C is equivalent to CH_4 production.

(Fumoto et al., GCB, 2008)

A comparative study: original *vs.* Rice



- A comparative study for simulating CH_4 emissions from seven rice paddies in Thailand.
- In most cases, the DNDC-Rice model showed an acceptable agreement with the observed fluxes, whereas the predictions of the original DNDC model deviated from the observed fluxes by up to 500%.
- These results indicate that the DNDC-Rice model has improved applicability compared with the original DNDC model, at least in part because it explicitly calculates the effect of biologically reducible Fe on CH_4 production in the paddy soils.

(Smakgahn et al., JGR, 2009)

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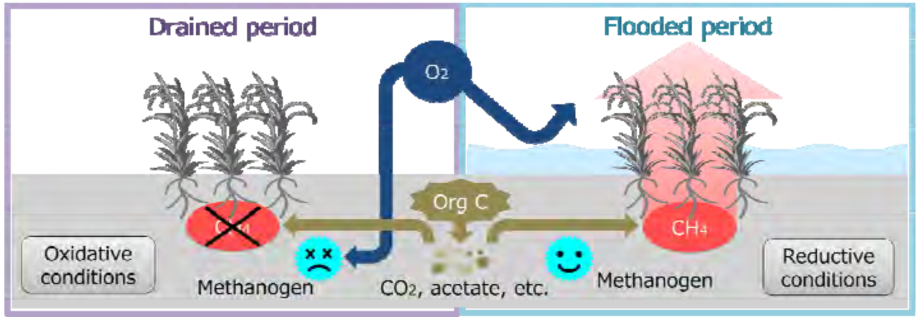
  - ✓ Results 2: long-term simulation

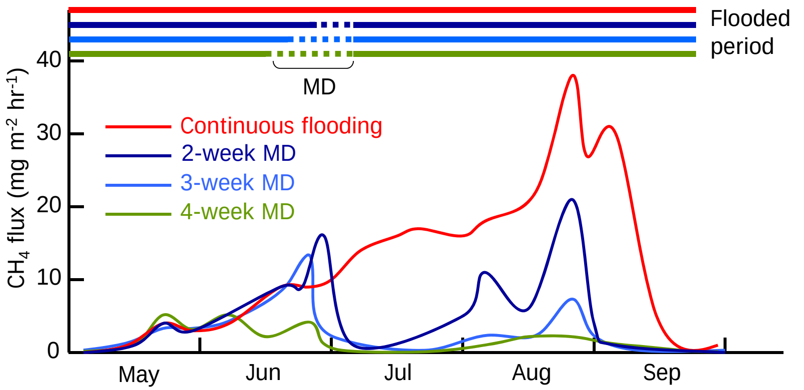
CH_4 emission from a paddy soil



- Methanogens are strict anaerobic archaea and thus their activity is enhanced under reductive conditions in a flooded paddy soil.
- In other words, methanogens are highly inhibited under oxidative drained conditions. => Drainage management is effective.

Midseason drainage: a field study in Japan

Midseason drainage (MD), a short-term drainage practice implemented at the panicle formation stage of rice plants, is used to control excessive tillering and to supply rice roots with O_2 to prevent sulfide toxicity.

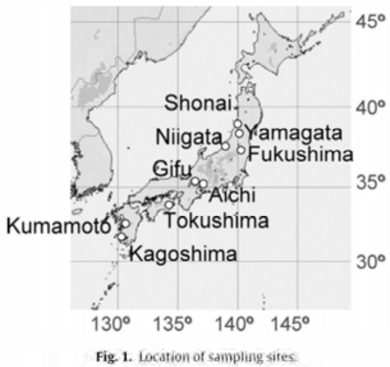


Note: Excessive drainage practices reduced rice yield.

(Saito et al., 2004)

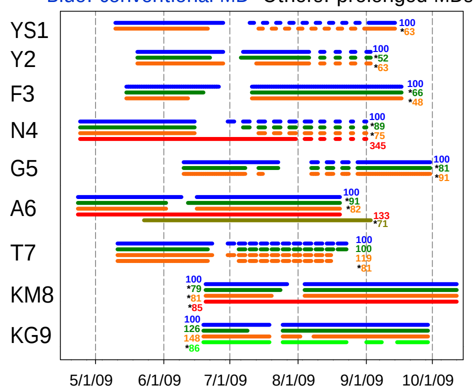
Prolonging MD for further reducing CH_4

National campaign to test the efficiency of prolonged MD for CH_4 reduction at nine sites across Japan for two years (2008-2009)



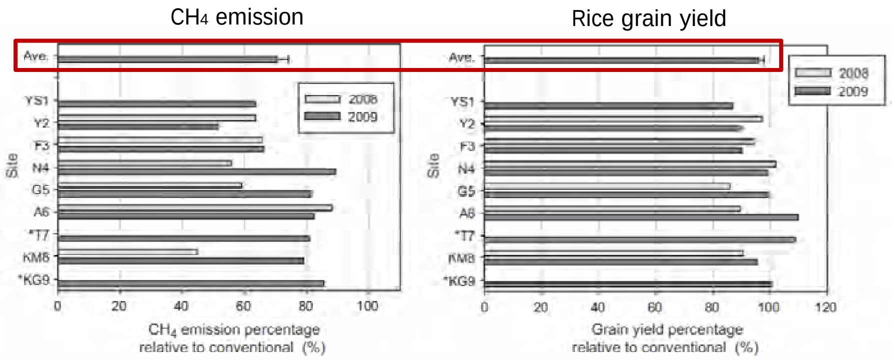
Schedule for water management in 2009

Blue: conventional MD Others: prolonged MDs



Note: Single cropping per year

Prolonged MD reduced CH_4 without sacrificing yield



As compared to conventional water-management strategies, the seasonal CH_4 emission was suppressed to 69.5 ± 3.4(SE)% while maintaining grain yields as high as 96.2 ± 2.0% by the prolonged MD specialized to each site.

(Itoh et al., Agric. Ecosyst. Environ., 2011)

Questions and motivation

- The optimal duration, timing, and frequency of water-management practices to obtain high levels of rice grain yield depend on locally regulated conventional cultivation practices.
- However, such conventional practices are often conservative to eliminate their negative effects on rice growth, leaving room for improved CH_4 reduction.

- Prolonging MD is one option for further reducing CH_4 emissions.
- However, the success or failure of such drainage practices is strongly dependent on prevailing weather conditions.
- Thus, it is difficult to derive the general effect of prolonged MD on CH_4 reduction from the results of short-term field experiments.

Model simulation is a useful way to compensate for the limits associated with short-term experiments.

Objectives and storyline

- The objective was to estimate the long-term mean effect of prolonged MD on the reduction of CH_4 emissions at the nine Japanese sites used by Itoh et al. (2011).
- We used the DNDC-Rice model with minor modifications.
- First, we validated the output of the model calibrated using the two-year measurement data at each site.
- Second, CH_4 emissions over a 20-year time period were simulated for each site using the calibrated model.
- N_2O emissions were not addressed in this study because the measured N_2O emissions were negligible at most sites and previous studies have found that the description provided by the current DNDC-Rice model cannot be used for an accurate estimation of N_2O emissions from rice paddies.

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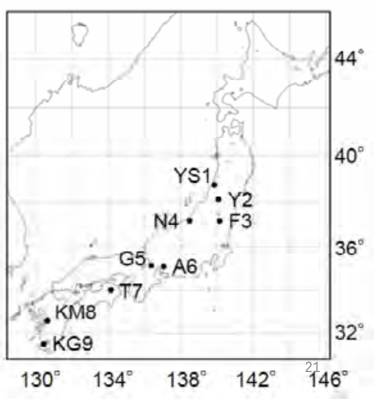
Dataset compilation

- Agricultural practices
- Soil properties
- Rice growth and yield
- CH_4 emissions

From Itoh et al. (2011) and through personal communication with the authors.

- Daily maximum and minimum air temperatures, precipitation, and solar radiation at the nine sites (i.e., the nearest observation station of the Japan Meteorological Agency)

From an agro-meteorological database (http://meteocrop.dc.affrc.go.jp)



Model modification: two minor points

- Dissolution rate of solid N fertilizers
  The current model calculates the rate using the built-in first-order rate constants depending on the type of fertilizer, with 0.5 d^{-1} for urea and 0.9 d^{-1} for other N fertilizers. <u>For the A6 and T7 sites, where a controlled-release N fertilizer was used, the constant was set to 0.05 d^{-1}.</u> This modification results in 90% release of the fertilized N by 45 days after application and reasonably reflects the actual situation.
- Direct emissions of CH_4 from unsaturated soil
  When paddy fields are drained, the DNDC-Rice model assumes that CH_4 in the soil is directly emitted to the atmosphere at a rate proportional to the soil CH_4 concentration and the air-filled porosity. When applying the model to an intermittently drained pot culture, however, Katayanagi et al. (2012) found that the DNDC-Rice model tended to overestimate CH_4 emissions during drained periods. This overestimation was presumably due to the overestimation of direct CH_4 emissions from unsaturated soil. <u>We therefore reduced the rate coefficient for direct CH_4 emissions to one-tenth of the original value.</u>

Estimating parameters that can not be directly measured

- Biologically reducible iron content is the most important parameter for the calculation of electron budget. As described in previous studies, <u>we substituted the content value with the maximum reduced iron (Fe^{2+}) content measured under field conditions.</u>
- Biologically reducible manganese content is another parameter used for the calculation of electron budget, but it has previously been reported to be approximately 1% of biologically reducible iron content. Because reduced manganese (Mn^{2+}) content data were not available for any of the sites, <u>the measured value for a typical Japanese rice paddy (1.6 mmol kg^{-1}) was used as the substitute for biologically reducible manganese content.</u>
- Microbial activity index indicates the impact of toxic materials in the soil on soil microbial activity and ranges from 0.0 to 1.0. Inubushi et al. (2005) reported a value of 0.00272 for the fraction of microbial biomass C concentration to soil organic C in Andosols, which is roughly one-tenth of the value in non-Andosols (0.0202). <u>We therefore assigned a value of 0.1 for the index at the KM8 site where the soil type was Andosols, and 1.0 for the other sites.</u>

Calibration, validation, and long-term simulation

- Field water capacity was calibrated so that the simulated volumetric water content in the topsoil during MD was consistent with the measured data.
- The developmental rate constants for the vegetative and reproductive phases were calibrated so that the simulated heading and maturation dates were consistent with the observed data.
- A preliminary run of the DNDC-Rice model was performed for a time period of 20 years with constant inputs of weather conditions and agricultural practices for conventional MD for all of the sites.
- Following the preliminary run, rice grain yield and CH_4 emissions were estimated using the calibrated model for two experimental years.
- The outputs of rice grain yield and CH_4 emissions from the calibrated model were validated using the measured values at each site.
- Following the preliminary run, CH_4 emissions were simulated using the calibrated model for another 20-year time period with continuous weather data from 1998 to 2007.

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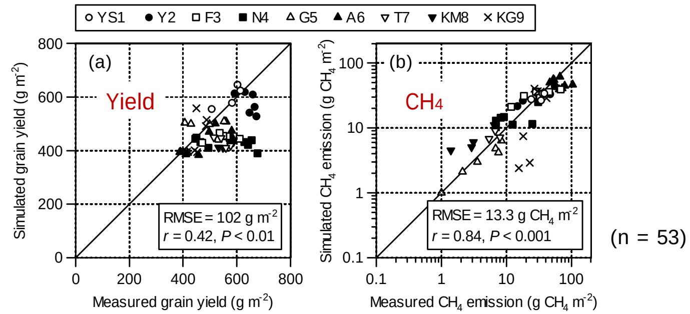
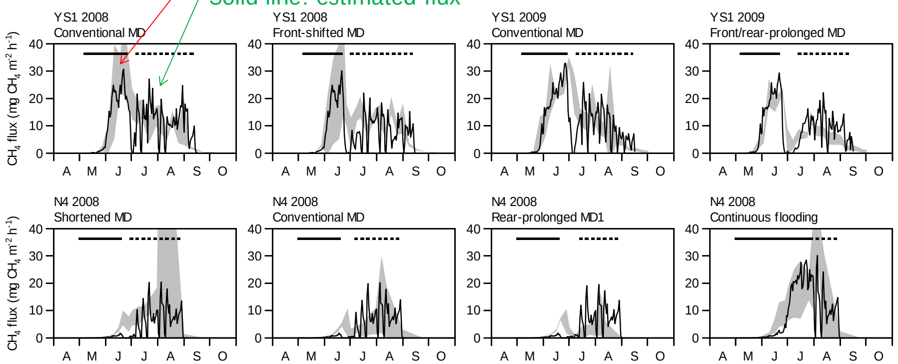
Validation for rice grain yield and total CH_4 emission



- On average, the calibrated model underestimated rice grain yield by 10.4 ± 3.8% (mean ± 95% CI) relative to the measured yield. Negative or positive effects of prolonged MD on the yield observed in the field were not adequately reproduced by the calibrated model.
- A positive effect of prolonged MD on the reduction of CH_4 emissions was relatively well reproduced by the calibrated model. On average, the model overestimated total CH_4 emissions by 7.8 ± 14.3% relative to the measured values.

Validation for seasonal CH_4 flux (examples)

Grey bar: 95% CIs of measured flux
Solid line: estimated flux



The calibrated model moderately reproduced the magnitude and shifting patterns of seasonal CH_4 flux.

Comparison of model performance for predicting CH_4

Model	Location	Experimental factors and conditions	Total number of simulation	$r^{\dagger}$	Relative RMSE‡	Reference
Original DNDC	9 sites in India	Calibrated with measured data in one site	11	0.99	0.17	Babu et al. (2006)
	6 sites in China	Type and rate of N fertilizer	9	0.98	0.14	Zhang et al. (2009)
DNDC-Rice	3 sites in China and Japan	Straw application and type of N fertilizer	12	0.87	0.50	Fumoto et al. (2008)
	9 sites in Thailand	Growing season (major or second)	17	0.60	0.72	Smakgahn et al. (2009)
	3 sites in Japan	Organic amendment and water management	23	0.91	0.27	Fumoto et al. (2010)
	1 site in Philippines	Water management, greenhouse conditions	2	1.00	0.11	Katayanagi et al. (2012)
	9 sites in Japan	Water management	53	0.84	0.48	This study

† Peason's correlation coefficient for relationship between measurement and simulation.
‡ The ratio of RMSE to mean of measured values.

- Both indices in this study fell within the range of values of previous studies.
- The error range of simulated CH_4 emissions was dependent not only on the model versions but also on the variation in experimental conditions and the method of calibration.

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Simulated reduction rate of CH_4 emission (1/2)

Site	Water management practice	Duration of MD (d)	Sim. CH_4 emission ($g\ CH_4\ m^{-2}\ yr^{-1}$)	Relative to conventional MD (%) Simulated	Measured[a]
YS1	Conventional MD	10	36.9 ± 2.2	—	—
	Front-shifted MD	10	32.0 ± 2.4	86.3 ± 3.7	95
	Front/rear-prolonged MD	21	28.8 ± 2.5	78.0 ± 5.9[†‡]	63[†‡]
Y2	Conventional MD	7	30.5 ± 2.7	—	—
	Front-prolonged MD	14	21.8 ± 3.5	70.1 ± 6.8[†]	52-64[†‡]
	Rear-prolonged MD	14	21.4 ± 2.8	69.1 ± 4.9[‡]	63-84
F3	Conventional MD	14	39.0 ± 2.9	—	—
	Front-prolonged MD1	21	33.6 ± 2.5	86.7 ± 3.6[†]	66-66[†]
	Front-prolonged MD2	28	29.0 ± 2.4	74.9 ± 4.7[‡]	42-48[‡]
N4	Conventional MD	14	30.4 ± 3.0	—	—
	Rear-prolonged MD1	21	28.4 ± 3.2	93.1 ± 3.1	56-89
	Rear-prolonged MD2	28	25.5 ± 3.1	83.3 ± 3.9[†‡]	75[†‡]
	Continuous flooding	0	51.5 ± 4.1	186.6 ± 13.3	247-375
G5	Conventional MD	7	2.7 ± 0.8	—	—
	Early MD	13	2.2 ± 0.7	82.5 ± 4.8[†]	59-81[†]
	Early + Front-prolonged MD	20	1.2 ± 0.5	45.1 ± 7.0[‡]	28-91[‡]
A6	Conventional MD	6	47.0 ± 2.0	—	—
	Front-shifted MD	9	43.6 ± 2.0	92.9 ± 3.3	91-103
	Front-prolonged MD	13	40.5 ± 2.2	86.2 ± 3.3[†‡]	82-88[†‡]
	Continuous flooding	0	51.5 ± 1.8	118.9 ± 3.5	126-133

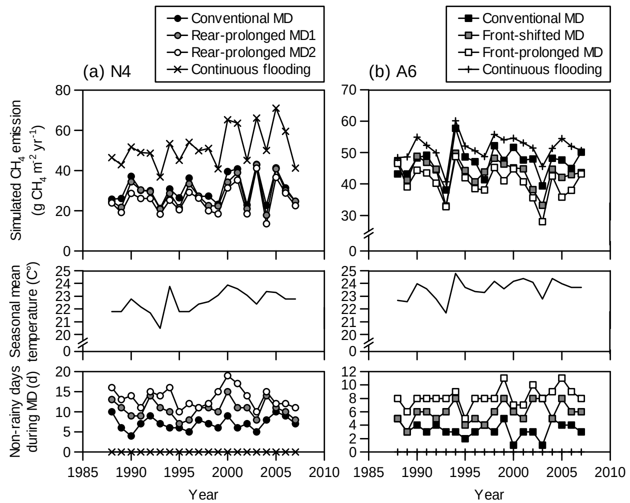
MD, midseason drainage; FD, final drainage; IM, intermittent irrigation.
(mean ± 95% CI, n = 20)
[a] Data from Itoh et al. (2011).
[b] In parantheses, duration of FD or IM.
[†] Acceptable practice for CH_4 recution without compromising rice grain yield (Itoh et al., 2011).
[‡] Best practice for CH_4 reduction without restriction on yield loss (Itoh et al., 2011).

Simulated reduction rate of CH_4 emission (2/2)

Site	Water management practice	Duration of MD (d)	Sim. CH_4 emission ($g\ CH_4\ m^{-2}\ yr^{-1}$)	Relative to conventional MD (%) Simulated	Measured[a]
T7	Conventional MD	6	10.1 ± 1.1	—	—
	Front/rear-prolonged MD	13	6.5 ± 1.1	62.4 ± 6.6	44-100
	Front-prolonged FD	6+(7)[b]	7.3 ± 0.9	71.8 ± 3.9	50-119
	Front/rear-prolonged MD + Front-prolonged FD	13+(7)[b]	4.2 ± 0.8	35.0 ± 4.3[†‡]	31-81[†‡]
KM8	Conventional MD	7	2.8 ± 0.7	—	—
	Front-prolonged MD1	10	2.1 ± 0.6	75.4 ± 8.0[†]	45-79[†‡]
	Front-prolonged MD2	14	1.6 ± 0.5	59.1 ± 10.5[‡]	81-94
	Continuous flooding	0	4.7 ± 1.2	237.9 ± 22.7	85-211
KG9	Conventional MD	4	31.1 ± 1.4	—	—
	Front-prolonged MD1	9	26.6 ± 1.8	85.9 ± 5.2	111
	Front-prolonged MD2	14	21.1 ± 1.6	68.2 ± 5.1[‡]	126-136
	Late-season IM	4+(12)[b]	24.3 ± 1.5	92.2 ± 5.6[†]	86[†‡]
	Continuous flooding	0	34.3 ± 1.2	166.4 ± 12.1	89

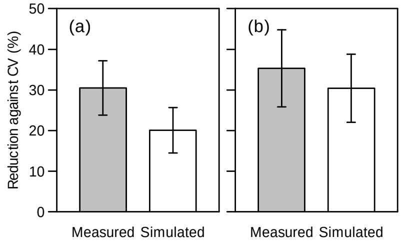
- The simulated reduction rates of CH_4 emissions by prolonged MD relative to conventional MD at the nine sites were roughly comparable to the measured rates.
- The timing of MD at each site typically occurred within the rainy season in Japan, thereby increasing the uncertainty (i.e., 95% CI) of the effect of prolonged MD.

Simulated CH_4 by year: examples of N4 and A6 sites



Spatiotemporal variability in weather conditions can mainly explain the magnitude of simulated CH_4 emission and the degree of simulated CH_4 reduction rate by prolonged MD for the target 20 years.

Mean reduction rate of the tested nine sites

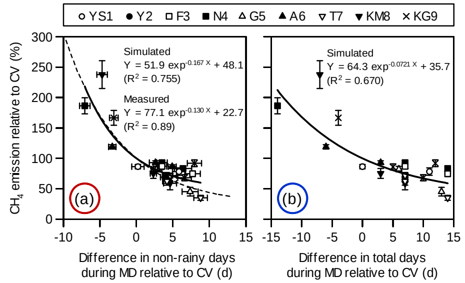


a. Acceptable prolonged MD **w/o** yield loss

b. Best prolonged MD **with** yield loss

- The simulated mean reduction rate for the acceptable MD practice (20.1 ± 5.6%) was slightly lower than the measured rate (30.5 ± 6.7%).
- The simulated mean reduction rate for the best MD practice (30.4 ± 8.4%) was comparable to the measured rate (35.3 ± 9.5%).
- There are two possible reasons for the slight difference between the measured and simulated reduction rates (for the measurement, 1. extended duration of MD at the G5 site in 2009, and 2. longer non-rainy days during prolonged MD at the YS1, F3, and G5 sites in 2008).
- We therefore concluded that the long-term simulated values better represent the mean reduction rates of CH_4 emissions by prolonged MD relative to conventional MD at the nine sites.

Generalizing the effect of prolonged MD



Relationships between the number of (a) non-rainy days and (b) total days during MD and the simulated CH_4 emissions for alternative water-management practices

Solid line: simulation
Dotted line: measurement

- We chose an exponential model with three parameters on the basis of the distribution of scatter plots and principle that the model should pass through coordinates (0, 100).
- The shape of the fitted model for simulated CH_4 emissions against the difference for non-rainy days between prolonged MD and conventional MD (a) was similar to that fitted for measured CH_4 emissions.
- Relatively strong correlation was also found for the relationship with the difference in the number of total days (b).
- Accordingly, the duration of MD can be a good indicator of the reduction rate of CH_4 emission from a rice paddy in Japan.

Conclusions

- This study performed a 20-year simulation of CH_4 emissions from Japanese rice paddies under various water-management practices using the DNDC-Rice model.
- The simulated mean reduction rate of CH_4 emissions from the nine study sites using acceptable prolonged MD practices that did not compromise rice grain yield (20.1 ± 5.6%) was more conservative than the rate derived from the two-year field measurements (30.5 ± 6.7%).
- A comparison of the measurement and simulation results revealed that the discrepancy was primarily due to differences in the method of dataset selection and the prerequisites for implementing MD.
- The magnitude of the effect of prolonged MD on CH_4 reduction can be explained by the duration of MD.
- We conclude that the simulated reduction rate adequately predicts the mean reduction rate of CH_4 emissions at the tested nine sites receiving rice straw application when acceptable prolonged MD practices that do not compromise rice grain yield are used.

Introduction to DNDC Input Data Site simulations

Ms. Nittaya Cha-un and Mr.Uday Pimple
The Joint Graduate School of Energy and Environment

Capacity Building Workshop on:
"Strategic rice cultivation with energy crop rotation in Southeast Asia –
A path toward climate change mitigation in the agricultural sector"
29-31 May 2013, Pullman hotel, Bangkok

DNDC Model

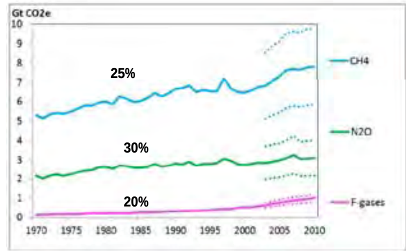
Why DNDC ? and Why Model ?

- CH_4 and N_2O from agricultural soils ~25% and 30% of global CO_2-equi emission
- Developed with management levers (tillage, fertilizer, irrigation, …)
- for the GHGs emission, hard to measure at the field level and long-term monitoring
- Need to use, predict for the future and improve models at regional scale

What is DNDC ?

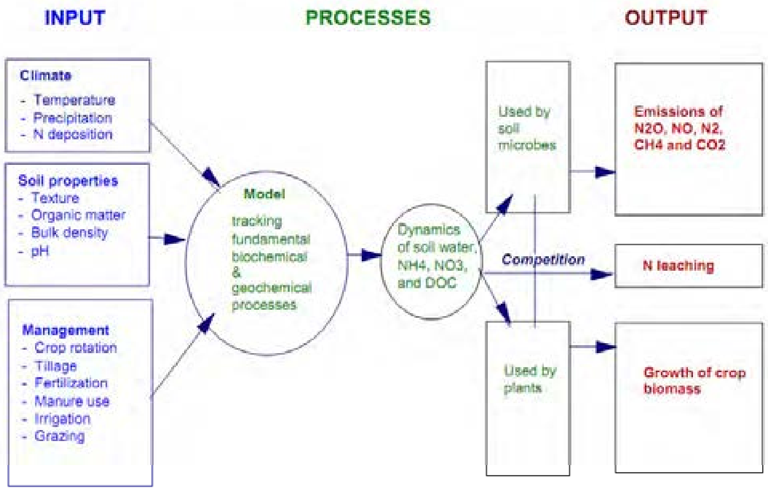
DNDC stands for Denitrification and Decomposition, two processes dominating loss of N and C from soil into the atmosphere,

- Mainly used for modeling GHG emission from agricultural soils



Trend of global emissions of methane, nitrous oxides and F-gases HFCs, PFCs and SF6. (Source: JRC/PBL, 2012, EDGAR 4.2 FT2010)

Biogeochemical Model Predicts Impacts of Alternative Management on Crop Yield and Environmental Safety

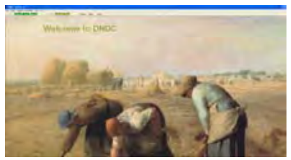


DNDC History

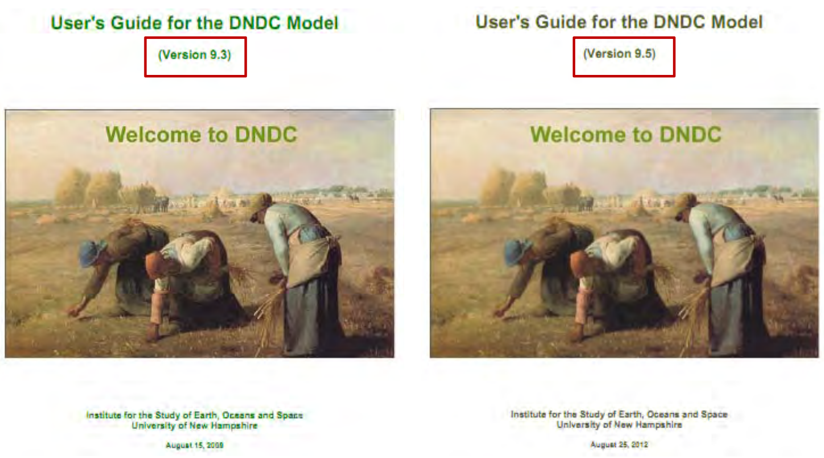
- Development began in 1989 by Changsheng Li for modeling N_2O emissions.
- First published in 1992, first N_2O emission inventory published in 1996.
- Over 50 peer reviewed publications with DNDC.
- Used for national GHG emission inventories in countries worldwide (e.g current NITRO Europe program for cropland, pasture and forest for entire EU).

Version of DNDC and Relevant models

- DNDC74 Daylight
- DNDC82
- DNDC93 (Aug 2009)
- DNDC95 (new ver., Aug 2012)
- Manure-DNDC
- Forest-DNDC



User's Guide

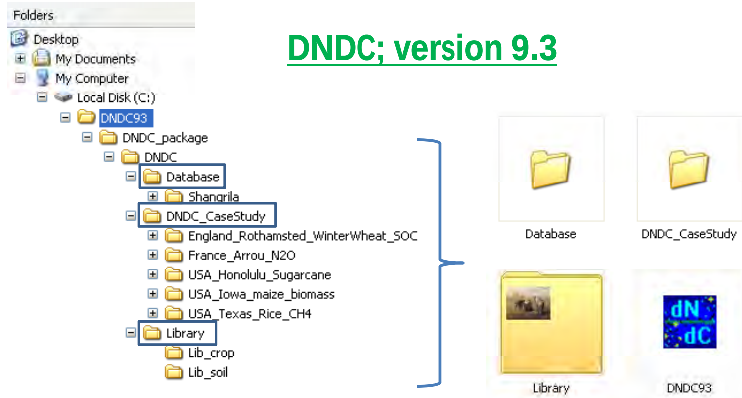


downloaded a DNDC package from web site http://www.dndc.sr.unh.edu

DNDC model Operation

- **The Site Mode:** Most of the parameters need to be typed in manually through the input interface
- **The Regional Mode:** Receives all of the input information from a database containing all the required input data for the simulated domain.

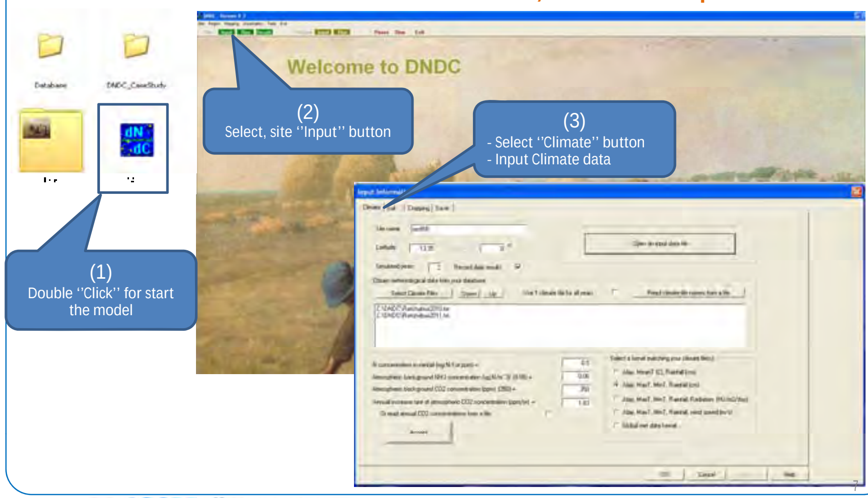
DNDC; version 9.3



Input Parameters

Page 1. Climate

Site mode at KMUTT, Ratchaburi Campus



Input Parameters

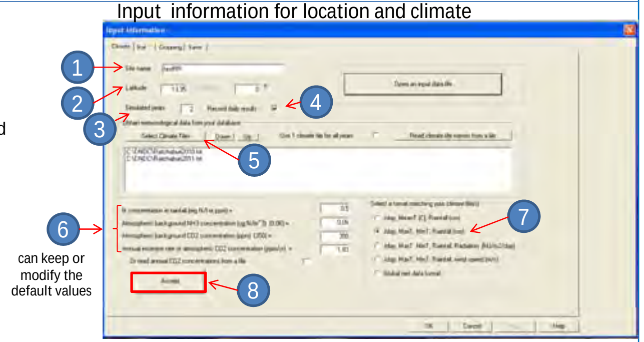
Page 1. Climate

Input information for location and climate

5 Daily meteorological data file(s) must be prepared in advance. The file(s) should have a plain text format.

7 The climate data file can be constructed with five different formats

8 Click "Accept"



Format 1:

IA1987		
1	-2.5	0.0
2	-1.0	1.2
3	-0.5	0.5
4	1.7	0.0
.		
.		
365	5.6	0.0

Format 2:

IA1987			
1	-0.5	-4.5	0.0
2	0.0	-1.2	1.2
3	3.5	0.8	0.5
4	5.7	2.0	0.0
.			
.			
365	5.6	-0.2	0.0

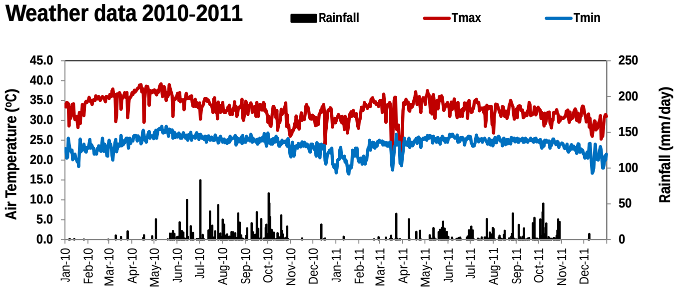
Format 3:

IA1987				
1	-0.5	-4.5	0.0	1.23
2	0.0	-1.2	1.2	1.59
3	3.5	0.8	0.5	3.20
4	5.7	2.0	0.0	2.25
.				
.				
365	5.6	-0.2	0.0	1.11

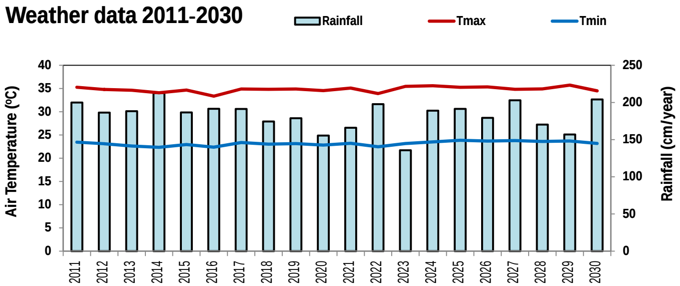
Format 4:

IA1987				
1	-0.5	-4.5	0.0	0.25
2	0.0	-1.2	1.2	1.10
3	3.5	0.8	0.5	0.80
4	5.7	2.0	0.0	0.02
.				
.				
365	5.6	-0.2	0.0	0.00

Climate data for DNDC simulation



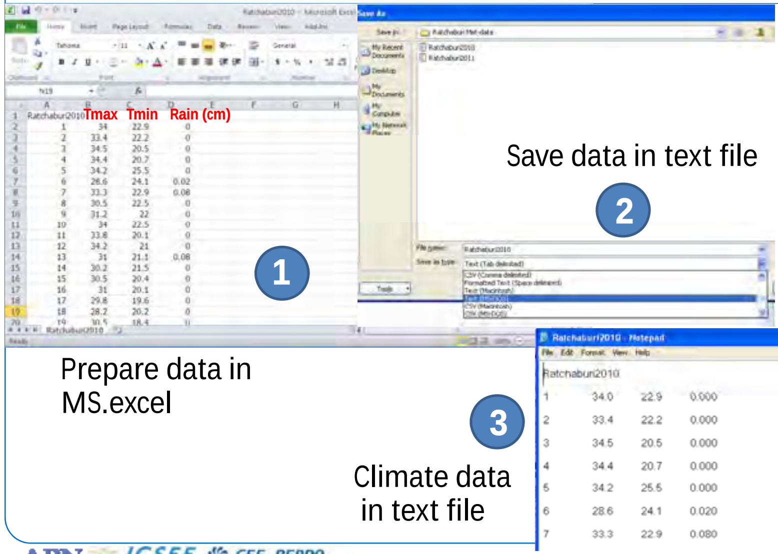
Thai Meteorological Department (TMD), Ratchaburi station



PRECIS climate model

ECHAM4 SRES B2

Climate data preparation



Save data in text file

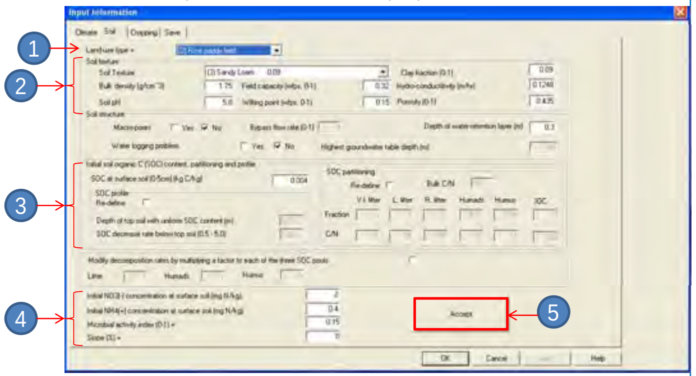
Prepare data in MS.excel

Climate data in text file

Input Parameters

Page 2. Soil

Input information for soil properties

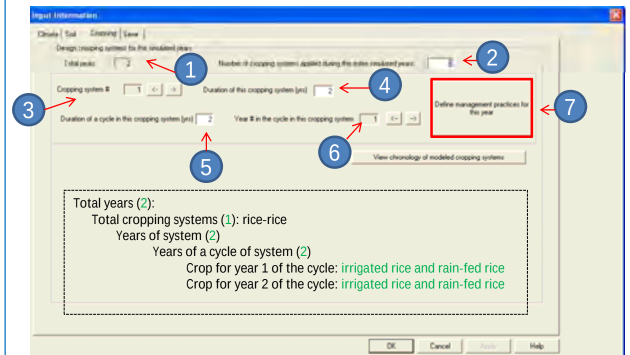


5 When the input process is done, don't forget clicking the "Accept" button

All of the soil parameters, including the defaults and the user-defined with specific field data.

Input Parameters

Page 3. Cropping

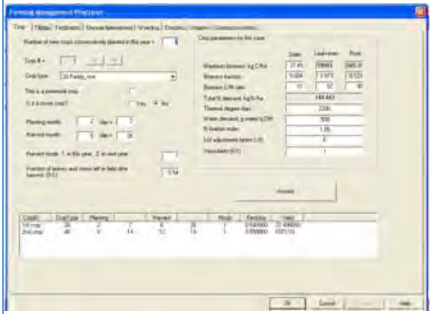


1. How many years I am going to simulate totally:
   - 2 years
2. How many cropping systems are involved in the simulation:
   - 1 cropping system (rice-rice rotation system)
4. How many years each cropping system lasts for:
   - The rice-rice system lasts for 2 years
5. How many years a cycle takes in each system:
   - A cycle of the rice-rice system takes 2 years

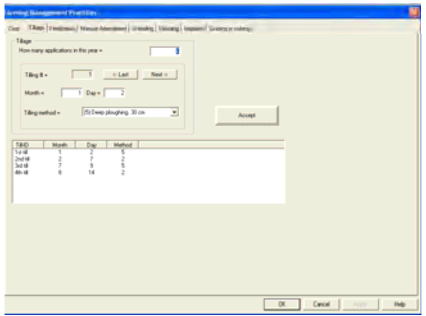
Input Parameters

Page 3. Cropping --> Farming Management Practices

Crop



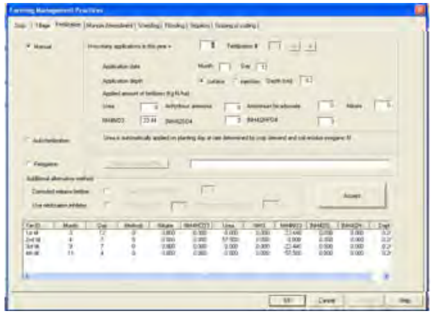
Tillage



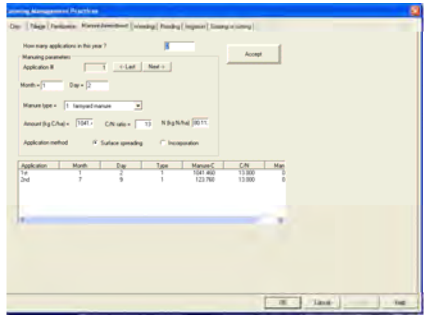
Input Parameters

Page 3. Cropping --> Farming Management Practices

Fertilization

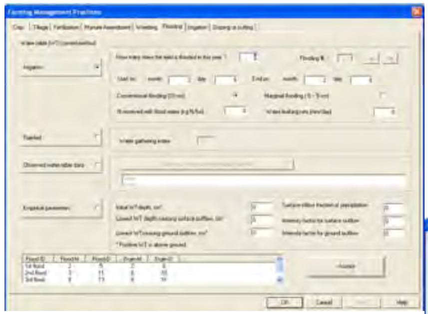


Manure Amendment

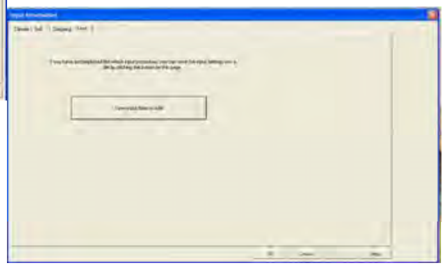


Input Parameters

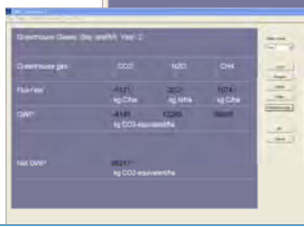
Page 3. Cropping --> Farming Management Practices



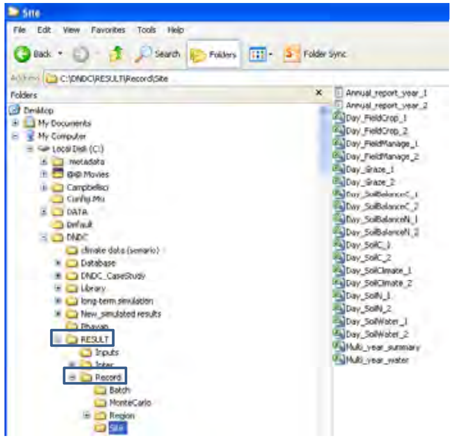
Page 4. Save



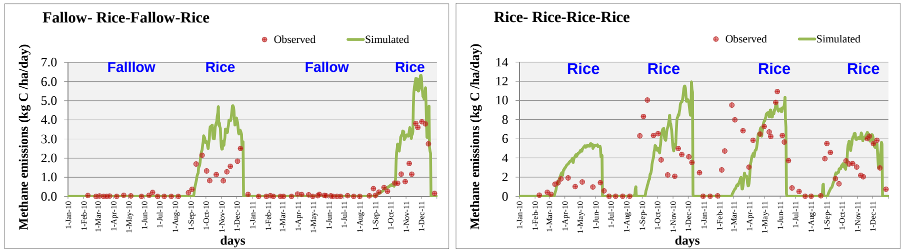
Run DNDC



Results DNDC



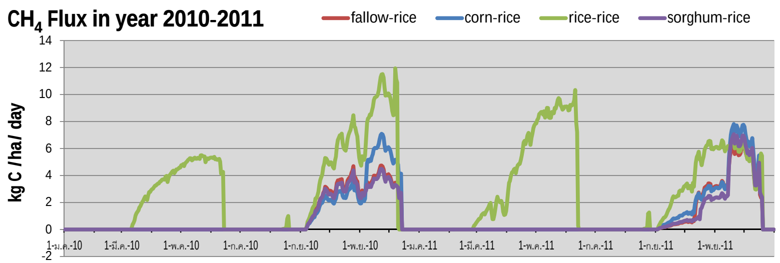
DNDC Validation

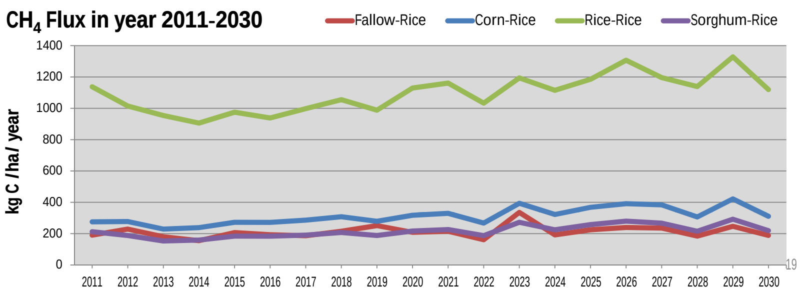


Treatments	Gross CH_4 Flux (kg C/ha)		% difference	MAE[a]	RMSE[b]	R^2
	Observed	Simulated				
RF	348.10	623.58	44.18	0.48	1.059	0.8551
RR	2,136.40	2,136.88	0.03	0.08	3.424	0.1954

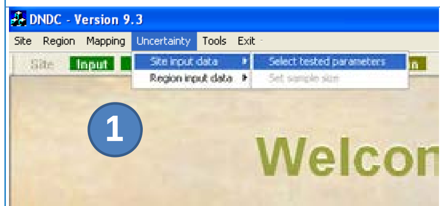
RF: good quality for model capture (R^2=0.855), but low quantity for gross CH_4 flux (44.18% difference)
RR: low quality for model capture (R^2=0.195), but good quantity for for gross CH_4 flux (0.03% difference)

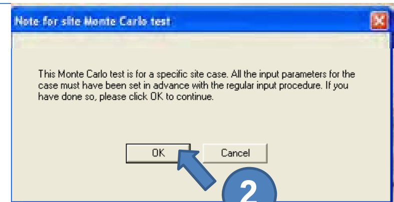
Long-term DNDC simulation in 2011-2030 for CH_4 emission

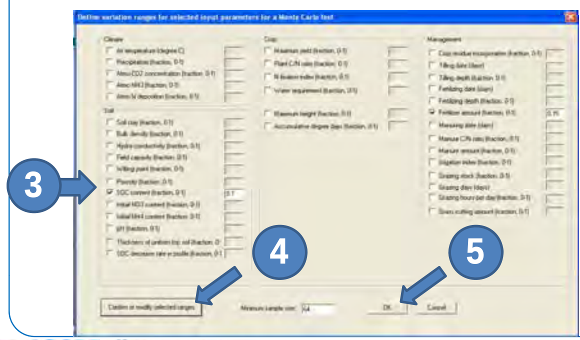




Run Uncertainty

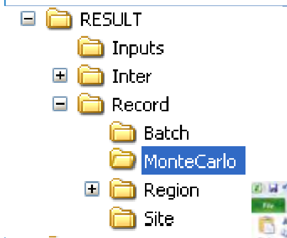


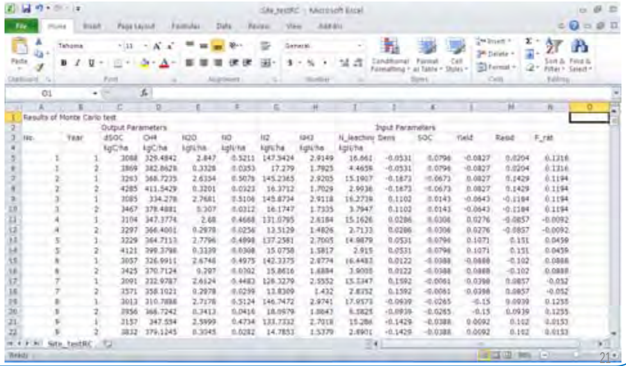




Monte Carlo methods are especially useful for simulating systems with many coupled degrees of freedom

Uncertainty file out put and result





Results of Monte Carlo test

		Output Parameters							Input Parameters				
No.	Year	dSOC	CH4	N2O	NO	N2	NH3	N_leaching	Dens	SOC	Yield	Resid	F_rat
		kgC/ha	kgC/ha	kgN/ha	kgN/ha	kgN/ha	kgN/ha	kgN/ha					
1	1	3088	329.4842	2.847	0.5211	147.3424	2.9149	16.661	-0.0531	0.0796	-0.0827	0.0204	0.1316
1	2	3869	382.8628	0.3328	0.0353	17.279	1.7925	4.4659	-0.0531	0.0796	-0.0827	0.0204	0.1316
2	1	3263	368.7235	2.6334	0.5076	145.2365	2.9205	15.1907	-0.1673	-0.0673	0.0827	0.1429	0.1194
2	2	4285	411.5429	0.3201	0.0323	16.3712	1.7029	2.9936	-0.1673	-0.0673	0.0827	0.1429	0.1194
3	1	3085	334.278	2.7681	0.5106	145.8734	2.9118	16.2739	0.1102	0.0143	-0.0643	-0.1184	0.1194
3	2	3467	378.4881	0.307	0.0312	16.1747	1.7335	3.7947	0.1102	0.0143	-0.0643	-0.1184	0.1194
4	1	3104	347.3774	2.68	0.4668	131.0795	2.6184	15.1626	0.0286	0.0306	0.0276	-0.0857	-0.0092
4	2	3297	366.4001	0.2978	0.0256	12.5129	1.4826	2.7133	0.0286	0.0306	0.0276	-0.0857	-0.0092
5	1	3229	364.7113	2.7796	0.4898	137.2581	2.7005	14.9879	0.0531	0.0796	0.1071	0.151	0.0459
5	2	4121	399.3798	0.3339	0.0308	15.0758	1.5817	2.915	0.0531	0.0796	0.1071	0.151	0.0459
6	1	3057	326.9911	2.6746	0.4975	142.3375	2.8774	16.4483	0.0122	-0.0388	0.0888	-0.102	0.0888
6	2	3425	370.7124	0.297	0.0302	15.8616	1.6884	3.9005	0.0122	-0.0388	0.0888	-0.102	0.0888
7	1	3091	332.9787	2.6124	0.4483	128.3279	2.5552	13.3347	0.1592	-0.0061	-0.0398	0.0857	-0.052
7	2	3571	358.1021	0.2978	0.0299	13.8309	1.432	2.8352	0.1592	-0.0061	-0.0398	0.0857	-0.052
8	1	3013	310.7888	2.7176	0.5124	146.7472	2.9741	17.9573	-0.0939	-0.0265	-0.15	0.0939	0.1255
8	2	3956	366.7242	0.3413	0.0416	18.0979	1.8843	6.3825	-0.0939	-0.0265	-0.15	0.0939	0.1255
9	1	3157	347.554	2.5999	0.4734	133.7332	2.7018	15.286	-0.1429	-0.0388	0.0092	0.102	0.0153
9	2	3832	379.1245	0.3045	0.0282	14.7853	1.5379	2.8901	-0.1429	-0.0388	0.0092	0.102	0.0153

Thank you

Kob-khun-kha

JGSEE — The Joint Graduate School of Energy and Environment
CEE PERDO — Center of Excellence on Energy Technology & Environment

Date: May 30, 2013

DNDC Regional Simulations and Data Input

By

Uday Pimple and Nittaya Cha-un
Joint Graduate School of Energy and Environment (JGSEE), Thailand

Outline

- What is DNDC
- DNDC input parameters
- Difference between DNDC and DNDC-rice
- DNDC regional mode
- DNDC-rice data input and processes
- Model Run

What is DNDC model ?

- DNDC (**DeNitrification-DeComposition**) is a computer simulation model of carbon and nitrogen biogeochemistry in agro-ecosystems
- The model can be used for predicting crop growth, soil temperature and moisture regimes, soil carbon dynamics, nitrogen leaching, and emissions of trace gases including nitrous oxide (N_2O), nitric oxide (NO), dinitrogen (N_2), ammonia (NH_3), methane (CH_4) and carbon dioxide (CO_2)
- http://www.dndc.sr.unh.edu/ (website)

DNDC Input Parameters

1. **Climate :** Daily air temperature and precipitation, Solar radiation*, Atmospheric N deposition
2. **Soil :** Bulk density, Texture (clay fraction) ,Total organic C content, pH
3. **Management:** Crop type and rotation, Tillage, Irrigation, Fertilization, Manure amendment

DNDC-rice (Fumuto et al., 2008) →
Fe: reducible Iron,
FWC: Field water capacity


Revising a process-based biogeochemistry model (DNDC) to simulate methane emission from rice paddy fields under various residue management and fertilizer regimes

Abstract

(Source: Li, C., S. Frolking and T.A. Frolking, 2012 ,DNDC user manual)

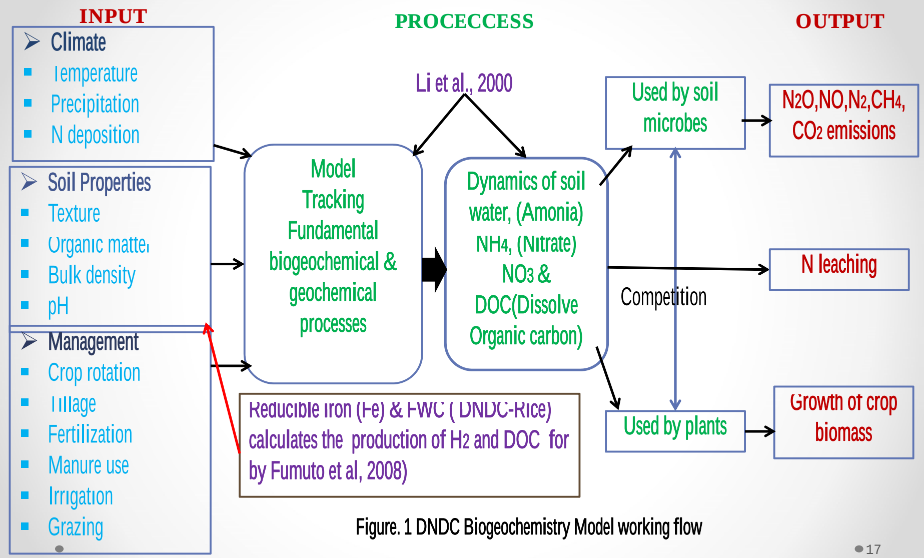


Figure. 1 DNDC Biogeochemistry Model working flow

DNDC model Operation Mode

- **The Site Mode**: Most of the parameters need to be typed in manually through the input interface
- **The Regional Mode**:
  - Receives all of the input information from a database containing all the required input data for the simulated domain
  - Polygon or grid data (Spatially differentiated information of input parameter's)

Regional Applications of DNDC

- More site than regional applications
- Field measurement lack space and time
- Regional estimates of GHG and their source strength are still limited and highly uncertain
- DNDC is coupled with (Geographic Information Systems) GIS data holding spatially & temporally distributed information
- DNDC coupled with GIS helps to understand long term seasonal variability and to identify the major environmental drivers to estimate GHG from agricultural ecosystem on regional as well as global scale

(Source: Kiese et al., 2005)

DNDC model Installation

- **Software:**
  - The DNDC –rice model predicts C and N biogeochemistry in agricultural ecosystem at site or regional mode
- **Hardware:**
  - The DNDC model requires a PC with windows operating system with 2GB RAM
  - The output files resulted from a 100 years simulation requires about 0.5 MB disk space
- **Installation:**
  - Copy DNDC folder to root directory (C-drive)

DNDC Regional Mode

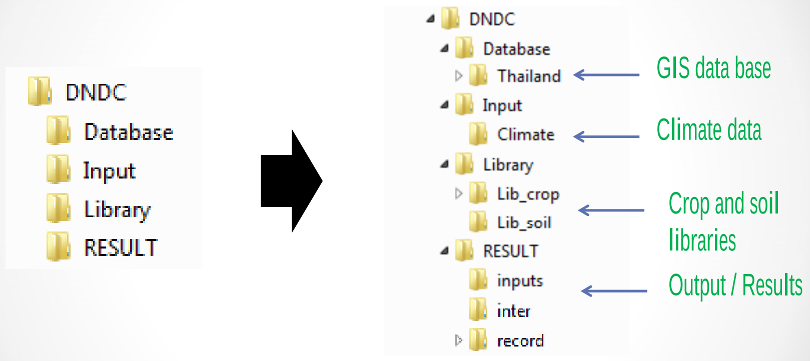


Figure 2. Data directory structure for DNDC – rice regional simulations (left main folders and right sub folders)

The Regional Mode Data Input

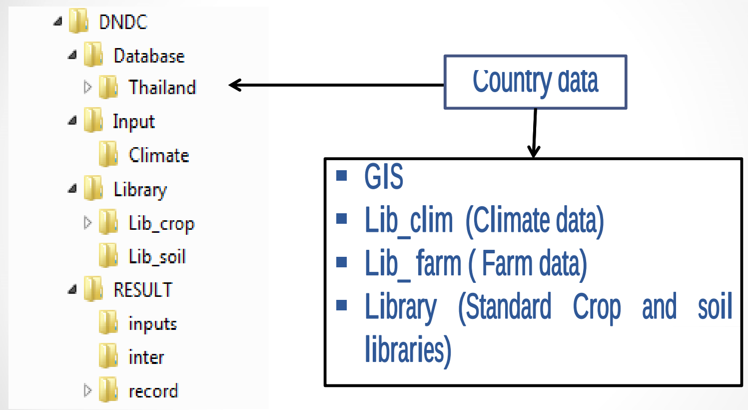


Figure 3. DNDC Domain data

The Regional Mode Data Input

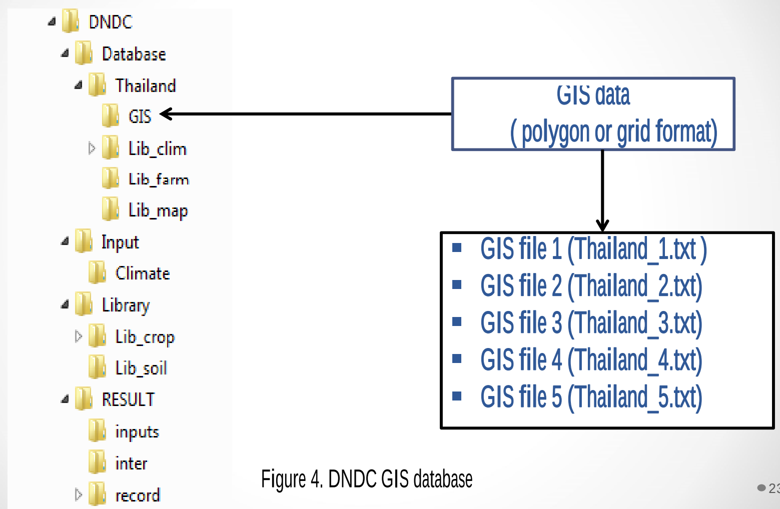


Figure 4. DNDC GIS database

The Regional Mode Data Input

- GIS file 1 (Thailand_1.txt)

Simulation unit code up to 8 digit (SUC)	Country /Region	Province	Longitude	Latitude
1000001	Thailand	Ratchaburi	99.407485	13.420379
1000002	Thailand	Ratchaburi	99.407485	13.420379
1000003	Thailand	Ratchaburi	99.407485	13.420379
1000004	Thailand	Ratchaburi	99.407485	13.420379
1000005	Thailand	Ratchaburi	99.677388	13.426453
1000006	Thailand	Ratchaburi	99.677388	13.426453
1000007	Thailand	Ratchaburi	99.677388	13.426453

The Regional Mode Data Input

- GIS file 2 (Thailand_2.txt)

SUC | Climate station ID | N concentration in Rainfall (ppm) 0.5 (Default)

SUC	Climate station ID	N concentration in Rainfall (ppm) 0.5 (Default)
1000001	424301	0.5
1000002	424301	0.5
1000003	424301	0.5
1000004	424301	0.5
1000005	424301	0.5
1000006	424301	0.5
1000007	424301	0.5

The Regional Mode Data Input

- GIS file 3 (Thailand_3.txt)

SUC | SOC | Clay | Soil pH | BD | Fe | FWC

	SOC_max (g/g)	SOC_min (g/g)	Clay_max (g/g)	Clay_min (g/g)	pH_max (-)	pH_min (-)	BD_max (g/cm3	BD_ min (g/cm3)	Fe_max (mol/kg)	Fe_min (mol/kg)	FWC_max (-)	FWC_min (-)
1000001	0.03102	0.0029	0.5	0.052	8.6	4.2	1.55	1.50.1	0.1	0.87	0.87	0.01
1000002	0.03102	0.0029	0.5	0.052	8.6	4.2	1.55	1.50.1	0.1	0.87	0.87	0.01
1000003	0.03102	0.0029	0.5	0.052	8.6	4.2	1.55	1.50.1	0.1	0.87	0.87	0.01
1000004	0.03102	0.0029	0.5	0.052	8.6	4.2	1.55	1.50.1	0.1	0.87	0.87	0.01
1000005	0.03102	0.0029	0.5	0.052	8.6	4.2	1.55	1.50.1	0.1	0.87	0.87	0.01
1000006	0.03102	0.0029	0.5	0.052	8.6	4.2	1.55	1.50.1	0.1	0.87	0.87	0.01
1000007	0.03102	0.0029	0.5	0.052	8.6	4.2	1.55	1.50.1	0.1	0.87	0.87	0.01

SOC: Soil organic carbon, BD: Bulk density, Fe: reducible Iron (0.1 mol/kg, Smakgahn et al, 2008), FWC: Field water capacity (0.87)

The Regional Mode Data Input

- GIS file 4 (Thailand_4.txt)

Total number of files we want to read

Range of total number of farm file that we want to read (e.g 28 to 43)

File Edit Format View Help

```
Thailand crop acreage census data(ha) 4hrs drainage with deep GWL
System x20RC 70N 8MT 8TC 90T 9UT 10MN 10ME 11CT 11KU 11SU 12CS 12TY 12CB 13TKY
15     28    29  31  32  33  34  35   36   37   38   39   40   41   42   43
1000001 1
1000002 1
1000003 1
1000004 1
1000005 1
1000006 1
1000007 1
```

SUC

The Regional Mode Data Input

- GIS file 5 (Thailand_5.txt)

SUC	Map ID
1000001	11111111
1000002	11111111
1000003	11111111
1000004	11111111
1000005	11111111
1000006	11111111
1000007	11111111

The Regional Mode Data Input

- Climate station data

- DNDC
  - Database
    - Thailand
      - GIS
      - Lib_clim
      - Lib_farm
      - Lib_map
  - Input
    - Climate
  - Library
    - Lib_crop
    - Lib_soil
  - RESULT
    - inputs
    - inter
    - record

Climate data → Lib_clim

- Lib_clim
  - 1971
  - 1972
  - 1973
  - 1974
  - 1975
  - 1976
  - 1977

The Regional Mode Data Input

- Climate station data

(Station ID)

424301_2010

Days (1-365)	Min Temp	Max Temp	Precipitation (cm)
1	33.4	22.2	0
2	34.5	20.5	0
3	34.4	20.7	0
4	34.2	25.5	0
5	30.5	22.5	0
6	31.2	22	0
7	34.0	22.5	0

The Regional Mode Data Input

- Farm data/Lib_farm

- DNDC
  - Database
    - Thailand
      - GIS
      - Lib_clim
      - Lib_farm
      - Lib_map
  - Input
    - Climate
  - Library
    - Lib_crop
    - Lib_soil
  - RESULT
    - inputs
    - inter
    - record

Farm data/Lib_farm → Lib_farm

Farm file
(details on next slide)

Farm file / Lib_farm

Value	Parameter	Description
1	number_of_crops	
20	rice	Crop code
8444.2	optimum_yield	Maximum yield (kg/ha)
5	planting_month	Transplanting month
25	planting_day	Transplanting day
9	harvest_month	Harvesting month
10	harvest_day	Harvesting day
1	percent_residue_left	Ratio percent of crop residue(0-1)
999	season_flag	Season flag(999 indicates the crop is the last crop planted in the year)
3	till_applications	
5	month	
5	day	
3	method	
5	month	
20	day	
3	method	
11	month	
1	day	
3	method	
2	number_of_fert	
5	fert_month1	
20	fert_day1	
70	fert_rate1	
6	fert_month1	
30	fert_day1	
20	fert_rate1	
0	manure_applications	
1	irrigation_index	Irrigation index (0-1)
2	flooding	2 Times of flooding
5	month(flooded)	Flooding month
20	day	Flooding day
6	month(drained)	Draining month
23	day	Draining day
6	month(flooded)	
28	day	
8	month(drained)	
20	day	

Till method: define tilling depth by selecting method as
(1) Ploughing slightly, 5cm (2) Ploughing with disk of chisel(10cm), (3) Ploughing with moldboard, 15cm

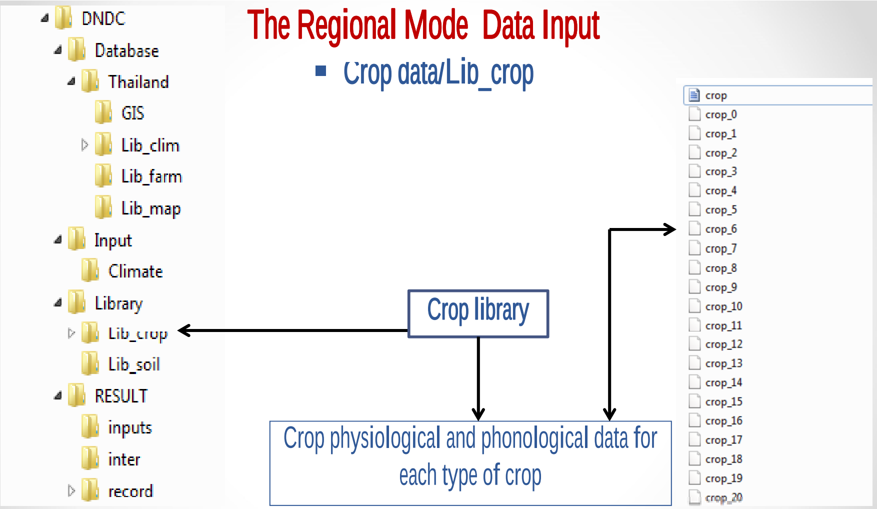
Fertilization rate(kg N/ha)

Amount (kg C/ha): Amount of manure application rate (kg C/ha)
C/N ratio: Ratio of C/N in the manure. Manure type is specified using CN ratio.

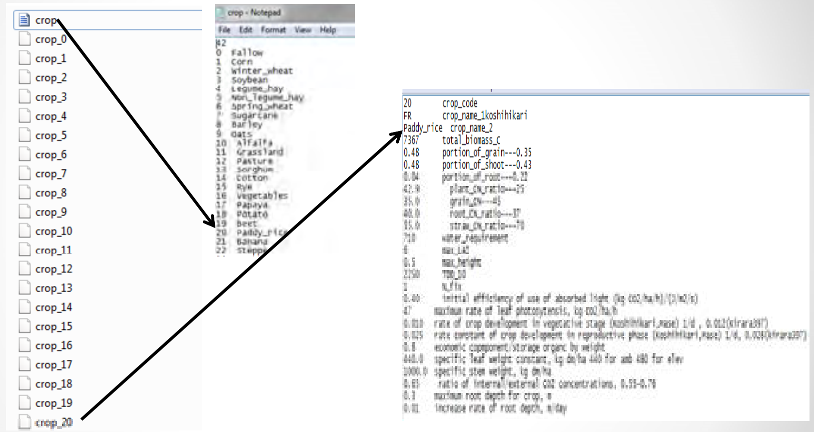
*A flooding event is defined by specifying its start date and end date

The Regional Mode Data Input

- Crop data/Lib_crop

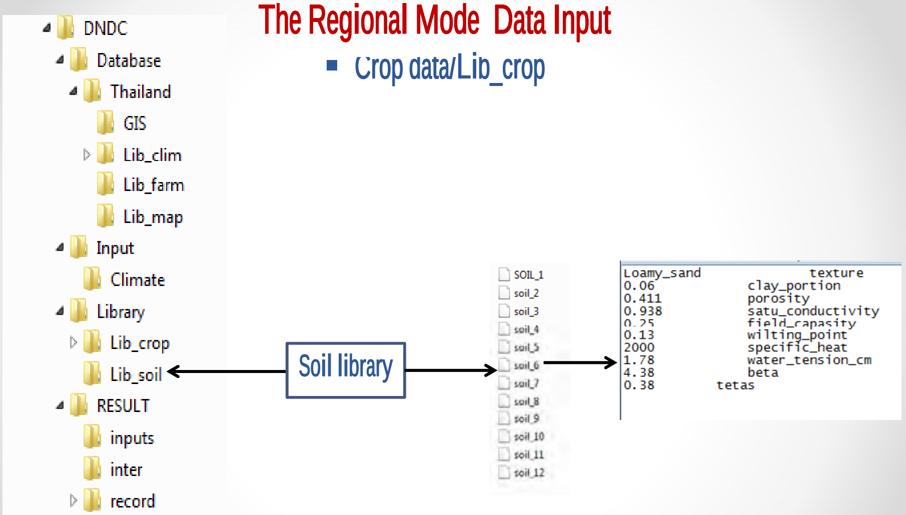


List of crops and code

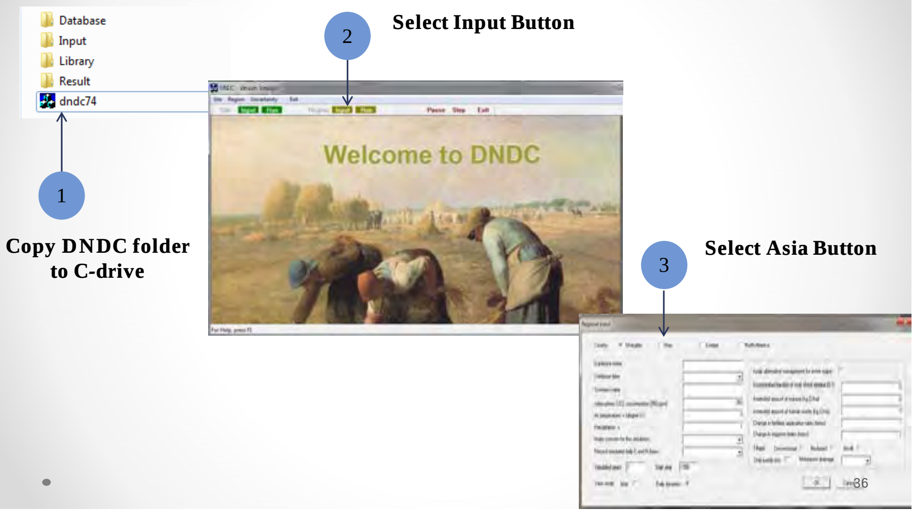


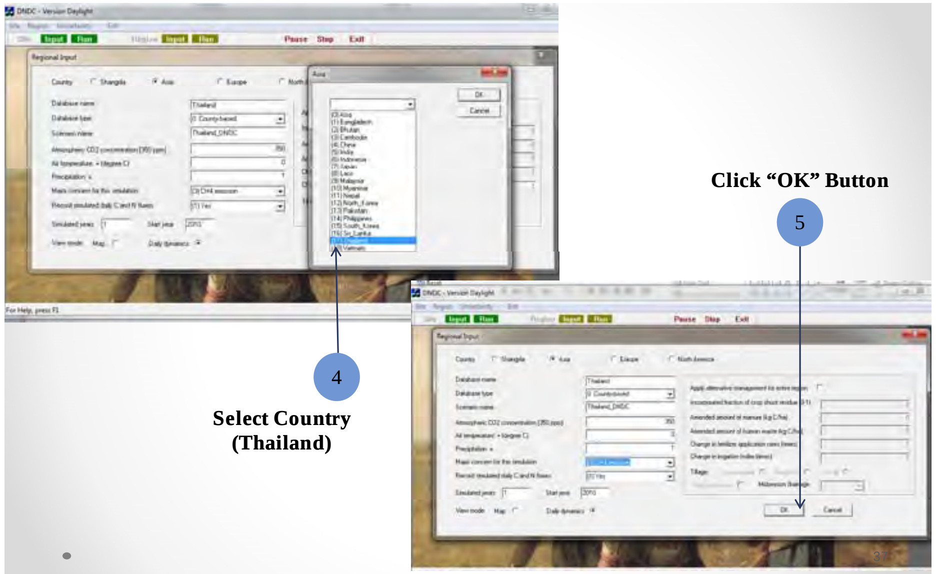
The Regional Mode Data Input

- Crop data/Lib_crop

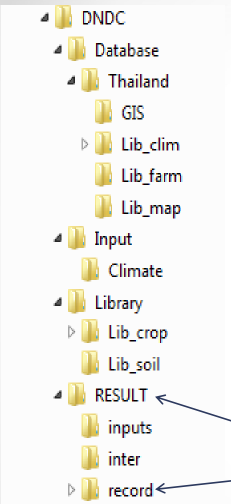


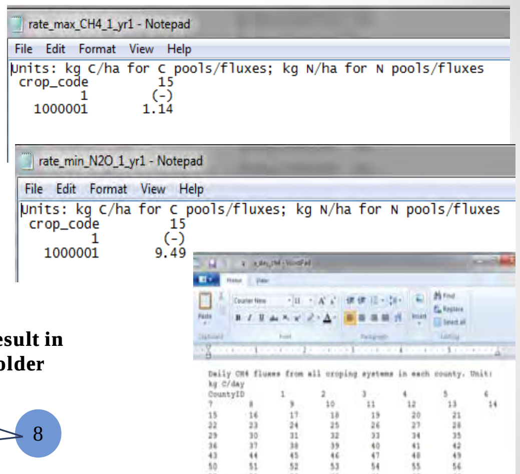
Run DNDC regional mode





Simulation Results





Explore result in
record folder

Case Study , China

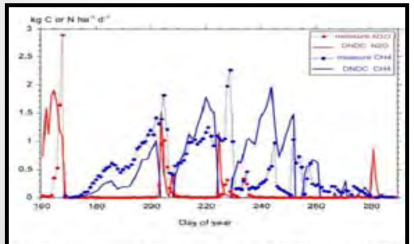


Fig. 2. Comparison between observed and DNDC-modeled CH_4 and N_2O fluxes from a paddy rice field applied with midseason drainage in Wu County, the Taihu Lake region, China, in 1995.

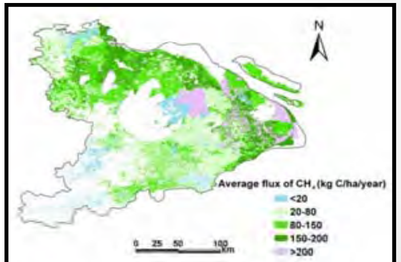


Fig. 3. Distribution of the average CH_4-C flux from 1982 to 2000 in the Taihu Lake region, China.

Thank You !

Introduction to ALU Software and Workbook

Assoc. Prof. Dr. Savitri Garivait and Dr. Agapol Junpen
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akjp@hotmail.com

Capacity Building Workshop on:
"Strategic rice cultivation with energy crop rotation in Southeast Asia – A path toward climate change mitigation in the agricultural sector"
29-31 May 2013, Pullman King Power Hotel, Bangkok, Thailand

Stephen M. Ogle, Ph.D.
Research Scientist and Associate Professor
Colorado State University
Natural Resource Ecology Laboratory
Fort Collins, Colorado USA

ALU Software Design

- Primary Purpose: Support reporting of GHG emissions to the UNFCCC
- Greenhouse Gas Inventory Software Program
  - Developed for LULUCF and Agricultural Sectors
  - Based on IPCC methods (96 GL and GPG)
    - Emphasis on incorporation of *good practices*
  - Accommodates IPCC Tier 1 methods, but allows compilers to advance inventory with the Tier 2 method capability
- User-interface guiding compiler through inventory process of data entry and calculations

ALU Software Design

- Data management capability
  - Relational database
  - Activity data, emission factors, emission results
  - Can incorporate GIS-based data on land use and land use change derived from remote sensing imagery
- Documentation and archive for all data and results
  - Self-contained database with data used in inventory as well as documentation references and results
  - Institutional memory for long-term sustainability of GHG inventory
- Includes an electronic help manual
  - Step by step guidance for software users

ALU Software & Good Practice

- *Inventories following good practice "contain neither over- nor under-estimates so far as can be judged, and which uncertainties are reduced as far as is practicable" (IPCC GPG 2000).*
- Estimate uncertainties
- Quality Assurance/Quality Control
- Document inventory methods and emission factors, and archive the database
- Development of Tier 2 methods for key source categories

Inventory Purpose: Reporting

- One of the main purposes of a national GHG inventory is to report emissions to the UNFCCC
- Reporting is generally done in spreadsheets
- Maps can be useful for illustrating variation in emissions across a country
- ALU provide emission reports that conform to the typical non-Annex I party reporting standards (i.e., UNFCCC software spreadsheet)
- ALU facilitates the development of emission maps to the extent that activity data and/or emission factors vary spatially

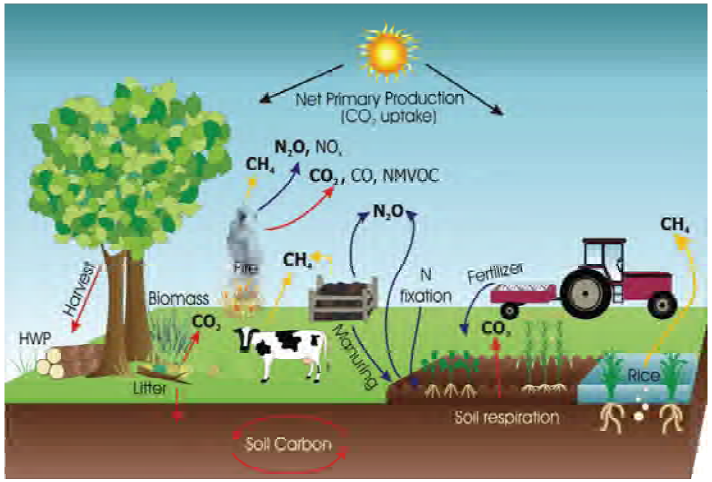
Inventory Purpose: Mitigation Analysis

- Inventories should form the basis to consider mitigation options and monitor outcomes of policy actions intended to reduce emissions (NAMAs and LEDS)
- With an inventory developed using good practices, compilers can be confident in assessing mitigation potentials
- ALU facilitates mitigation analysis using the GHG inventory developed in the software with good practice for the baseline emissions

Source Categories in ALU

Biomass C Stock Changes

Non-CO_2 GHG Emissions from Burning



CH_4 and N_2O from Manure

Soil N_2O Emissions

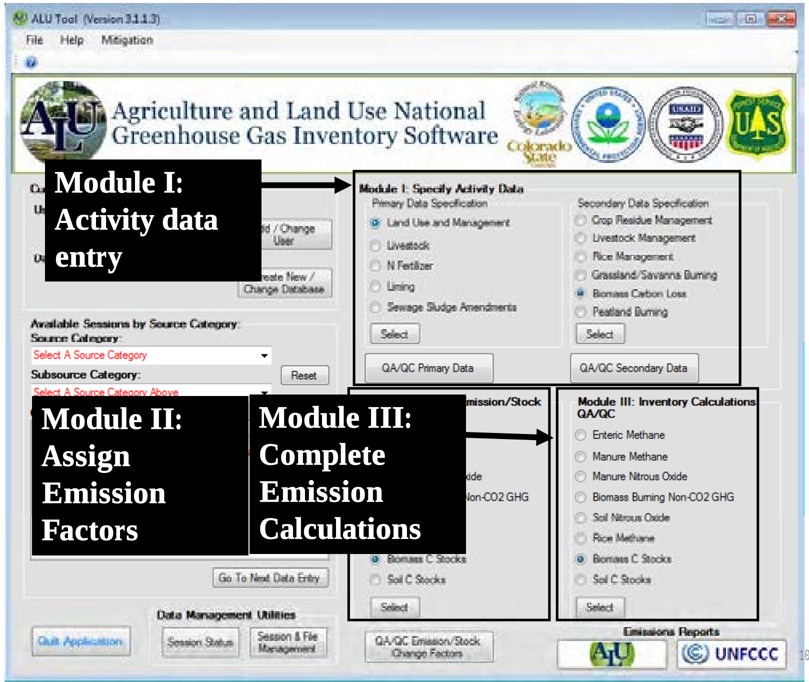
Rice Methane

Enteric Methane

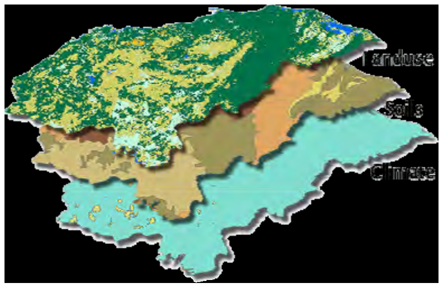
Soil C Stock Changes

From 2006 IPCC Guidelines

Example: ALU Land Use Session



Utilize Spatial Data



Geographic Information System

Export

Text File

(Import into ALU)

1102,TRMM,HAC,FL,35117.19922
1103,TRMM,HAC,GL,65306
1104,TRMM,HAC,GL,9724.410156
1105,TRMM,HAC,OL,215.460006
1106,TRMM,HAC,SM,373.23001
1107,TRMM,HAC,CL,4032.090087
1109,TRMM,HAC,WL,7.559999
1110,TRMM,HAC,FL,0.449999
1111,TRMM,HAC,WL,2316.23999
1202,TMSD,HAC,FL,106793
1203,TMSD,HAC,GL,721293
1204,TMSD,HAC,GL,292541
1205,TMSD,HAC,OL,20048.59961
1206,TMSD,HAC,SM,4145.759765
1207,TMSD,HAC,CL,229119
1209,TMSD,HAC,WL,3208.050048
1210,TMSD,HAC,FL,31221.69922
1211,TMSD,HAC,WL,41818.60156
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3103,TRMM,VOL,GL,20436.19922
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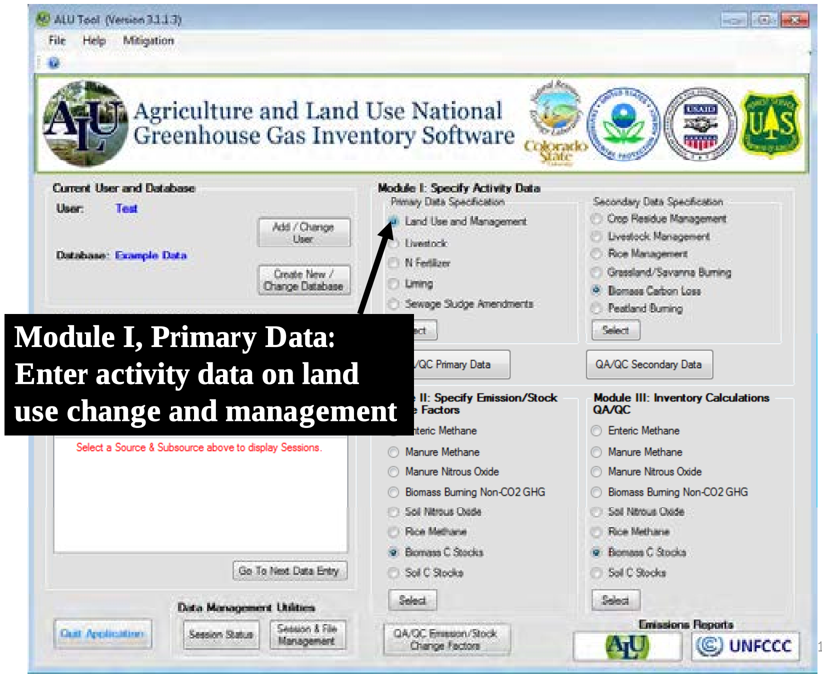
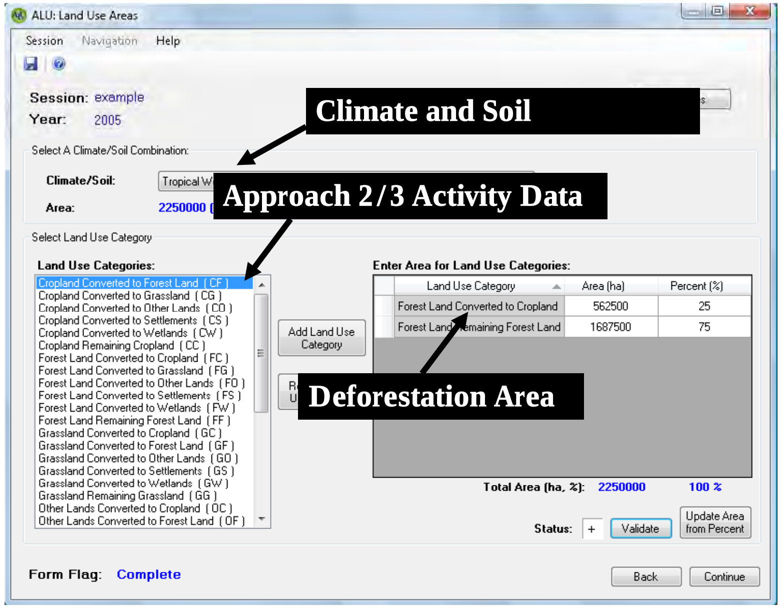
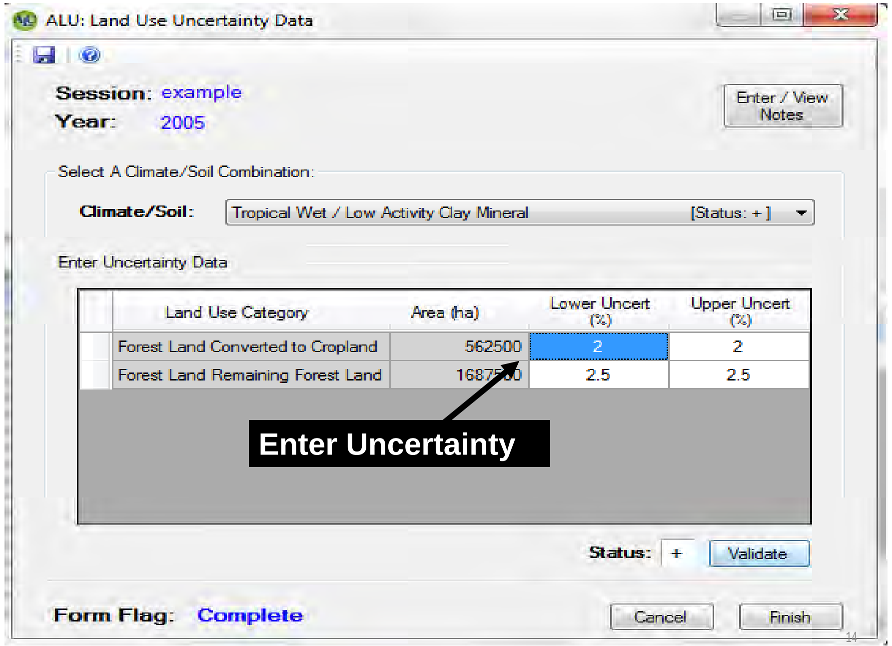
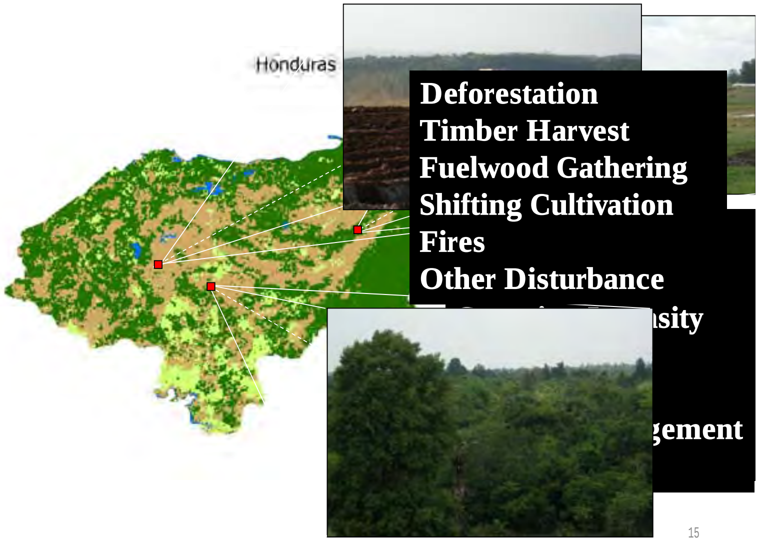
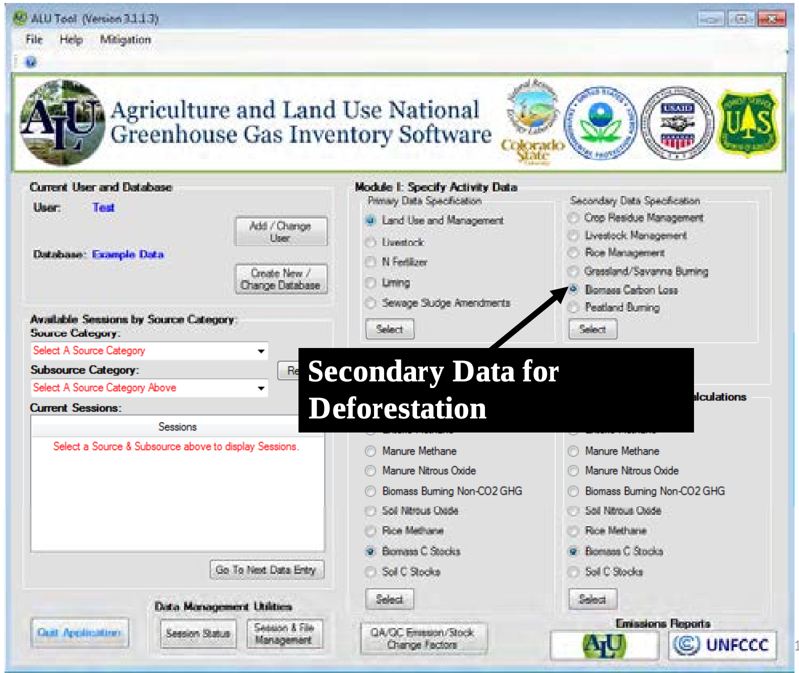


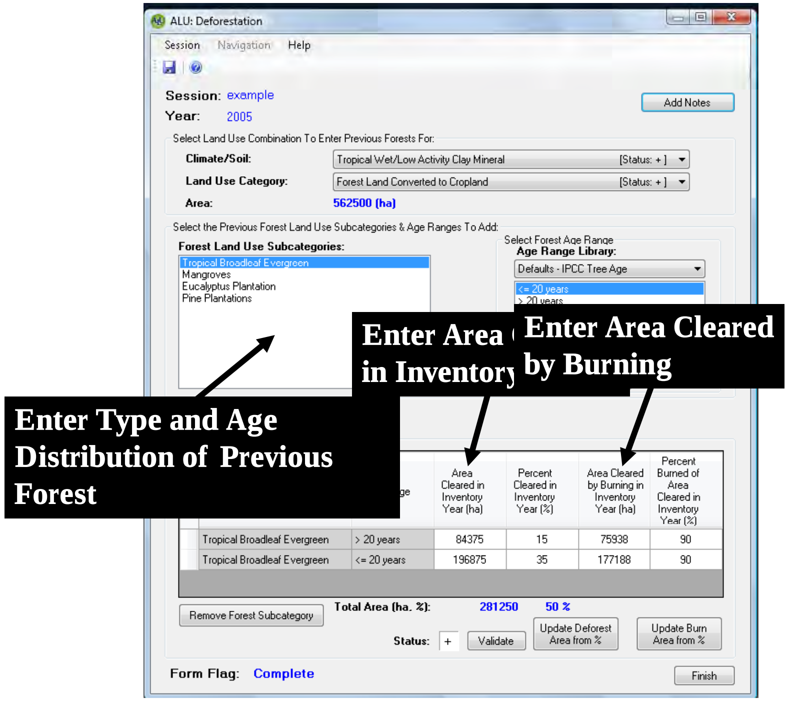




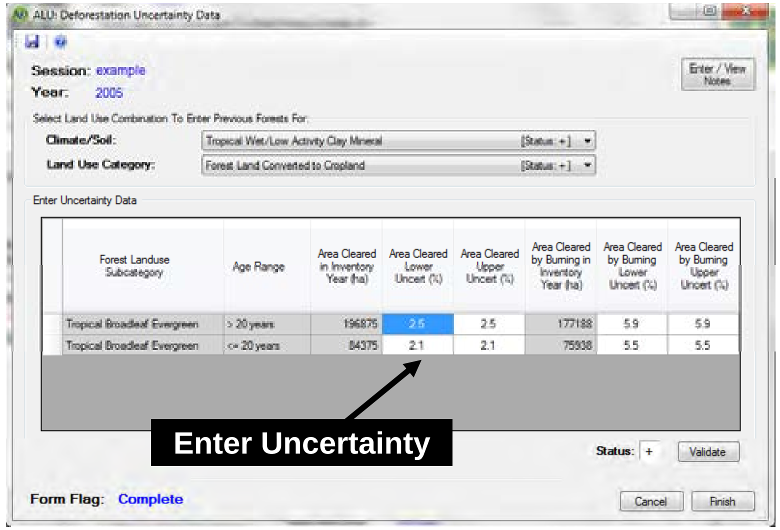
Management Data



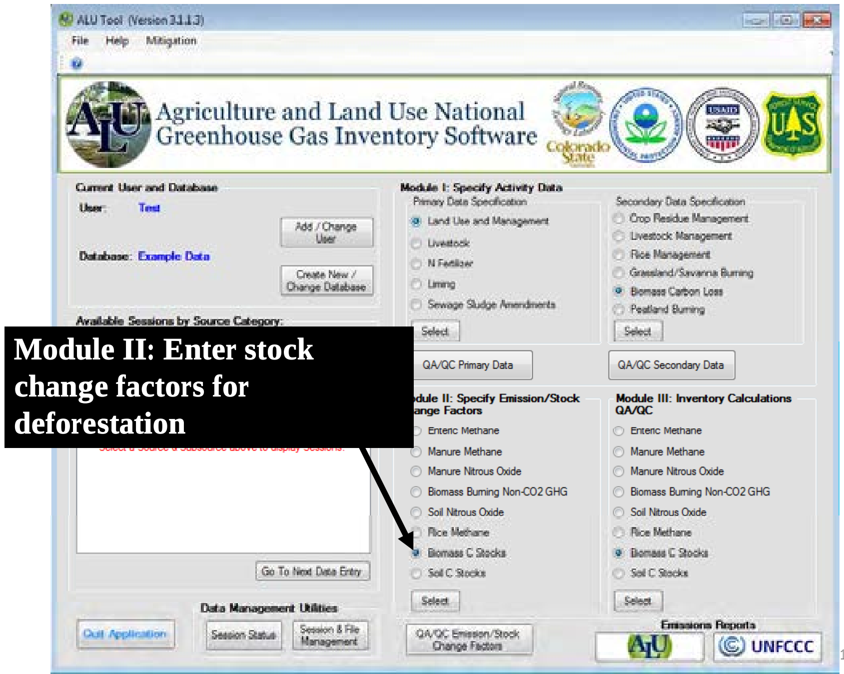



ALU: Deforestation
Enter Type and Age Distribution of Previous Forest
Enter Area Cleared in Inventory
Enter Area Cleared by Burning

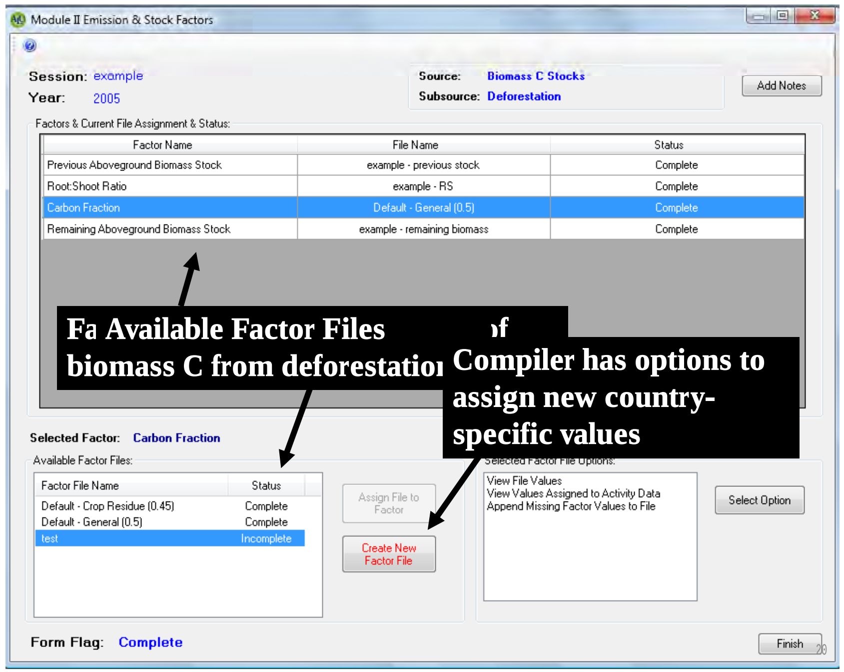
17


ALU: Deforestation Uncertainty Data
Enter Uncertainty

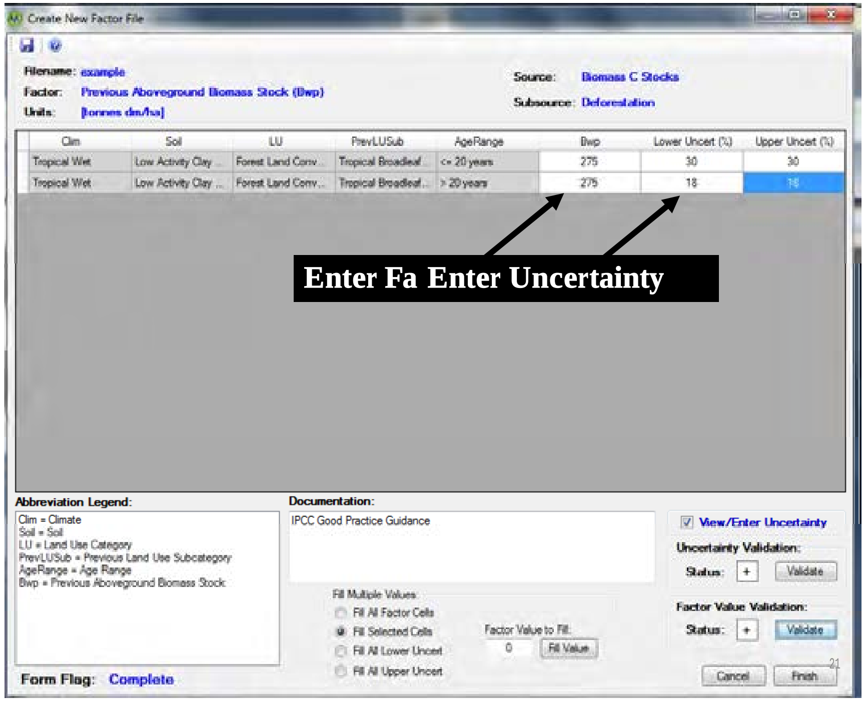
18

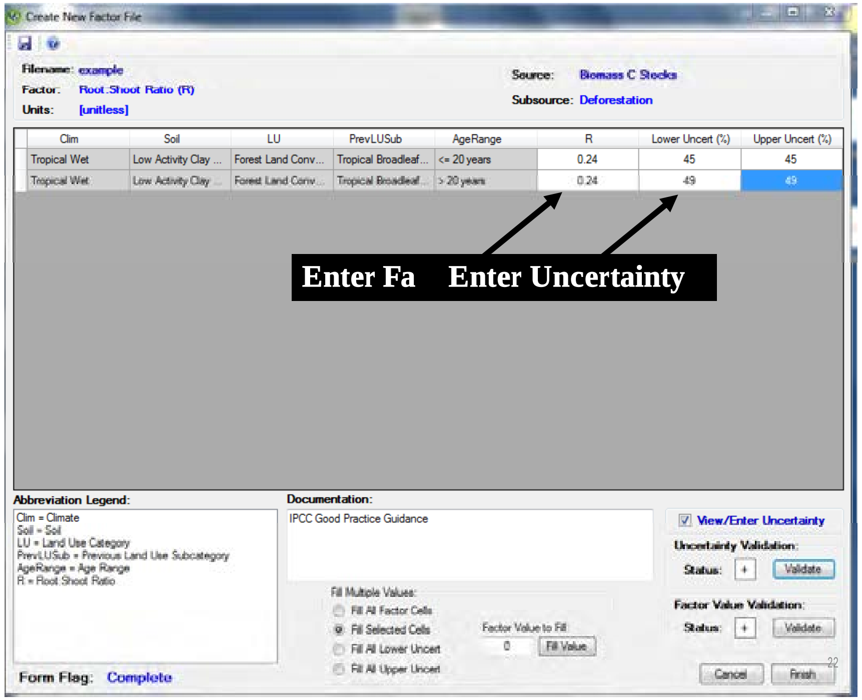

Agriculture and Land Use National Greenhouse Gas Inventory Software
Module II: Enter stock change factors for deforestation

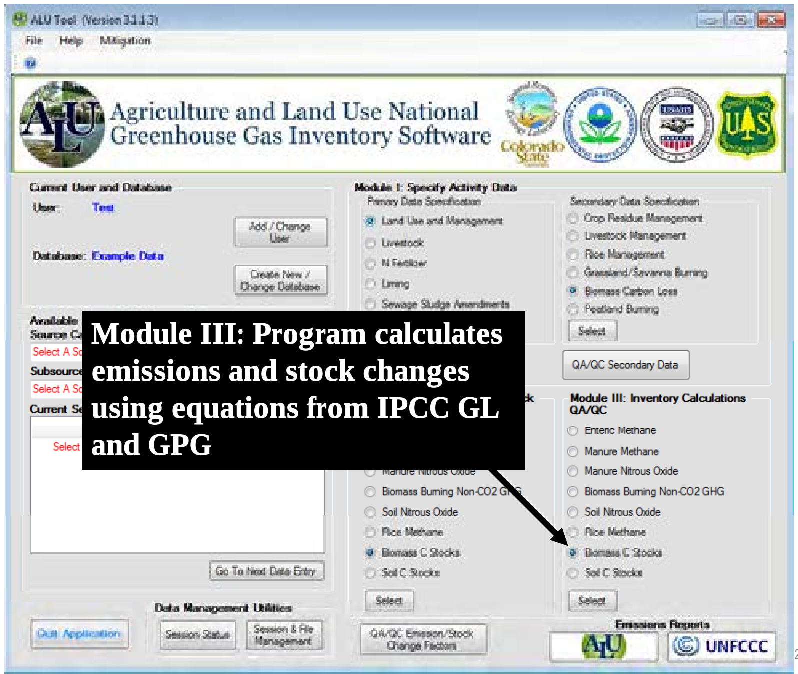
19

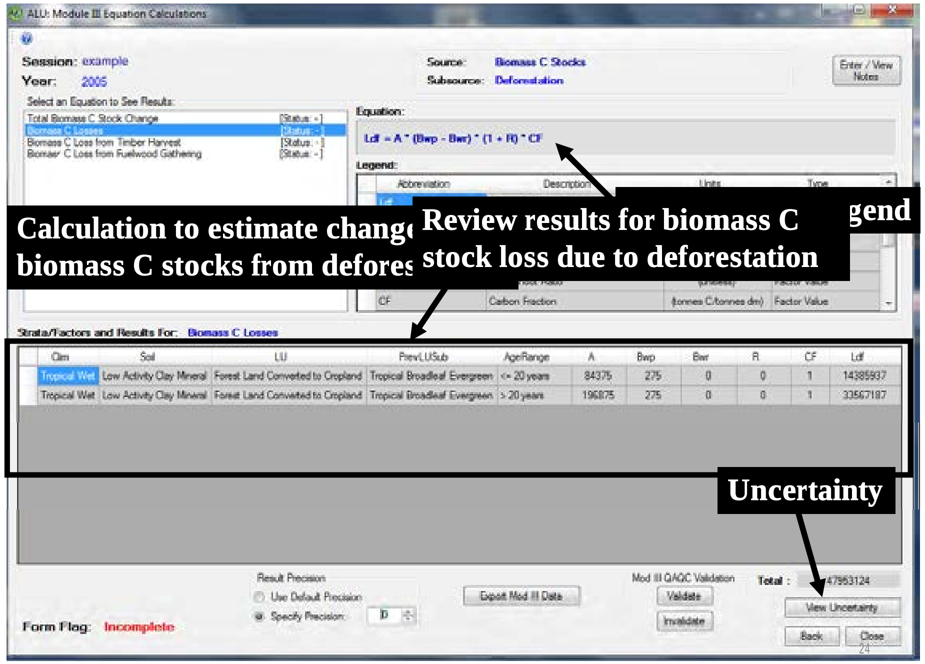

Module II Emission & Stock Factors
Available Factor Files biomass C from deforestation
Compiler has options to assign new country-specific values

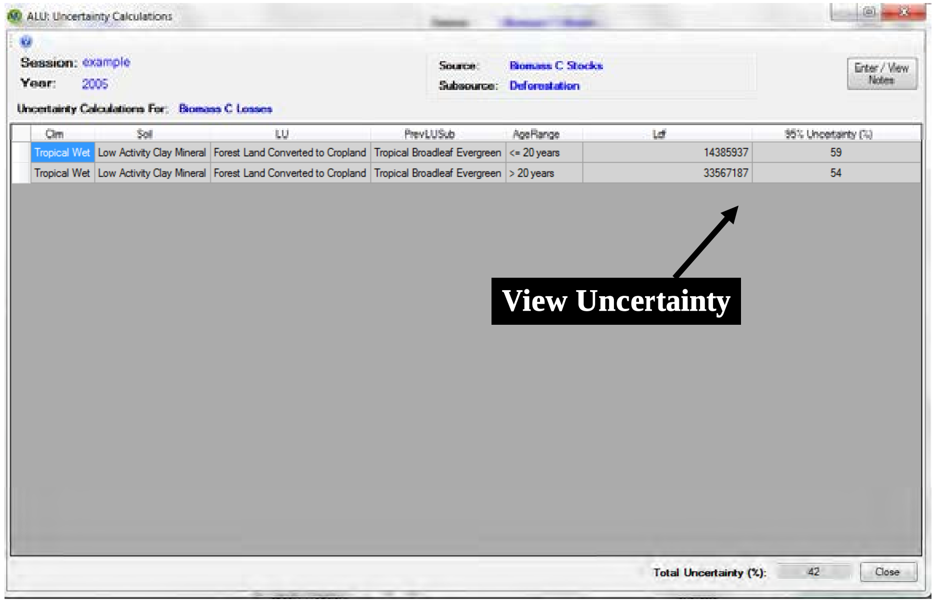
20

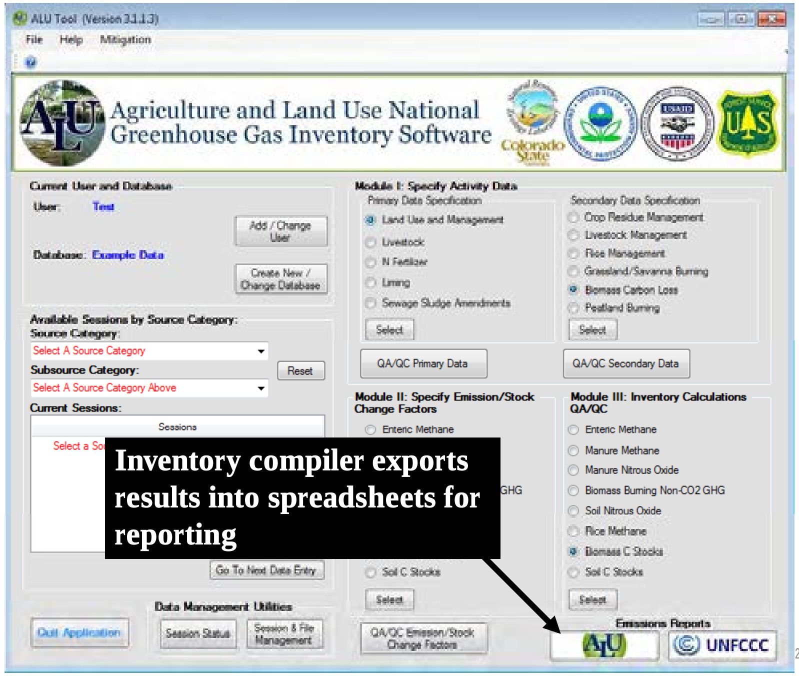

Create New Factor File
Filename: example
Factor: Previous Aboveground Biomass Stock (Bwp)
Units: [tonnes dm/ha]
Source: Biomass C Stocks
Subsource: Deforestation
Enter Fa Enter Uncertainty
Form Flag: Complete
21

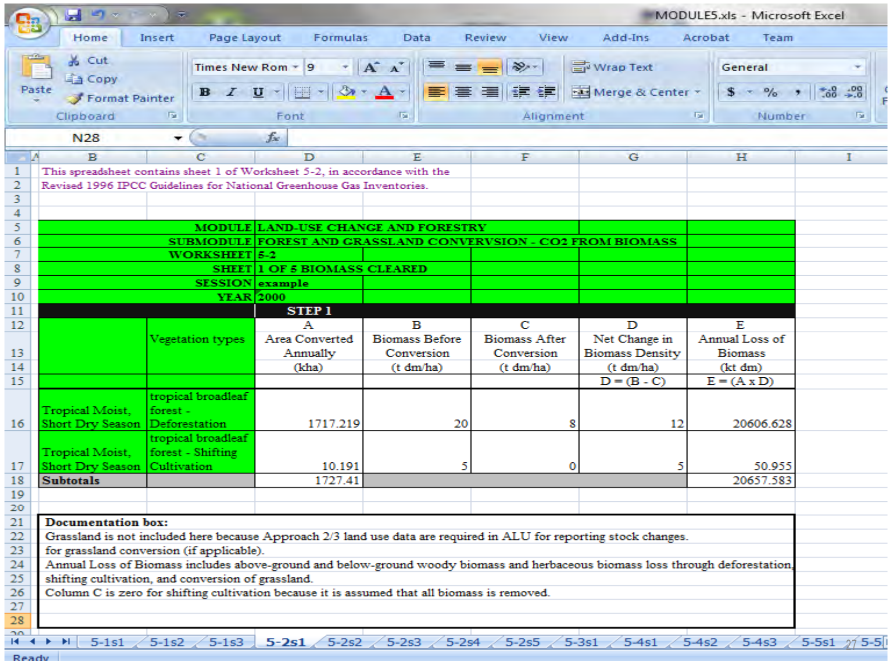

Create New Factor File
Filename: example
Factor: Root:Shoot Ratio (R)
Units: [unitless]
Source: Biomass C Stocks
Subsource: Deforestation
Enter Fa Enter Uncertainty
Form Flag: Complete
22


ALU Tool (Version 3.1.1.3)
Agriculture and Land Use National Greenhouse Gas Inventory Software
Module III: Program calculates emissions and stock changes using equations from IPCC GL and GPG
23


ALU: Module III Equation Calculations
Session: example
Year: 2005
Source: Biomass C Stocks
Subsource: Deforestation
Calculation to estimate chang biomass C stocks from defores
Review results for biomass C stock loss due to deforestation
gend
Uncertainty
Form Flag: Incomplete
24







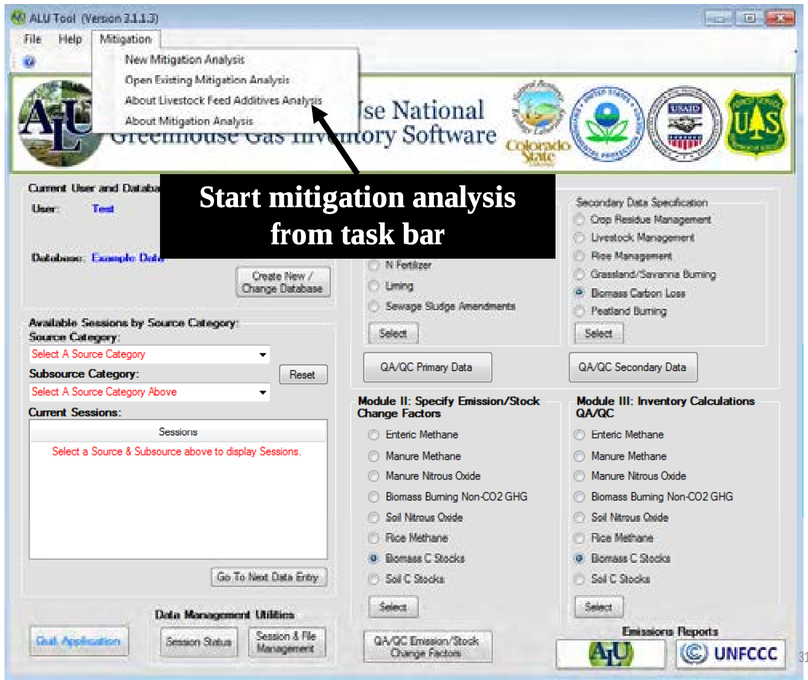
Example: ALU Mitigation Analysis

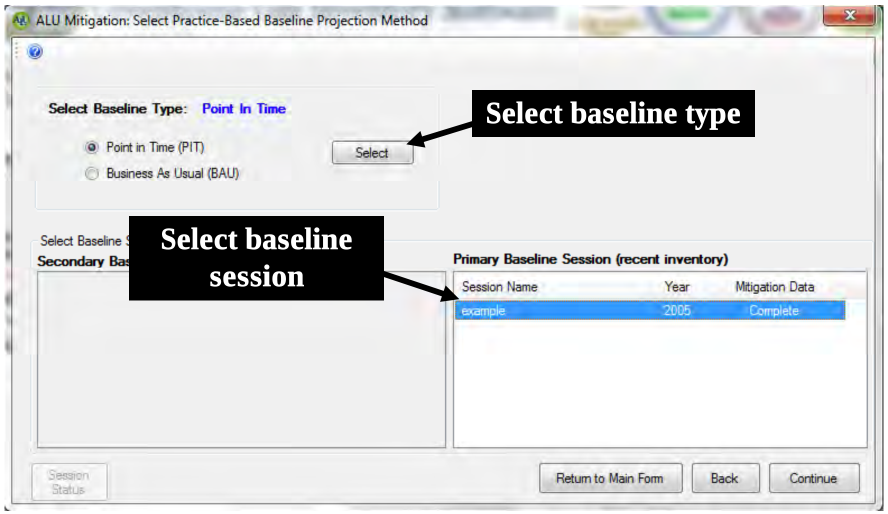
Scope of Analysis

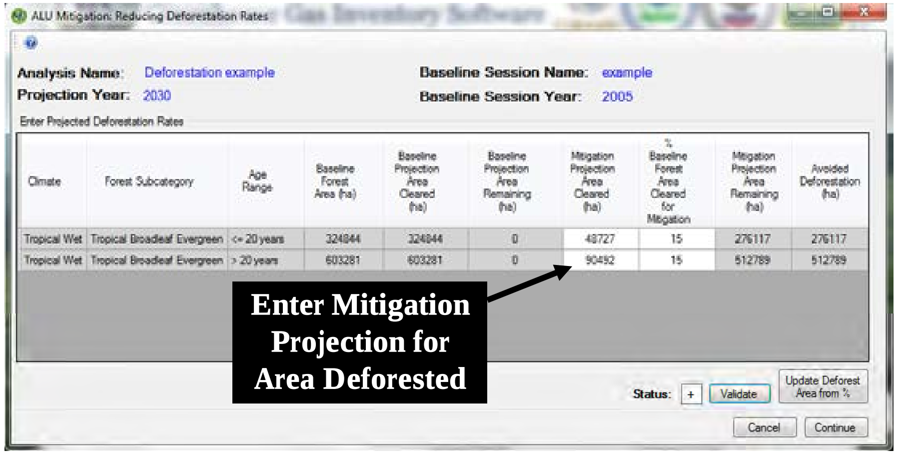
- Analyze the potential change in greenhouse gas emissions from changing management of land and livestock
- Use existing inventory in ALU as the baseline
- Include multiple source categories influenced by practice
  - Within Agriculture and LULUCF
- Biophysical potentials estimated by ALU, but projections can be informed by economic forecasts of commodity production and consequences for management of land and livestock

Approaches for Mitigation Analysis

- **Whole Session Approach**
  - Focus on all practices
    - Maximum utility
  - Assesses all drivers of emissions and mitigation potential
    - Population growth, economic growth and technology
- **Practice-Based Approach**
  - Focus on specific practice
  - Assesses technology as a driver of emissions and mitigation potential







ALU Mitigation: Reducing Deforestation Rates

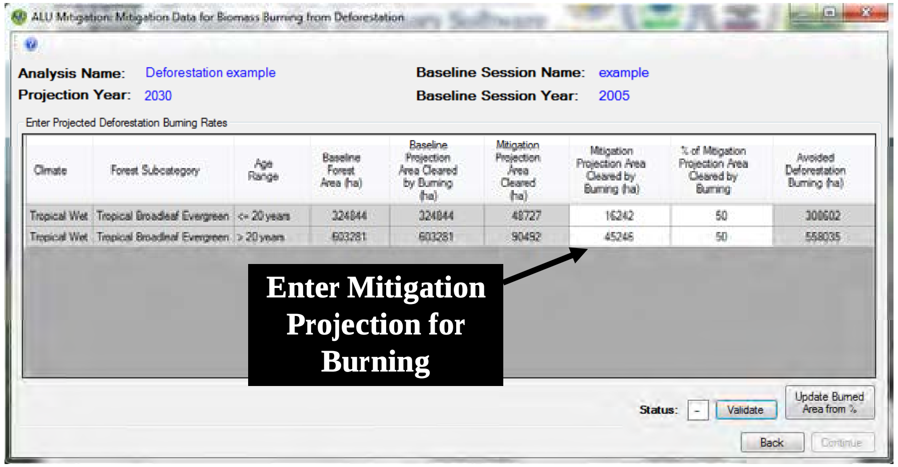
Analysis Name: Deforestation example
Projection Year: 2030
Baseline Session Name: example
Baseline Session Year: 2005

Enter Projected Deforestation Rates

Climate	Forest Subcategory	Age Range	Baseline Forest Area (ha)	Baseline Projection Area Cleared (ha)	Baseline Projection Area Remaining (ha)	Mitigation Projection Area Cleared (ha)	% Baseline Forest Area Cleared for Mitigation	Mitigation Projection Area Remaining (ha)	Avoided Deforestation (ha)
Tropical Wet	Tropical Broadleaf Evergreen	<= 20 years	324844	324844	0	48727	15	276117	276117
Tropical Wet	Tropical Broadleaf Evergreen	> 20 years	603281	603281	0	90492	15	512789	512789

Enter Mitigation Projection for Area Deforested

Status: + Validate Update Deforest Area from %
Cancel Continue



ALU Mitigation: Mitigation Data for Biomass Burning from Deforestation

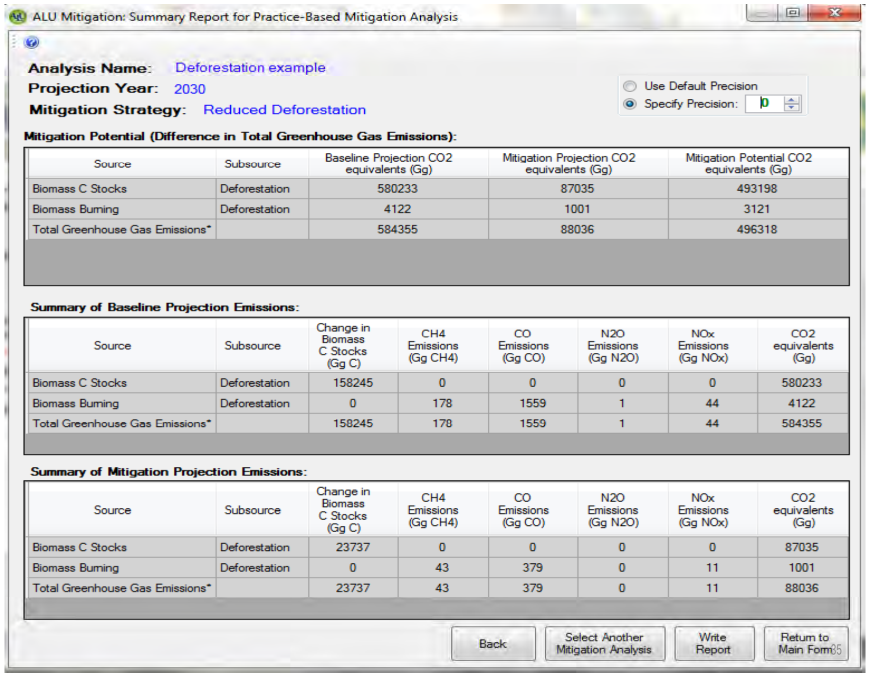
Analysis Name: Deforestation example
Projection Year: 2030
Baseline Session Name: example
Baseline Session Year: 2005

Enter Projected Deforestation Burning Rates

Climate	Forest Subcategory	Age Range	Baseline Forest Area (ha)	Baseline Projection Area Cleared by Burning (ha)	Mitigation Projection Area Cleared (ha)	Mitigation Projection Area Cleared by Burning (ha)	% of Mitigation Projection Area Cleared by Burning	Avoided Deforestation Burning (ha)
Tropical Wet	Tropical Broadleaf Evergreen	<= 20 years	324844	324844	48727	16242	50	308602
Tropical Wet	Tropical Broadleaf Evergreen	> 20 years	603281	603281	90492	45246	50	558035

Enter Mitigation Projection for Burning

Status: - Validate Update Burned Area from %
Back Continue



ALU Mitigation: Summary Report for Practice-Based Mitigation Analysis

Analysis Name: Deforestation example
Projection Year: 2030
Mitigation Strategy: Reduced Deforestation

Use Default Precision
Specify Precision: 0

Mitigation Potential (Difference in Total Greenhouse Gas Emissions):

Source	Subsource	Baseline Projection CO2 equivalents (Gg)	Mitigation Projection CO2 equivalents (Gg)	Mitigation Potential CO2 equivalents (Gg)
Biomass C Stocks	Deforestation	580233	87035	493198
Biomass Burning	Deforestation	4122	1001	3121
Total Greenhouse Gas Emissions*		584355	88036	496318

Summary of Baseline Projection Emissions:

Source	Subsource	Change in Biomass C Stocks (Gg C)	CH4 Emissions (Gg CH4)	CO Emissions (Gg CO)	N2O Emissions (Gg N2O)	NOx Emissions (Gg NOx)	CO2 equivalents (Gg)
Biomass C Stocks	Deforestation	158245	0	0	0	0	580233
Biomass Burning	Deforestation	0	178	1559	1	44	4122
Total Greenhouse Gas Emissions*		158245	178	1559	1	44	584355

Summary of Mitigation Projection Emissions:

Source	Subsource	Change in Biomass C Stocks (Gg C)	CH4 Emissions (Gg CH4)	CO Emissions (Gg CO)	N2O Emissions (Gg N2O)	NOx Emissions (Gg NOx)	CO2 equivalents (Gg)
Biomass C Stocks	Deforestation	23737	0	0	0	0	87035
Biomass Burning	Deforestation	0	43	379	0	11	1001
Total Greenhouse Gas Emissions*		23737	43	379	0	11	88036

Back | Select Another Mitigation Analysis | Write Report | Return to Main Form

Acknowledgements:

ALU Software Programmers/Testers: Shannon Spencer (lead programmer), Melannie Hartman, Guhan Dheenadayalan, Fatmah Assiri, Bill Tucker, Prasanna Venkatesh, Mark Easter, Fadi Wedyan, Shilpa Halvadar, Hussein Al-Rousan, Dean Selby, Stephen Williams, Karen Galles and Amy Swan

More Information:
http://www.epa.gov/climatechange/emissions/ghginventorycapacitybuilding/index.html

http://www.nrel.colostate.edu/projects/ALUsoftware/

Review of ALU Workbook

Assoc. Prof. Dr. Savitri Garivait and Dr. Agapol Junpen
The Joint Graduate School of Energy and Environment

savitri_g@jgsee.kmutt.ac.th
akjp@hotmail.com

Capacity Building Workshop on:
"Strategic rice cultivation with energy crop rotation in Southeast Asia –
A path toward climate change mitigation in the agricultural sector"
29-31 May 2013, Pullman King Power Hotel, Bangkok, Thailand

Stephen M. Ogle, Ph.D.
Research Scientist and Associate Professor
Colorado State University
Natural Resource Ecology Laboratory
Fort Collins, Colorado USA

Fertilization and Application of Carbonate Lime

Carbonate Limes

- Carbonate lime amendments include crushed limestone and dolomite
- Potential activity data sources
  - Mining records and import/export data
  - Soil application data
- Subtract lime used in cement production if relying on mining records, import/export data

Mineral Nitrogen Fertilizer

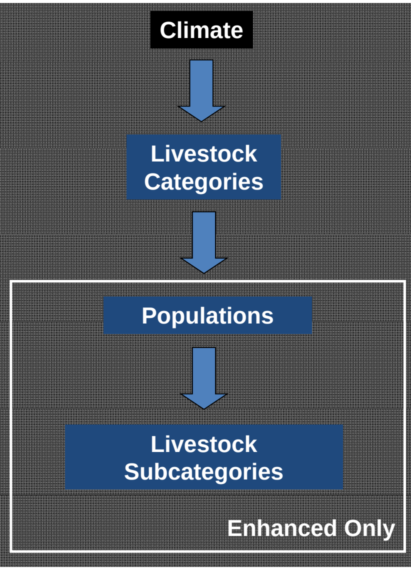
- Fertilizer application to soils influences soil N_2O emissions
  - Direct and indirect soil N_2O emissions
  - N fertilizer often key driver of soil N_2O emissions
- Compile N fertilizer types and %N in fertilizer
- Enter amount of N fertilizer added to soils
  - Fertilizer sales data
  - Fertilizer production/import/export data
  - Fertilizer application data

Sewage Sludge N

- Similar to N fertilizers, sewage sludge N application to soils influences soil N_2O emissions
  - Direct and indirect soil N_2O emissions
- Enter amount of sewage sludge added to soils
  - Municipal waste records
- Enter %N content of human waste

Livestock & Manure Management

Livestock Data Hierarchy



Basic Characterization

- Enter animal numbers for each livestock category in a climate region
  - Dairy cows
  - Non-dairy cattle
  - Buffalo
  - Camels
  - Sheep
  - Goats
  - Horses
  - Mules and asses
  - Swine
  - Poultry

Enhanced Characterization

- Optional, but recommended if methane emissions from enteric fermentation and/or manure management is a key category
- Only available for dairy cows, non-dairy cattle, buffalo, and swine
  - Livestock categories contributing most emissions to methane from enteric fermentation and manure
- Subdivide animals by populations & subcategories
  - Populations are specified by compiler to meet national circumstances
  - Subcategories are age/gender classes based on IPCC 2000 GPG
- Activity data from livestock associations, new surveys, expert knowledge (e.g., animal scientists)

Enhanced Characterization

- Gross Energy Intake (GEI)
  - Estimate Tier 2 emission factors for methane emissions from enteric fermentation and manure management
  - Variety of livestock characteristics needed to complete calculation
    - Average daily weight gain, average daily work, average live weight, digestibility of feed, feeding situation, and typical mature weight for breed
    - Mature females only: % females lactating, % females pregnant, daily milk production, fat content of milk
- *All information required; otherwise use basic characterization*

Enhanced Characterization

- Volatile Solid (VS) excretion
  - Estimate Tier 2 emission factors for methane emissions from manure management
  - Only for dairy cows, non-dairy cattle, buffalo and swine
  - Estimate VS with calculation based on feed intake and digestibility
    - Enter GEI (for swine), % ash content of manure and digestibility of feed
- *All information required; otherwise use basic characterization*

Manure N & Management

- Assign manure management systems
  - Livestock categories for basic characterization
  - Populations for enhanced characterization
  - Seventeen manure management systems
- Nitrogen excretion rates
  - IPCC default N excretion rates
  - Rates entered for basic and/or enhanced characterization
- Activity data from livestock associations, new surveys, expert knowledge (e.g., animal scientists)

Land Representation

Overview – Land Representation

- LULUCF and Agricultural sectors require land representation to estimate emissions and removals
  - C Stocks Changes
    - Biomass, Dead Biomass and Soils
  - Non-CO_2 emissions from Biomass Burning
    - Grassland, forestland, and crop residues
  - Rice Methane
- Emission factors are assigned based land representation, i.e., stratification of land
  - Typical strata include land use, climate, soil types, ecological zones, land use subcategories, management
  - Your stratification should be consistent with Tier 1 stratification if using Tier 1 methods
  - Customized for national circumstances if using Tier 2 and 3

General Guidance

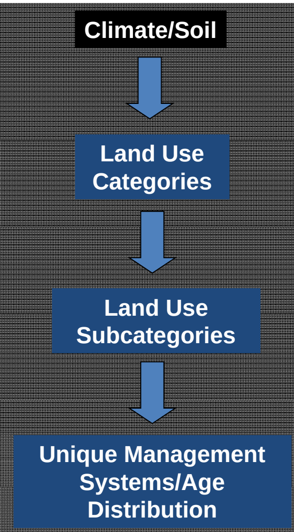
- Need an adequate classification of land
  - Represent land uses as provided by IPCC
    - Comparability between countries in reporting
  - Further disaggregation by strata as needed to assign emission factors
- Need a complete representation of land
  - Managed and unmanaged land
- Need a consistent application land representation data
  - Definitions and classifications are applied consistently
    - e.g., managed land base
  - Harmonize data as needed

General Guidance

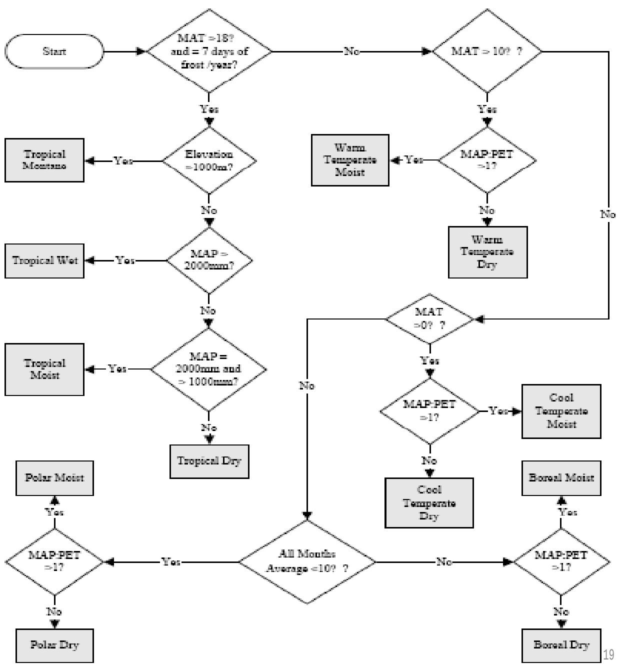
- **Ensure all relevant anthropogenic activities are included in land representation**
  - **All that influence greenhouse gas emissions**
- **Need to be transparent**
  - **Classifications**
  - **Application to methods**
  - **Assumptions**
- **Ensure the total land area of country is represented across time series**
- **Estimate uncertainty**

Land Representation

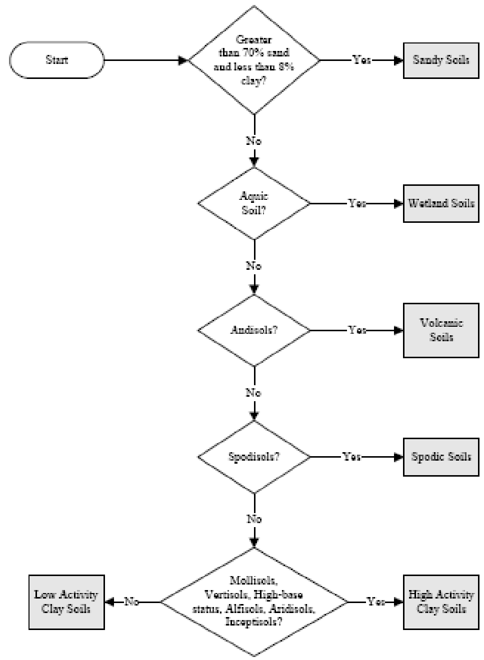
Spatial Hierarchy for Consistency in Land Representation



IPCC Climate Classification



IPCC Soil Classification



Managed Land

- Managed land is a proxy for anthropogenic emissions
  - Must estimate all emissions from managed land
- Define managed land to meet national circumstances
  - … Managed land is influenced by direct human intervention … (2006 GL)
- Can neither increase or decrease managed land base over time
- Must assign all land area in the country to managed or unmanaged

Approaches

- Three general methods for collecting activity data
  - Approach 1: Data that is not spatially explicit and does not track land use change through time
  - Approach 2: Data that provides land use change through time but is not spatially explicit
  - Approach 3: Data that provides land use change through time and is spatially explicit
- Mixed approaches can be used for different regions of the country

Approach I

- Land uses represented within a particular area, such as a political unit
- Land use change is not explicitly represented
- Categories: Forestland, Cropland, Grassland, Settlements, Wetlands, Other Lands
- Sources
  - Maps, surveys, and census

Approach I

TABLE 3.2
EXAMPLE OF APPROACH 1: AVAILABLE LAND USE DATA WITH COMPLETE NATIONAL COVERAGE

Time 1			Time 2			Net land-use conversion between Time 1 and Time 2		
F	=	18	F	=	19	Forest Land	=	+1
G	=	84	G	=	82	Grassland	=	-2
C	=	31	C	=	29	Cropland	=	-2
W	=	0	W	=	0	Wetlands	=	0
S	=	5	S	=	8	Settlements	=	+3
O	=	2	O	=	2	Other Land	=	0
Sum	=	140	Sum	=	140	Sum	=	0

Note: F = Forest Land, G = Grassland, C = Cropland, W = Wetlands, S = Settlements, O = Other Land. Numbers represent area units (Mha in this example).

Approach II

- Land use and land use change represented within a particular area, such as a political unit
- Emission factors can be assigned to represent rates that vary depending on prior land use and time since the land use conversion
- Categories: 36 categories for land use remaining in a category and conversions between categories
  - Cropland, Grassland, Settlements, Wetlands, Other Lands
- Sources
  - Surveys or census

Approach II

TABLE 3.6
SIMPLIFIED LAND-USE CONVERSION MATRIX FOR APPROACH 2 EXAMPLE

Net land-use conversion matrix

Final \ Initial	F	G	C	W	S	O	*Final sum*
F	15	3	1				*19*
G	2	80					*82*
C			29				*29*
W				0			*0*
S	1	1	1		5		*8*
O						2	*2*
Initial sum	*18*	*84*	*31*	*0*	*5*	*2*	*140*

Note:
F = Forest Land, G = Grassland, C = Cropland, W = Wetlands,
S = Settlements, O = Other Land
Numbers represent area units (Mha in this example).

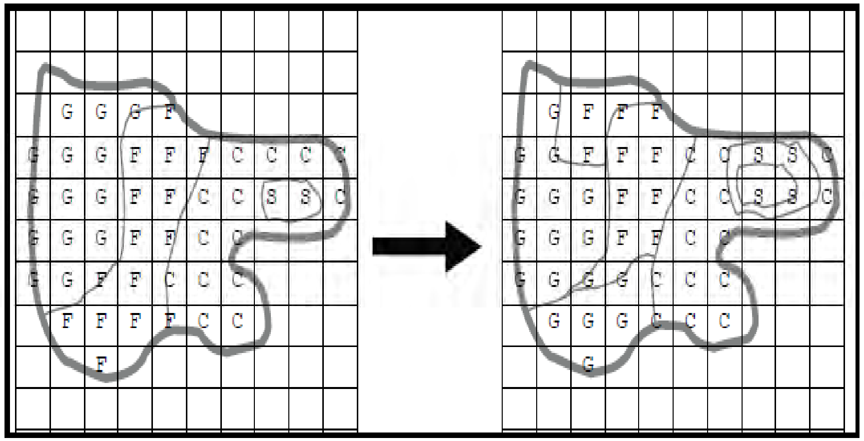
Approach III

- Spatially-explicit representation of land use and land use change
- Similar to Approach II, emission factors can represent rates that vary by prior land use and time since the land use conversion
- Same as Approach II, 36 categories of land use remaining in a category and conversions between categories
- Sources
  - Geo-referenced surveys, map products (e.g., remote sensing data)

Approach III

Time 1 Time 2

Figure 3A.4.1A Remote sensing can also enable complete coverage of all grid cells.



Land Use Subcategories

- Further subdivision of land use categories
  - e.g., forest types
- Only for forest, grassland and cropland
- Generally, remote sensing-based products will provide more disaggregation
  - Incorporated as subcategories into the analysis
- Can improve accuracy and precision of emission factor assignments
- May also be important for policy and management

LULUCF Biomass C

Forest

- C stock changes in biomass (2 methods)
- Non-CO_2 greenhouse gases
- Forest
  - Forest land use subcategories (i.e., forest types)
  - Meet country circumstances
- Age/diameter distribution
  - Important for determining growth

Forest Management

- Management of forests:
  - Fuel wood gathering
  - Wood removals (e.g. harvest)
  - Forest disturbance
    - Fire, pest, disease
  - Shifting cultivation
  - Drainage of organic soils (i.e., Histosols)

C Stock Change Method

- Stock-based

$$\Delta C = (C_{t_2} - C_{t_1}) / (t_2 - t_1)$$

ΔC = change of carbon stock

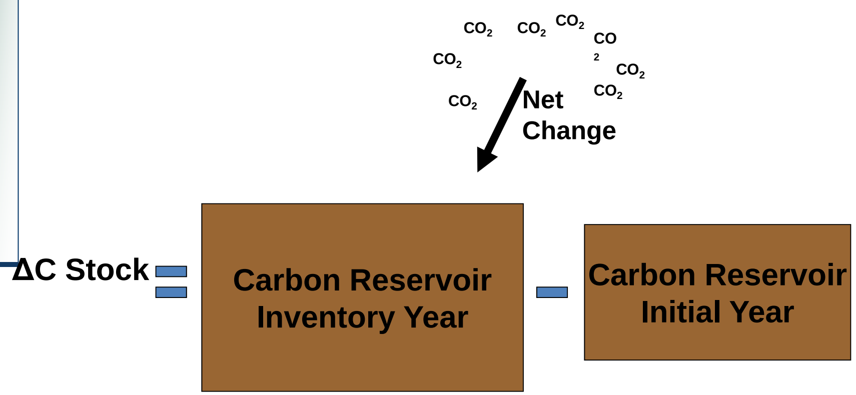
C_{t_2} = carbon stock at **time 2**

C_{t_1} = carbon stock at **time 1**

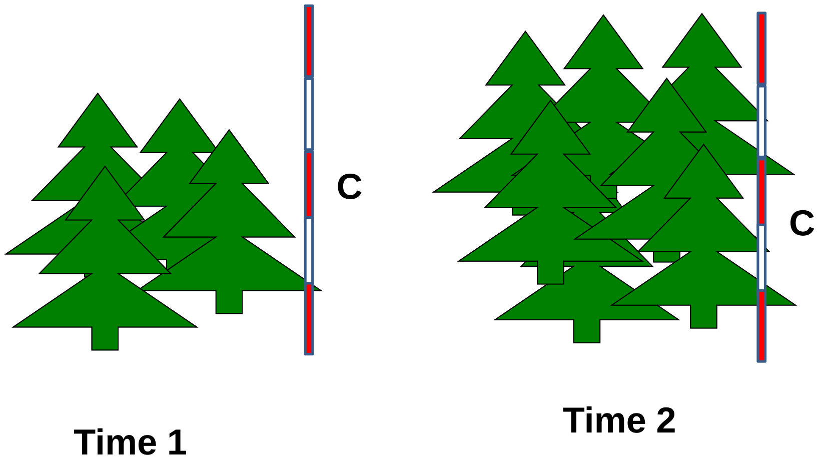
- Applicable in countries that have NFI, different biomass pools are periodically measured, requires greater resources, suitable for countries using tier 2, 3 approach

Carbon Stock Change Method

Carbon Stock Change Method



Carbon Stock Change Method



Gain-Loss Method

- Process-based

$$\Delta C = \Delta C_G - \Delta C_L$$

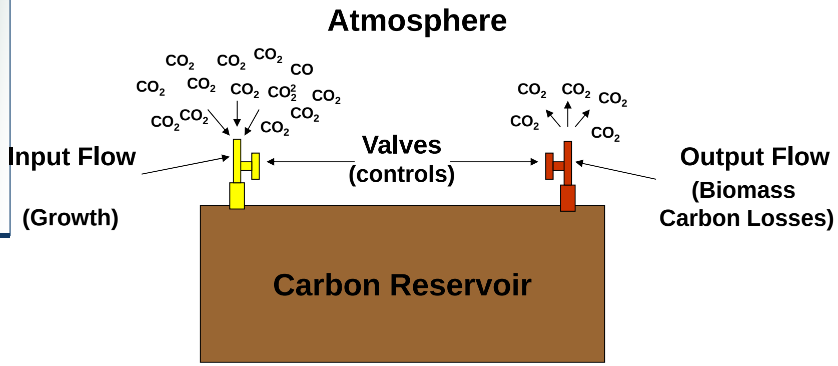
ΔC: change of carbon stocks

ΔC_G: increase due to **gain** of C

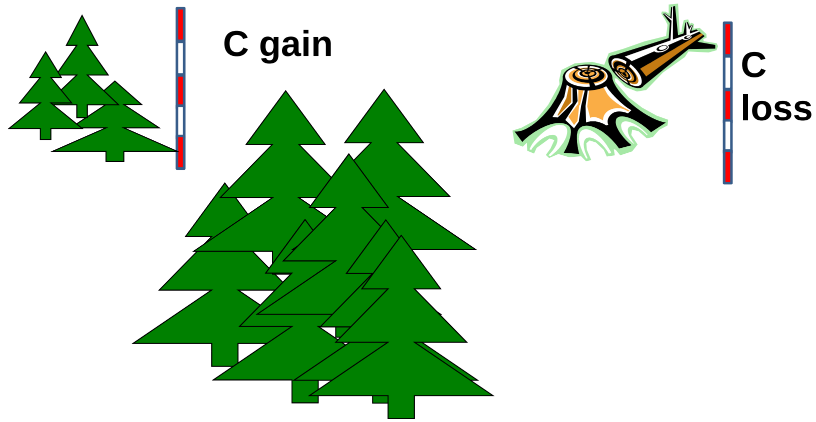
ΔC_L : decrease due to **loss** of C

Gain-Loss Method

Gain-Loss: $Carbon_{Input} - Carbon_{Output}$



Gain-Loss Method



Non-Forest Trees

- Non-forest trees
  - Silvipasture/Savanna
  - Woody perennial crops
  - Agroforestry
  - Settlement tree cover
- Growth-Loss method
- Biomass C stock changes and non-CO_2 greenhouse emissions due to burning of organic matter
- Age/diameter distribution
  - Important for determining growth

Non-Forest Trees

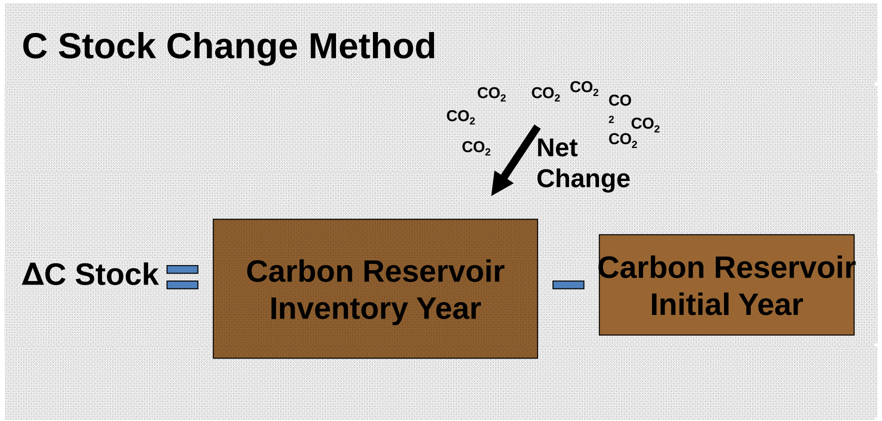
- Removals of C
  - Timber harvest & fuelwood gathering
  - Stand-replacing disturbances and deforestation
    - Fire, Windstorms/hurricanes/typhoons, Pest/disease outbreaks, Other
- Data from forestry/agricultural statistics, timber companies, permits and expert knowledge (e.g., foresters and researchers)

LULUCF Soils

Soils - Background

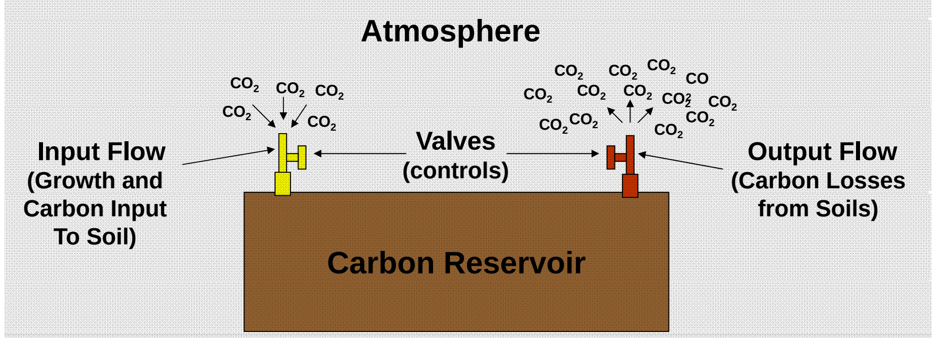
- Divided between mineral and organic soils
- Mineral Soils use C stock change method
  - A native reference C stock is modified using factors representing the impact of land use, management and input on C Stocks
- Organic soils are estimated using a C emission approach
  - Organic soils are drained in many cases for management purposes
  - Drainage creates aerobic conditions and high loss of C from the soil or peat
  - Emission factors represent the net emission rate

Mineral C Pools: Stock Change



Organic Soil: Input/Output

Organic Soil Emission Factor: $Carbon_{Output} – Carbon_{input}$

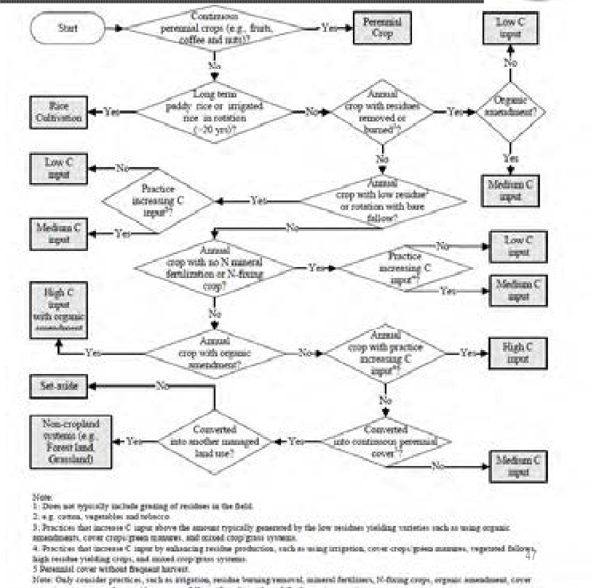


Management Systems

- Data used in emission estimates in soil N_2O, rice methane, biomass burning non-CO_2 emissions, biomass C, and soil C
- Unique set of practices
- Cropland and grassland land uses
  - Cropland: crop sequence, tillage practice, residue management, fertilization practices, irrigation, liming, crop varieties, cover crops, vegetated/bare fallow
  - Grassland: condition (improved, degraded, native), fertilization practices, irrigation, liming, legumes
- Focus on dominant unique management systems
- Data from agricultural census, crop grower associations, new survey, expert knowledge (e.g., agronomists)

Cropland Management

- Subdivide key systems
  - Wetland Rice
  - Perennial Crops
  - Annual Crops
  - Agroforestry
  - Shifting Cultivation
  - Set-asides (reserve cropland)
- Determine crop types and rotations

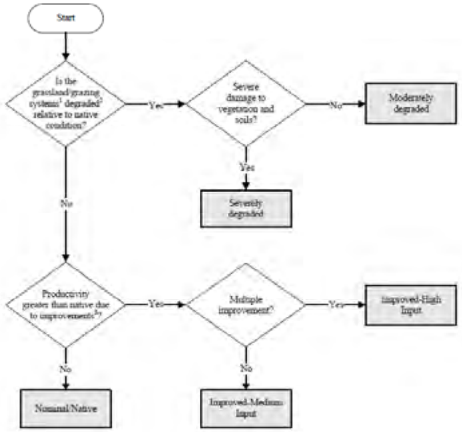


Cropland Management

- Assign key management practices
  - Tillage management
  - Residue management
  - Fertilizer management (Mineral and Organic)
  - Liming
  - Drainage of organic soils (i.e., Histosols)
  - Hay/pasture in rotation
  - Green manure
  - Vegetated and bare-fallow
  - Irrigation
  - Agroforestry
  - Wetland rice
    - Water table management
    - Organic amendments and residue management

Grassland Management

- Assign grassland types
  - e.g., managed pasture, subtropical savanna, silvipasture
- Determine condition
  - Degraded grassland
  - Nominal
  - Improved grassland



Note:
1: Includes continuous pasture, hay lands and rangelands.
2: Degradation is equated with C input to the soil relative to native conditions, which may be caused by long-term heavy grazing or planting less productive plants relative to native vegetation.
3. Productivity refers explicitly to C input to soil (management improvements that increase input e.g., fertilization, organic amendment, irrigation, planting more productive varieties, liming, and seeding legumes).

Grassland Management

- Assign management practices
  - Fertilizer management (Mineral and Organic)
  - Liming
  - Irrigation
  - Drainage of organic soils (i.e., Histosols)
  - More productive varieties
  - Burning
  - Seeding legumes

Other Land Uses - Soil C Classification

- Forest land
  - No clear impact of forest management on soil C based on literature
  - Assumed to be the same as native soil C stock
- Settlements
  - Assumed to lose soil C relative to native
  - Default in ALU is 20% loss
- Other land
  - Assumes all soil C is lost
- Wetlands
  - Assumed to be the same as native soil C stock

Organic Soil C Classification

- This classification is for Histosols, i.e., organic soils
- Classification is based on drainage
  - Soils that are drained emit CO_2
- Cropland
  - Mostly drained except set-aside and rice cultivation
- Grassland
  - Drained or Undrained
  - Designated in unique management system
- Forest land
  - Drained or Undrained
  - Designated on forest management of primary data
- Settlements
  - Always considered drained
- Wetlands and Other Lands
  - Always considered undrained

Forestland Management

- Management of forests and influence on Soil C
  - Shifting cultivation
  - Drainage of organic soils (i.e., Histosols)

Crop Residue Data

Crop Residue Data

- Residue management influences soil N_2O, biomass burning emissions, and soil C stocks
- Types of management: burning, retaining in field, grazing, or collected
- Crop yields and residue to yield ratios
  - Enter crop yields in tonnes wet matter per hectare
  - IPCC 2003 GPG provides some residue:yield ratios
- Agricultural census, crop grower associations, expert knowledge (e.g., agronomists)

Grassland Burning Data

Grassland Burning Data

- Non-CO_2 greenhouse gas emissions with oxidation of organic matter
- Enter fire return intervals or exact area that is burned in inventory year
  - More than once per year up to once every 10 years or longer
- Remote sensing, new surveys, expert knowledge

Wetland Rice Management

Wetland Rice Management

- Methanogenesis in flooded soils
- Key practices
  - Water management data
    - Irrigated Continuous Flooded, Irrigated Intermittently Flooded with Single Aeration, Irrigated Intermittently Flooded with Multiple Aerations, Rainfed – Flood Prone, Rainfed – Drought Prone, Deep Water – 50-100 cm depth, Deep Water - >100 cm depth
  - Organic amendment rates and fermentation status
    - Rice straw, livestock manure, green manure, compost and other organic waste products
    - Fermentation prior to application
- Agricultural census, rice grower associations, new surveys, expert knowledge (e.g., agronomists)

References

References

- IPCC Data Distribution Center (http://www.ipcc-data.org/)
- IPCC Task Force on National GHG Inventory (http://www.ipcc-nggip.iges.or.jp/) ➔ EFDB and National GHG Inventory GLs (revised 1996 GLs, 2000 GPG, 2003 GPG LULUCF, 2006 GLs)
- FAO (http://www.faostat.fao.org/)
- IRRI (http://www.irri.org/)

- MOST IMPORTANT!: National literature and experts

Activity III – ALU Equations and Data Inputs

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Capacity Building Workshop on:
"Strategic rice cultivation with energy crop rotation in Southeast Asia –
A path toward climate change mitigation in the agricultural sector"
29-31 May 2013, Pullman King Power Hotel, Bangkok, Thailand

Activity III: Capacity assessment of GHG emissions and soil carbon stock from sustainable cultivation practices in SEA

Description of Tasks

- Assessment of the capacity of C budget in terms of emissions and soil carbon stock of rice fields in SEA
- Development of GIS maps of GHG emissions from existing and sustainable cultivation practices
- Assessment of potential mitigation options based on different scenarios

Deliverables

- GIS maps of GHG emissions from rice fields for selected cultivation practices in SEA
- GIS maps of carbon stock of rice fields in SEA
- Database of GHG emissions inventory using ALU software
- Assessment of C budget of the rice cultivation systems investigated under existing and sustainable practices in SEA

Methane Emission from Rice Cultivation

EQUATION 5.1
CH_4 EMISSIONS FROM RICE CULTIVATION

$$CH_{4\ Rice} = \sum_{i,j,k} (EF_{i,j,k} \bullet t_{i,j,k} \bullet A_{i,j,k} \bullet 10^{-6})$$

Where:

$CH_{4\ Rice}$ = annual methane emissions from rice cultivation, Gg CH_4 yr^{-1}

EF_{ijk} = a daily emission factor for *i*, *j*, and *k* conditions, kg CH_4 ha^{-1} day^{-1}

t_{ijk} = cultivation period of rice for *i*, *j*, and *k* conditions, day

A_{ijk} = annual harvested area of rice for *i*, *j*, and *k* conditions, ha yr^{-1}

i, *j*, and *k* = represent different ecosystems, water regimes, type and amount of organic amendments, and other conditions under which CH_4 emissions from rice may vary

Methane Emission from Rice Cultivation

Adjusted daily emission factor: EF_i

EQUATION 5.2
ADJUSTED DAILY EMISSION FACTOR

$$EF_i = EF_c \bullet SF_w \bullet SF_p \bullet SF_o \bullet SF_{s,r}$$

Where:

EF_i = adjusted daily emission factor for a particular harvested area

EF_c = baseline emission factor for continuously flooded fields without organic amendments

SF_w = scaling factor to account for the differences in water regime during the cultivation period (from Table 5.12)

SF_p = scaling factor to account for the differences in water regime in the pre-season before the cultivation period (from Table 5.13)

SF_o = scaling factor should vary for both type and amount of organic amendment applied (from Equation 5.3 and Table 5.14)

$SF_{s,r}$ = scaling factor for soil type, rice cultivar, etc., if available

Methane Emission from Rice Cultivation

Base line emission factor: EF_C

TABLE 5.11
DEFAULT CH_4 BASELINE EMISSION FACTOR ASSUMING NO FLOODING FOR LESS THAN 180 DAYS PRIOR TO RICE CULTIVATION, AND CONTINUOUSLY FLOODED DURING RICE CULTIVATION WITHOUT ORGANIC AMENDMENTS

	Emission factor	Error range
CH_4 emission (kg CH_4 ha^{-1} d^{-1})	1.30	0.80 - 2.20

Source: Yan et al., 2005

Methane Emission from Rice Cultivation

SF_W

TABLE 5.12
DEFAULT CH_4 EMISSION SCALING FACTORS FOR WATER REGIMES DURING THE CULTIVATION PERIOD RELATIVE TO CONTINUOUSLY FLOODED FIELDS

Water regime		Aggregated case		Disaggregated case	
		Scaling factor (SF_w)	Error range	Scaling factor (SF_w)	Error range
Upland [a]		0	-	0	-
Irrigated [b]	Continuously flooded	0.78	0.62 - 0.98	1	0.79 - 1.26
	Intermittently flooded – single aeration			0.60	0.46 - 0.80
	Intermittently flooded – multiple aeration			0.52	0.41 - 0.66
Rainfed and deep water [c]	Regular rainfed	0.27	0.21 - 0.34	0.28	0.21 - 0.37
	Drought prone			0.25	0.18 - 0.36
	Deep water			0.31	ND

Methane Emission from Rice Cultivation

TABLE 5.13
DEFAULT CH_4 EMISSION SCALING FACTORS FOR WATER REGIMES BEFORE THE CULTIVATION PERIOD

Water regime prior to rice cultivation (schematic presentation showing flooded periods as shaded)		Aggregated case		Disaggregated case	
		Scaling factor (SF_p)	Error range	Scaling factor (SF_p)	Error range
Non flooded pre-season <180 d	< 180 d CROP	1.22	1.07 - 1.40	1	0.88 - 1.14
Non flooded pre-season >180 d	> 180 d CROP			0.68	0.58 - 0.80
Flooded pre-season (>30 d)[a,b]	> 30 d CROP			1.90	1.65 - 2.18

[a] Short pre-season flooding periods of less than 30 d are not considered in selection of SFp
[b] For calculation of pre-season emission see below (section on completeness)
Source: Yan *et al.*, 2005

Methane Emission from Rice Cultivation

EQUATION 5.3
ADJUSTED CH_4 EMISSION SCALING FACTORS FOR ORGANIC AMENDMENTS

$$SF_o = \left(1 + \sum_i ROA_i \bullet CFOA_i\right)^{0.59}$$

Where:

SF_o = scaling factor for both type and amount of organic amendment applied

ROA_i = application rate of organic amendment i, in dry weight for straw and fresh weight for others, tonne ha^{-1}

$CFOA_i$ = conversion factor for organic amendment i (in terms of its relative effect with respect to straw applied shortly before cultivation) as shown in Table 5.14.

Methane Emission from Rice Cultivation

TABLE 5.14
DEFAULT CONVERSION FACTOR FOR DIFFERENT TYPES OF ORGANIC AMENDMENT

Organic amendment	Conversion factor (CFOA)	Error range
Straw incorporated shortly (<30 days) before cultivation[a]	1	0.97 - 1.04
Straw incorporated long (>30 days) before cultivation[a]	0.29	0.20 - 0.40
Compost	0.05	0.01 - 0.08
Farm yard manure	0.14	0.07 - 0.20
Green manure	0.50	0.30 - 0.60

[a] Straw application means that straw is incorporated into the soil, it does not include case that straw just placed on the soil surface, nor that straw was burnt on the field.

Source: Yan *et al.*, 2005

Direct N_2O Emissions from Rice Cultivation

$$N_2O = N_2O\text{–}N \bullet 44/28$$

EQUATION 11.1
DIRECT N_2O EMISSIONS FROM MANAGED SOILS (TIER 1)

$$N_2O_{Direct}\text{–}N = N_2O\text{–}N_{N\,inputs} + N_2O\text{–}N_{OS} + N_2O\text{–}N_{PRP}$$

Where:

$$N_2O\text{–}N_{N\,inputs} = \begin{bmatrix} \left[(F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \bullet EF_1 \right] + \\ \left[(F_{SN} + F_{ON} + F_{CR} + F_{SOM})_{FR} \bullet EF_{1FR} \right] \end{bmatrix}$$

$$N_2O\text{–}N_{OS} = \begin{bmatrix} (F_{OS,CG,Temp} \bullet EF_{2CG,Temp}) + (F_{OS,CG,Trop} \bullet EF_{2CG,Trop}) + \\ (F_{OS,F,Temp,NR} \bullet EF_{2F,Temp,NR}) + (F_{OS,F,Temp,NP} \bullet EF_{2F,Temp,NP}) + \\ (F_{OS,F,Trop} \bullet EF_{2F,Trop}) \end{bmatrix}$$

$$N_2O\text{–}N_{PRP} = \left[(F_{PRP,CPP} \bullet EF_{3PRP,CPP}) + (F_{PRP,SO} \bullet EF_{3PRP,SO}) \right]$$

Where:

N_2O_{Direct}–N = annual direct N_2O–N emissions produced from managed soils, kg N_2O–N yr^{-1}

N_2O–$N_{N\,inputs}$ = annual direct N_2O–N emissions from N inputs to managed soils, kg N_2O–N yr^{-1}

N_2O–N_{OS} = annual direct N_2O–N emissions from managed organic soils, kg N_2O–N yr^{-1}

N_2O–N_{PRP} = annual direct N_2O–N emissions from urine and dung inputs to grazed soils, kg N_2O–N yr^{-1}

F_{SN} = annual amount of synthetic fertiliser N applied to soils, kg N yr^{-1}

F_{ON} = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (Note: If including sewage sludge, cross-check with Waste Sector to ensure there is no double counting of N_2O emissions from the N in sewage sludge), kg N yr^{-1}

F_{CR} = annual amount of N in crop residues (above-ground and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soils, kg N yr^{-1}

F_{SOM} = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg N yr^{-1}

F_{OS} = annual area of managed/drained organic soils, ha (Note: the subscripts CG, F, Temp, Trop, NR and NP refer to Cropland and Grassland, Forest Land, Temperate, Tropical, Nutrient Rich, and Nutrient Poor, respectively)

F_{PRP}= annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr^{-1} (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)

EF_1 = emission factor for N_2O emissions from N inputs, kg N_2O–N (kg N input)$^{-1}$(Table 11.1)

EF_{1FR} is the emission factor for N_2O emissions from N inputs to flooded rice, kg N_2O–N (kg N input)$^{-1}$ (Table 11.1) [5]

EF_2 = emission factor for N_2O emissions from drained/managed organic soils, kg N_2O–N ha^{-1} yr^{-1}; (Table 11.1) (Note: the subscripts CG, F, Temp, Trop, NR and NP refer to Cropland and Grassland, Forest Land, Temperate, Tropical, Nutrient Rich, and Nutrient Poor, respectively)

EF_{3PRP} = emission factor for N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals, kg N_2O–N (kg N input)$^{-1}$; (Table 11.1) (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)

Direct N_2O Emissions from Rice Cultivation

Tier 2

If more detailed emission factors and corresponding activity data are available to a country than are presented in Equation 11.1, further disaggregation of the terms in the equation can be undertaken. For example, if emission factors and activity data are available for the application of synthetic fertilisers and organic N (F_{SN} and F_{ON}) under different conditions *i*, Equation 11.1 would be expanded to become [6]:

EQUATION 11.2
DIRECT N_2O EMISSIONS FROM MANAGED SOILS (TIER 2)

$$N_2O_{Direct}\text{–}N = \sum_i (F_{SN} + F_{ON})_i \bullet EF_{1i} + (F_{CR} + F_{SOM}) \bullet EF_1 + N_2O\text{–}N_{OS} + N_2O\text{–}N_{PRP}$$

Where:

EF_{1i} = emission factors developed for N_2O emissions from synthetic fertiliser and organic N application under conditions *i* (kg N_2O–N (kg N input)$^{-1}$); $i = 1, \ldots n$.

TABLE 11.1
DEFAULT EMISSION FACTORS TO ESTIMATE DIRECT N_2O EMISSIONS FROM MANAGED SOILS

Emission factor	Default value	Uncertainty range
EF_1 for N additions from mineral fertilisers, organic amendments and crop residues, and N mineralised from mineral soil as a result of loss of soil carbon [kg N_2O–N (kg N)$^{-1}$]	0.01	0.003 - 0.03
EF_{1FR} for flooded rice fields [kg N_2O–N (kg N)$^{-1}$]	0.003	0.000 - 0.006
$EF_{2CG,Temp}$ for temperate organic crop and grassland soils (kg N_2O–N ha^{-1})	8	2 - 24
$EF_{2CG,Trop}$ for tropical organic crop and grassland soils (kg N_2O–N ha^{-1})	16	5 - 48
$EF_{2F,Temp,Org,R}$ for temperate and boreal organic nutrient rich forest soils (kg N_2O–N ha^{-1})	0.6	0.16 - 2.4
$EF_{2F,Temp,Org,P}$ for temperate and boreal organic nutrient poor forest soils (kg N_2O–N ha^{-1})	0.1	0.02 - 0.3
$EF_{2F,Trop}$ for tropical organic forest soils (kg N_2O–N ha^{-1})	8	0 - 24
$EF_{3PRP,CPP}$ for cattle (dairy, non-dairy and buffalo), poultry and pigs [kg N_2O–N (kg N)$^{-1}$]	0.02	0.007 - 0.06
$EF_{3PRP,SO}$ for sheep and 'other animals' [kg N_2O–N (kg N)$^{-1}$]	0.01	0.003 - 0.03

Sources:
EF_1: Bouwman et al. 2002a,b; Stehfest & Bouwman, 2006; Novoa & Tejeda, 2006 in press; EF_{1FR}: Akiyama *et al.*, 2005; $EF_{2CG,Temp}$, $EF_{2CG,Trop}$, $EF_{2F,Trop}$: Klemedtsson *et al.*, 1999, IPCC Good Practice Guidance, 2000; $EF_{2F,Temp}$: Alm *et al.*, 1999; Laine *et al.*, 1996; Martikainen *et al.*, 1995; Minkkinen *et al.*, 2002; Regina *et al.*, 1996; Klemedtsson *et al.*, 2002; $EF_{3,CPP}$, $EF_{3,SO}$: de Klein, 2004.

Direct N_2O Emissions from Rice Cultivation

EQUATION 11.3
N FROM ORGANIC N ADDITIONS APPLIED TO SOILS (TIER 1)

$$F_{ON} = F_{AM} + F_{SEW} + F_{COMP} + F_{OOA}$$

Where:

F_{ON} = total annual amount of organic N fertiliser applied to soils other than by grazing animals, kg N yr^{-1}

F_{AM} = annual amount of animal manure N applied to soils, kg N yr^{-1}

F_{SEW} = annual amount of total sewage N (coordinate with Waste Sector to ensure that sewage N is not double-counted) that is applied to soils, kg N yr^{-1}

F_{COMP} = annual amount of total compost N applied to soils (ensure that manure N in compost is not double-counted), kg N yr^{-1}

Direct N_2O Emissions from Rice Cultivation

EQUATION 11.4
N FROM ANIMAL MANURE APPLIED TO SOILS (TIER 1)

$$F_{AM} = N_{MMS\_Avb} \bullet \left[1 - \left(Frac_{FEED} + Frac_{FUEL} + Frac_{CNST}\right)\right]$$

Where:

F_{AM} = annual amount of animal manure N applied to soils, kg N yr^{-1}

N_{MMS_Avb} = amount of managed manure N available for soil application, feed, fuel or construction, kg N yr^{-1} (see Equation 10.34 in Chapter 10)

$Frac_{FEED}$ = fraction of managed manure used for feed

$Frac_{FUEL}$ = fraction of managed manure used for fuel

$Frac_{CNST}$ = fraction of managed manure used for construction

Direct N_2O Emissions from Rice Cultivation

EQUATION 11.5
N IN URINE AND DUNG DEPOSITED BY GRAZING ANIMALS ON PASTURE, RANGE AND PADDOCK (TIER 1)

$$F_{PRP} = \sum_{T}\left[\left(N_{(T)} \bullet Nex_{(T)}\right) \bullet MS_{(T,PRP)}\right]$$

Where:

F_{PRP} = annual amount of urine and dung N deposited on pasture, range, paddock and by grazing animals, kg N yr^{-1}

$N_{(T)}$ = number of head of livestock species/category *T* in the country (see Chapter 10, Section 10.2)

$Nex_{(T)}$ = annual average N excretion per head of species/category *T* in the country, kg N animal^{-1} yr^{-1} (see Chapter 10, Section 10.5)

$MS_{(T,PRP)}$ = fraction of total annual N excretion for each livestock species/category *T* that is deposited on pasture, range and paddock[12] (see Chapter 10, Section 10.5)

EQUATION 11.6
N FROM CROP RESIDUES AND FORAGE/PASTURE RENEWAL (TIER 1)

$$F_{CR} = \sum_T \left\{ Crop_{(T)} \bullet \left(Area_{(T)} - Area\ burnt_{(T)} \bullet C_f\right) \bullet Frac_{Renew(T)} \bullet \left[R_{AG(T)} \bullet N_{AG(T)} \bullet \left(1 - Frac_{Remove(T)}\right) + R_{BG(T)} \bullet N_{BG(T)}\right] \right\}$$

Where:

F_{CR} = annual amount of N in crop residues (above and below ground), including N-fixing crops, and from forage/pasture renewal, returned to soils annually, kg N yr^{-1}

$Crop_{(T)}$ = harvested annual dry matter yield for crop T, kg d.m. ha^{-1}

$Area_{(T)}$ = total annual area harvested of crop T, ha yr^{-1}

Area burnt $_{(T)}$ = annual area of crop T burnt, ha yr^{-1}

C_f = combustion factor (dimensionless) (refer to Chapter 2, Table 2.6)

$Frac_{Renew\ (T)}$ = fraction of total area under crop T that is renewed annually [15]. For countries where pastures are renewed on average every X years, $Frac_{Renew}$ = 1/X. For annual crops $Frac_{Renew}$ = 1

$R_{AG(T)}$ = ratio of above-ground residues dry matter ($AG_{DM(T)}$) to harvested yield for crop T ($Crop_{(T)}$), kg d.m. (kg d.m.)$^{-1}$,

= $AG_{DM(T)}$ • 1000 / $Crop_{(T)}$ (calculating $AG_{DM(T)}$ from the information in Table 11.2)

$N_{AG(T)}$ = N content of above-ground residues for crop T, kg N (kg d.m.) $^{-1}$, (Table 11.2)

$Frac_{Remove(T)}$ = fraction of above-ground residues of crop T removed annually for purposes such as feed, bedding and construction, kg N (kg crop-N)$^{-1}$. Survey of experts in country is required to obtain data. If data for $Frac_{Remove}$ are not available, assume no removal.

$R_{BG(T)}$ = ratio of below-ground residues to harvested yield for crop T, kg d.m. (kg d.m.)$^{-1}$. If alternative data are not available, $R_{BG(T)}$ may be calculated by multiplying $R_{BG\text{-}BIO}$ in Table 11.2 by the ratio of total above-ground biomass to crop yield (= [($AG_{DM(T)}$ • 1000 + $Crop_{(T)}$) / $Crop_{(T)}$], (also calculating $AG_{DM(T)}$ from the information in Table 11.2).

Direct N_2O Emissions from Rice Cultivation

EQUATION 11.7
DRY-WEIGHT CORRECTION OF REPORTED CROP YIELDS

$$Crop_{(T)} = Yield\ Fresh_{(T)} \bullet DRY$$

Where:

$Crop_{(T)}$ = harvested dry matter yield for crop T, kg d.m. ha^{-1}

$Yield\_Fresh_{(T)}$ = harvested fresh yield for crop T, kg fresh weight ha^{-1}

DRY = dry matter fraction of harvested crop T, kg d.m. (kg fresh weight)$^{-1}$

The regression equations in Table 11.2 may also be used to calculate the total above-ground residue dry matter, and the other data in the table then permit the calculation in turn of the N in the above-ground residues, the below-ground dry matter, and the total N in the below-ground residues. The total N addition, F_{CR}, is the sum of the above-and below-ground N contents. With this approach, F_{CR} is given by Equation 11.7A:

EQUATION 11.7A
ALTERNATIVE APPROACH TO ESTIMATE F_{CR} (USING TABLE 11.2)

$$F_{CR} = \sum_T \left\{ AG_{DM(T)} \bullet \left(Area_{(T)} - Area\ burnt_{(T)} \bullet CF\right) \bullet Frac_{Renew(T)} \bullet \left[N_{AG(T)} \bullet \left(1 - Frac_{Remove(T)}\right) + R_{BG-BIO(T)} \bullet N_{BG(T)}\right] \right\}$$

TABLE 11.2
DEFAULT FACTORS FOR ESTIMATION OF N ADDED TO SOILS FROM CROP RESIDUES [a]

Crop	Dry matter fraction of harvested product (DRY)	Above-ground residue dry matter $AG_{DM(T)}$ (Mg/ha): $AG_{DM(T)} = Crop_{(T)} * slope_{(T)} + intercept_{(T)}$					N content of above-ground residues (N_{AG})	Ratio of below-ground residues to above-ground biomass ($R_{BG\text{-}BIO}$)	N content of below-ground residues (N_{BG})
		Slope	± 2 s.d. as % of mean	Intercept	± 2 s.d. as % of mean	R^2 adj.			
Major crop types									
Grains	0.88	1.09	± 2%	0.88	± 6%	0.65	0.006	0.22 (± 16%)	0.009
Beans & pulses[b]	0.91	1.13	± 19%	0.85	± 56%	0.28	0.008	0.19 (± 45%)	0.008
Tubers[c]	0.22	0.10	± 69%	1.06	± 70%	0.18	0.019	0.20 (± 50%)	0.014
Root crops, other[d]	0.94	1.07	± 19%	1.54	± 41%	0.63	0.016	0.20 (± 50%)	0.014
N-fixing forages	0.90	0.3	± 50% default	0	-	-	0.027	0.40 (± 50%)	0.022
Non-N-fixing forages	0.90	0.3	± 50% default	0	-	-	0.015	0.54 (± 50%)	0.012
Perennial grasses	0.90	0.3	± 50% default	0	-	-	0.015	0.80 (± 50%)[l]	0.012
Grass-clover mixtures	0.90	0.3	± 50% default	0	-	-	0.025	0.80 (± 50%)[l]	0.016[p]
Individual crops									
Maize	0.87	1.03	± 3%	0.61	± 19%	0.76	0.006	0.22 (± 26%)	0.007
Wheat	0.89	1.51	± 3%	0.52	± 17%	0.68	0.006	0.24 (± 32%)	0.009
Winter wheat	0.89	1.61	± 3%	0.40	± 25%	0.67	0.006	0.23 (± 41%)	0.009
Spring wheat	0.89	1.29	± 5%	0.75	± 26%	0.76	0.006	0.28 (± 26%)	0.009
Rice	0.89	0.95	±19%	2.46	± 41%	0.47	0.007	0.16 (± 35%)	NA
Barley	0.89	0.98	± 8%	0.59	± 41%	0.68	0.007	0.22 (± 33%)	0.014
Oats	0.89	0.91	± 5%	0.89	± 8%	0.45	0.007	0.25 (± 120%)	0.008
Millet	0.90	1.43	± 18%	0.14	± 308%	0.50	0.007	NA	NA
Sorghum	0.89	0.88	± 13%	1.33	± 27%	0.36	0.007	NA	0.006
Rye[e]	0.88	1.09	± 50% default	0.88	± 50% default	-	0.005	NA	0.011
Soyabean[f]	0.91	0.93	± 31%	1.35	± 49%	0.16	0.008	0.19 (± 45%)	0.008
Dry bean[g]	0.90	0.36	± 100%	0.68	± 47%	0.15	0.01	NA	0.01
Potato[h]	0.22	0.10	± 69%	1.06	± 70%	0.18	0.019	0.20 (± 50%)[m]	0.014
Peanut (w/pod)[i]	0.94	1.07	± 19%	1.54	± 41%	0.63	0.016	NA	NA
Alfalfa[j]	0.90	0.29[k]	± 31%	0	-	-	0.027	0.40 (± 50%)[n]	0.019
Non-legume hay[j]	0.90	0.18	± 50% default	0	-	-	0.015	0.54 (± 50%)[n]	0.012

Carbon Stock Change Estimation

EQUATION 2.1
ANNUAL CARBON STOCK CHANGES FOR THE ENTIRE AFOLU SECTOR ESTIMATED AS THE SUM OF CHANGES IN ALL LAND-USE CATEGORIES

$$\Delta C_{AFOLU} = \Delta C_{FL} + \Delta C_{CL} + \Delta C_{GL} + \Delta C_{WL} + \Delta C_{SL} + \Delta C_{OL}$$

Where:

ΔC = carbon stock change

Indices denote the following land-use categories:

AFOLU = Agriculture, Forestry and Other Land Use

FL = Forest Land

CL = Cropland

GL = Grassland

WL = Wetlands

SL = Settlements

OL = Other Land

Carbon Stock Change Estimation

EQUATION 2.3
ANNUAL CARBON STOCK CHANGES FOR A STRATUM OF A LAND-USE CATEGORY AS A SUM OF CHANGES IN ALL POOLS

$$\Delta C_{LU_i} = \Delta C_{AB} + \Delta C_{BB} + \Delta C_{DW} + \Delta C_{LI} + \Delta C_{SO} + \Delta C_{HWP}$$

Where:

ΔC_{LU_i} = carbon stock changes for a stratum of a land-use category

Subscripts denote the following carbon pools:

AB = above-ground biomass

BB = below-ground biomass

DW = deadwood

LI = litter

SO = soils

HWP = harvested wood products

Annual Change in Carbon Stocks in Soils

EQUATION 2.24
ANNUAL CHANGE IN CARBON STOCKS IN SOILS

$$\Delta C_{Soils} = \Delta C_{Mineral} - L_{Organic} + \Delta C_{Inorganic}$$

Where:

ΔC_{Soils} = annual change in carbon stocks in soils, tonnes C yr^{-1}

$\Delta C_{Mineral}$ = annual change in organic carbon stocks in mineral soils, tonnes C yr^{-1}

$L_{Organic}$ = annual loss of carbon from drained organic soils, tonnes C yr^{-1}

$\Delta C_{Inorganic}$ = annual change in inorganic carbon stocks from soils, tonnes C yr^{-1} (assumed to be 0 unless using a Tier 3 approach)

Annual Change in Carbon Stocks in Soils

EQUATION 2.25
ANNUAL CHANGE IN ORGANIC CARBON STOCKS IN MINERAL SOILS

$$\Delta C_{Mineral} = \frac{(SOC_0 - SOC_{(0-T)})}{D}$$

$$SOC = \sum_{c,s,i} \left(SOC_{REF_{c,s,i}} \bullet F_{LU_{c,s,i}} \bullet F_{MG_{c,s,i}} \bullet F_{I_{c,s,i}} \bullet A_{c,s,i} \right)$$

(Note: T is used in place of D in this equation if T is ≥ 20 years, see note below)

Where:

$\Delta C_{Mineral}$ = annual change in carbon stocks in mineral soils, tonnes C yr^{-1}

SOC_0 = soil organic carbon stock in the last year of an inventory time period, tonnes C

$SOC_{(0-T)}$ = soil organic carbon stock at the beginning of the inventory time period, tonnes C

SOC_0 and $SOC_{(0-T)}$ are calculated using the SOC equation in the box where the reference carbon stocks and stock change factors are assigned according to the land-use and management activities and corresponding areas at each of the points in time (time = 0 and time = 0-T)

T = number of years over a single inventory time period, yr

D = Time dependence of stock change factors which is the default time period for transition between equilibrium SOC values, yr. Commonly 20 years, but depends on assumptions made in computing the factors F_{LU}, F_{MG} and F_I. If T exceeds D, use the value for T to obtain an annual rate of change over the inventory time period (0-T years).

Annual Change in Carbon Stocks in Soils

c = represents the climate zones, *s* the soil types, and *i* the set of management systems that are present in a country.

SOC_{REF} = the reference carbon stock, tonnes C ha^{-1} (Table 2.3)

F_{LU} = stock change factor for land-use systems or sub-system for a particular land-use, dimensionless

[Note: F_{ND} is substituted for F_{LU} in forest soil C calculation to estimate the influence of natural disturbance regimes.

F_{MG} = stock change factor for management regime, dimensionless

F_I = stock change factor for input of organic matter, dimensionless

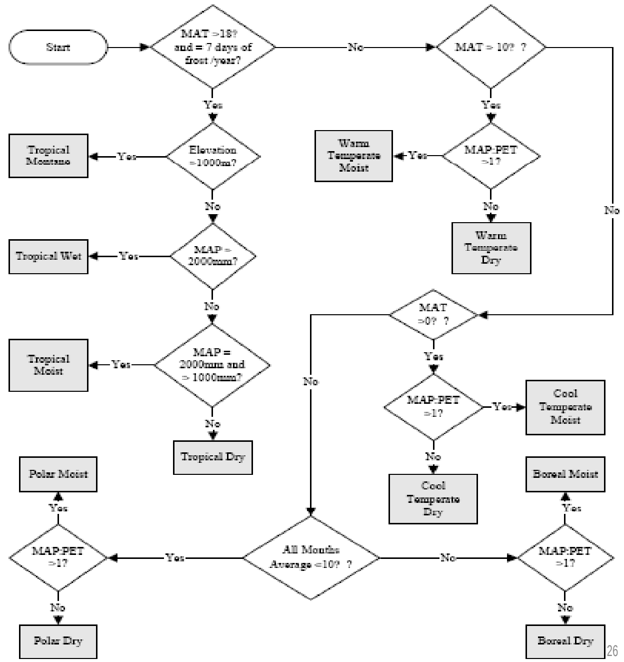
A = land area of the stratum being estimated, ha. All land in the stratum should have common biophysical conditions (i.e., climate and soil type) and management history over the inventory time period to be treated together for analytical purposes.

Annual Change in Carbon Stocks in Soils

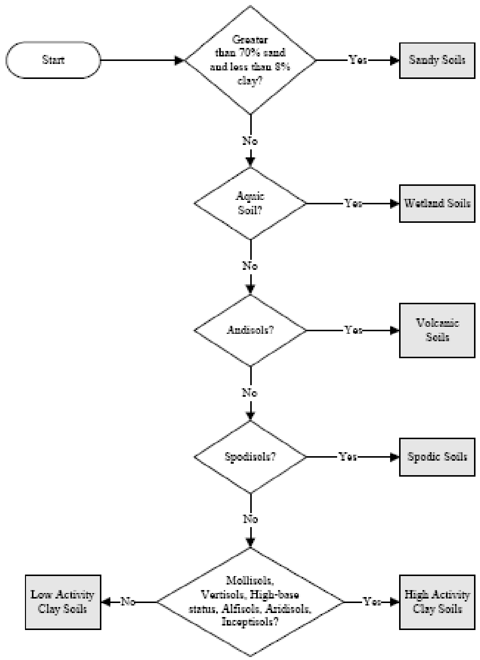
TABLE 2.3
DEFAULT REFERENCE (UNDER NATIVE VEGETATION) SOIL ORGANIC C STOCKS (SOC_{REF}) FOR MINERAL SOILS
(TONNES C HA^{-1} IN 0-30 CM DEPTH)

Climate region	HAC soils[1]	LAC soils[2]	Sandy soils[3]	Spodic soils[4]	Volcanic soils[5]	Wetland soils[6]
Boreal	68	NA	10#	117	20#	146
Cold temperate, dry	50	33	34	NA	20#	87
Cold temperate, moist	95	85	71	115	130	
Warm temperate, dry	38	24	19	NA	70#	88
Warm temperate, moist	88	63	34	NA	80	
Tropical, dry	38	35	31	NA	50#	86
Tropical, moist	65	47	39	NA	70#	
Tropical, wet	44	60	66	NA	130#	
Tropical montane	88*	63*	34*	NA	80*	

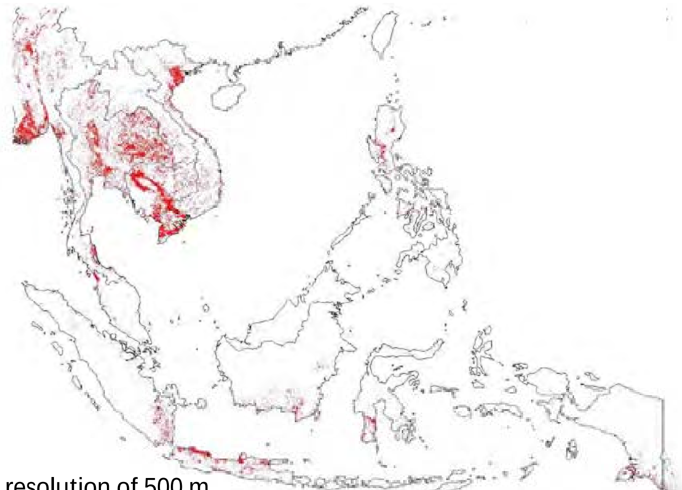
IPCC Climate Classification



IPCC Soil Classification based on USDA taxonomy



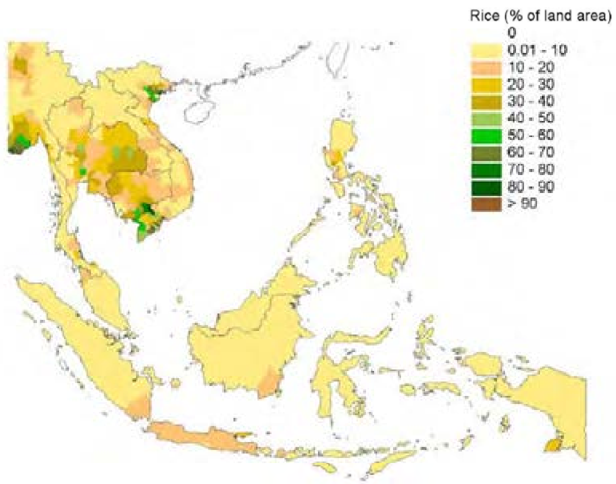
Spatial distribution of paddy rice derived from analysis of MODIS 8-day surface reflectance data in 2002



Spatial resolution of 500 m.

Reference: X. Xiao *et al / Remote Sensing of Environment (2006)*

Spatial distribution of paddy rice area in SEA (2002)



Reference: X. Xiao *et al / Remote Sensing of Environment (2006)*

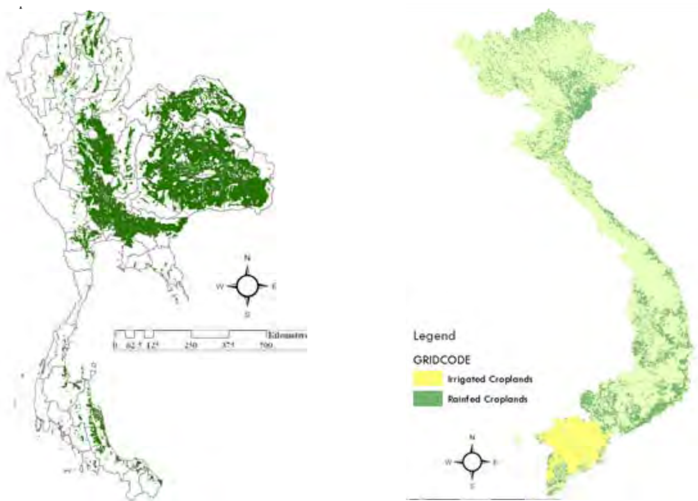
Rice Cultivation Area in SEA

Country	Rice Cultivation Area in SEA (1,000 ha)			
	Irrigated rice[a]	Rainfed lowland rice	Upland rice	Flood prone
Cambodia	154	1,124	33	614
Indonesia	6,154	4,015	1,247	23
Laos	40	319	201	-
Malaysia	445	152	84	-
Myanmar	1,124	4,166	252	602
Philippines	2,334	1,304	120	-
Thailand	2,075	6,792	36	117
Vietnam	3,687	1,955	345	778
Total	16,015	19,827	2,318	2,134

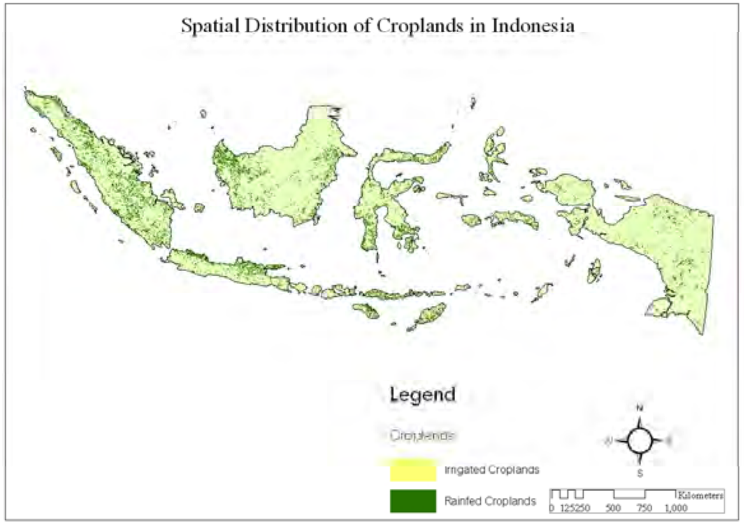
[a]Irrigated rice = 2.5 crop/yr

Reference: *IRRI Rice Facts, 2002*

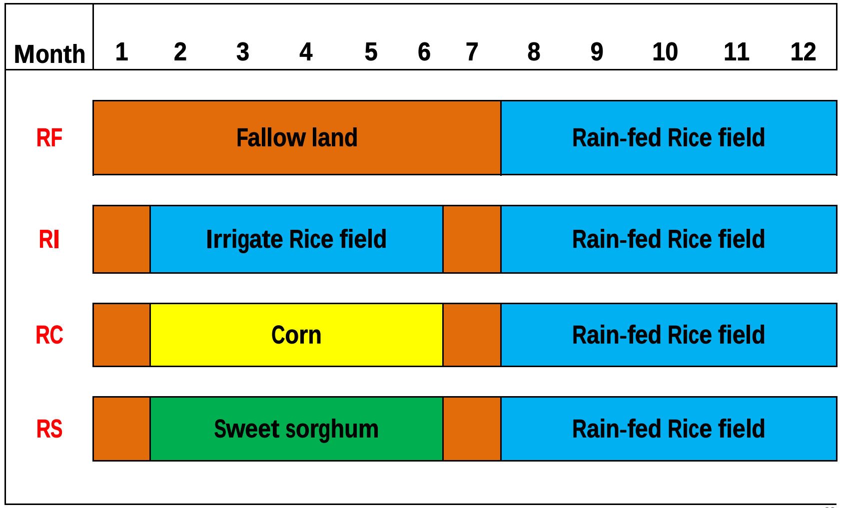
Activity III: GIS maps of rice fields for selected cultivation practices in SEA



Activity III: GIS maps of rice fields for selected cultivation practices in SEA



Activity III: Assessment of potential mitigation options based on different scenarios



References

- **IPCC Task Force on National GHG Inventory (http://www.ipcc-nggip.iges.or.jp/) ➔ EFDB and National GHG Inventory GLs (2006 GLs)**
- **IRRI (http://www.irri.org/)**
- **National literature (statistics, research papers and reports, etc.) and experts**

Activity III – ALU Outputs

Assoc. Prof. Dr. Savitri Garivait and Dr. Agapol Junpen
The Joint Graduate School of Energy and Environment

savitri_g@jgsee.kmutt.ac.th
akjp@hotmail.com

Capacity Building Workshop on:
"Strategic rice cultivation with energy crop rotation in Southeast Asia –
A path toward climate change mitigation in the agricultural sector"
29-31 May 2013, Pullman King Power Hotel, Bangkok, Thailand

Activity III: Capacity assessment of GHG emissions and soil carbon stock from sustainable cultivation practices in SEA

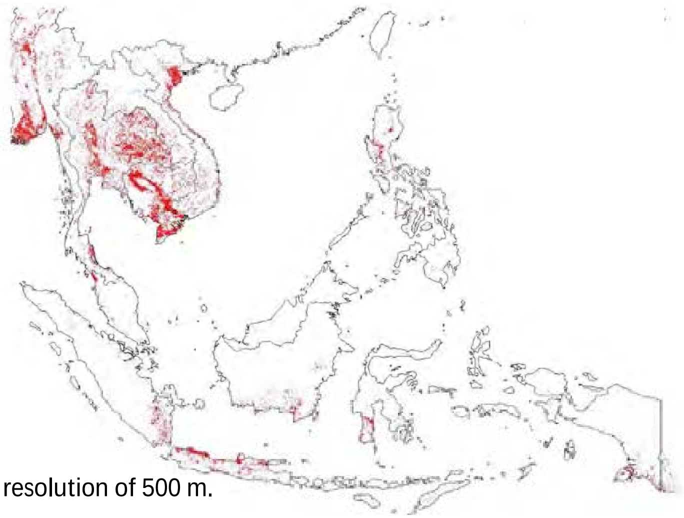
Description of Tasks

- Assessment of the capacity of C budget in terms of emissions and soil carbon stock of rice fields in SEA
- Development of GIS maps of GHG emissions from existing and sustainable cultivation practices
- Assessment of potential mitigation options based on different scenarios

Deliverables

- GIS maps of GHG emissions from rice fields for selected cultivation practices in SEA
- GIS maps of carbon stock of rice fields in SEA
- Database of GHG emissions inventory using ALU software
- Assessment of C budget of the rice cultivation systems investigated under existing and sustainable practices in SEA

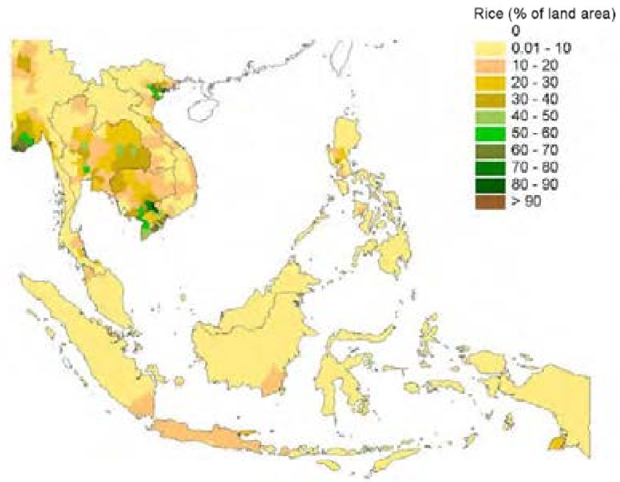
Spatial distribution of paddy rice derived from analysis of MODIS 8-day surface reflectance data in 2002



Spatial resolution of 500 m.

Reference: X. Xiao *et al / Remote Sensing of Environment 100 (2006)*

Spatial distribution of paddy rice area in SEA (2002)



Reference: X. Xiao *et al / Remote Sensing of Environment 100 (2006)*

Rice Cultivation Area in SEA

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	Irrigated rice[a]	Rainfed lowland rice	Upland rice	Flood prone
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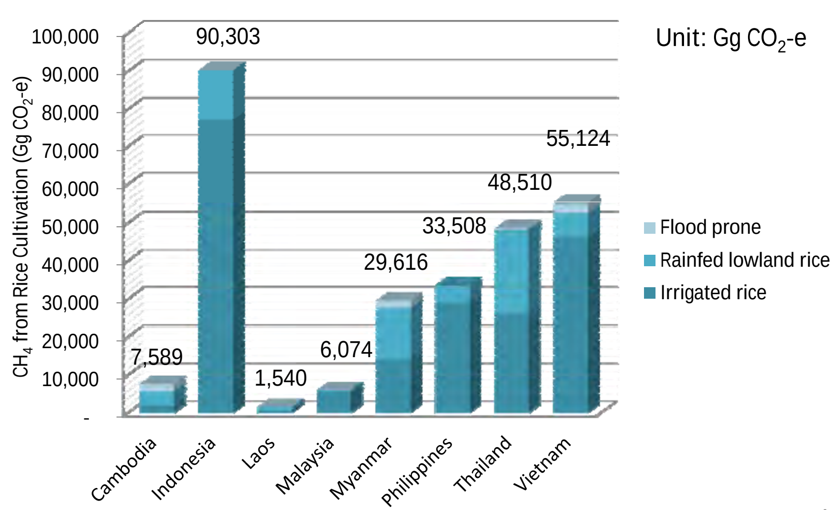
Total	16,015	19,827	2,318	2,134

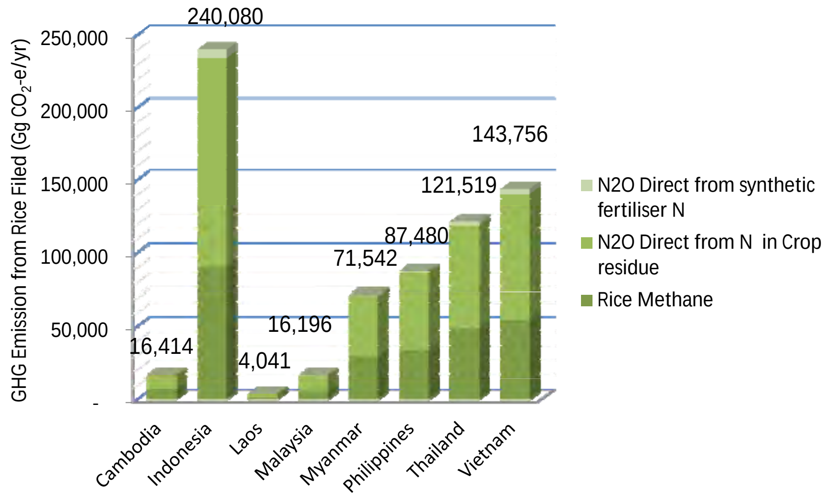
[a]Irrigated rice = 2.5 crop/yr

Reference: *IRRI Rice Facts, 2002*

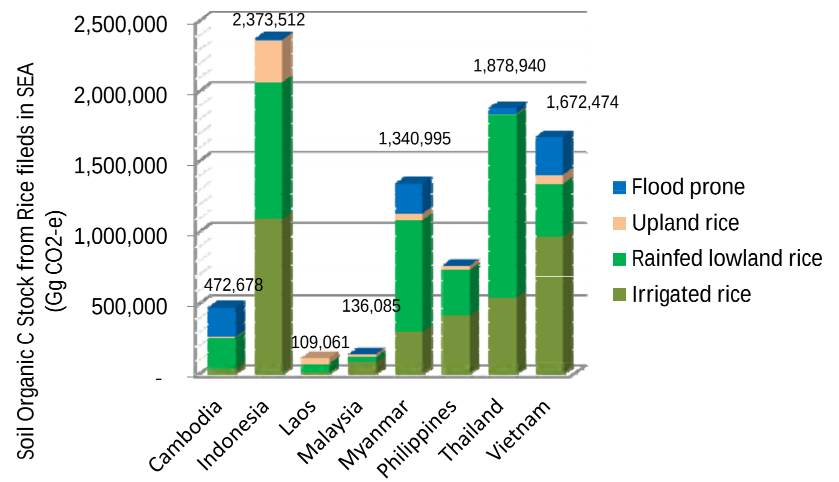
Activity III: Assessment of CH_4 from rice fields in SEA



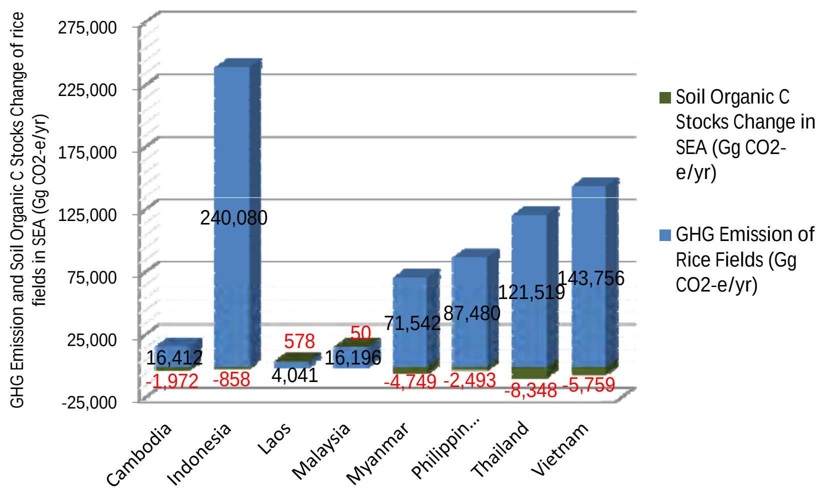
Activity III: Assessment of the GHG emissions of rice fields in SEA



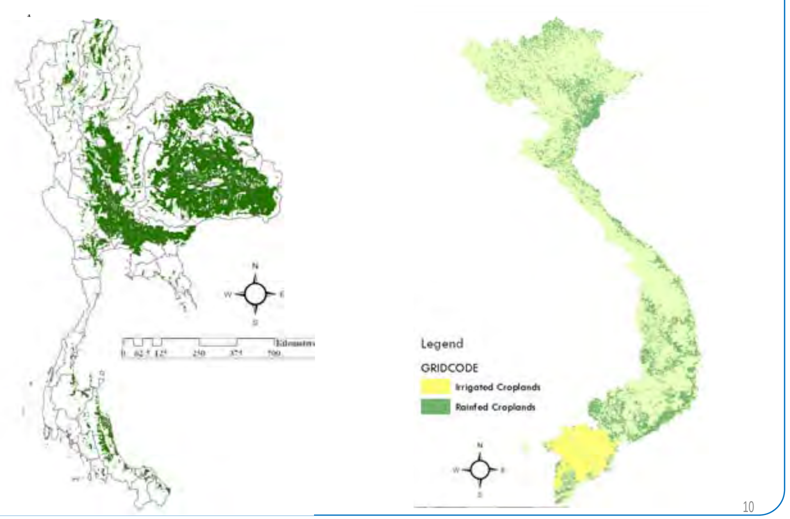
Activity III: Assessment of the soil organic C stock of rice fields in SEA (Yr 2030)



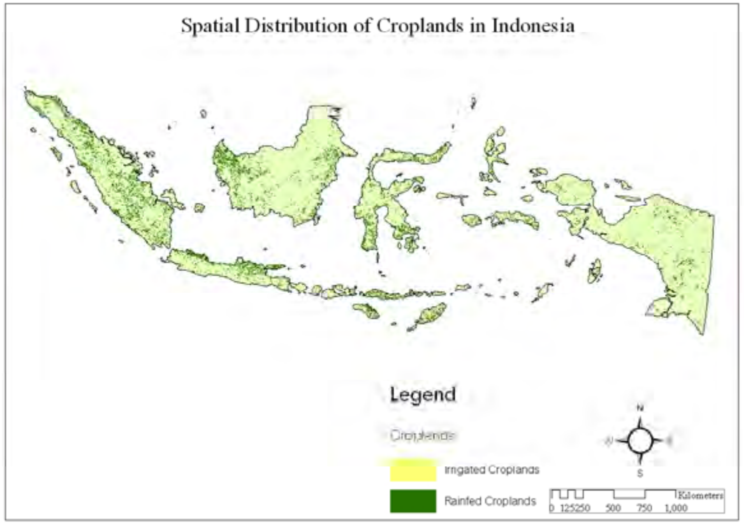
Activity III: Assessment of the GHG emissions and soil C stock Change of rice fields in SEA



Activity III: GIS maps of rice fields for selected cultivation practices in SEA



Activity III: GIS maps of rice fields for selected cultivation practices in SEA

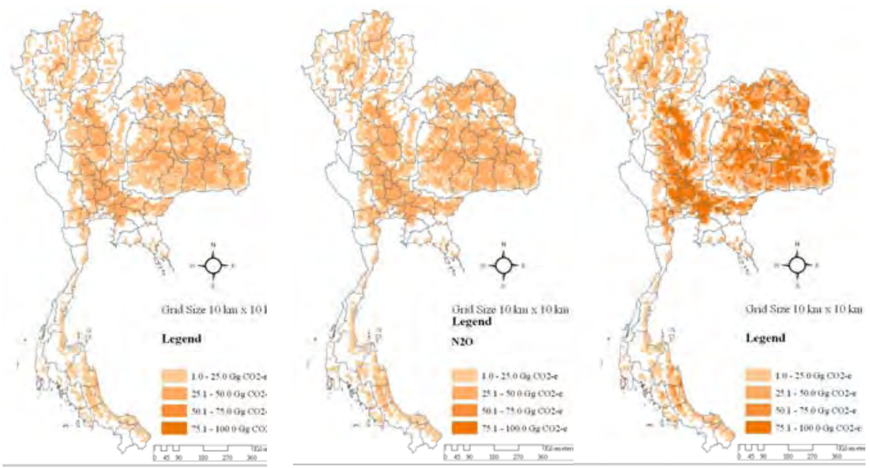


Activity III: GIS maps of GHG emissions from rice fields for selected cultivation practices in SEA

Rice Methane

N_2O Emission

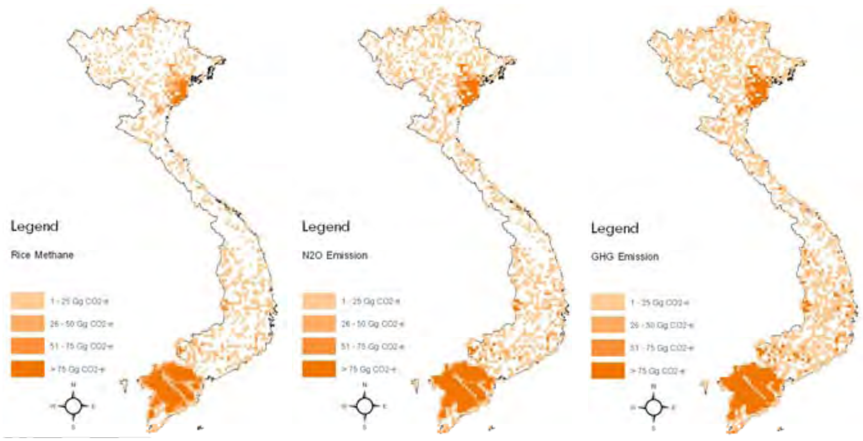
GHG Emission from Rice Fields



Grid Size = 10 km x 10 km

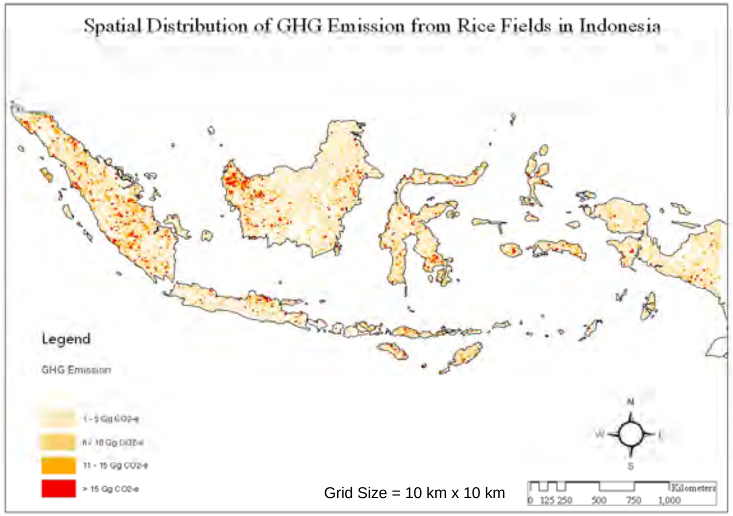
Activity III: GIS maps of GHG emissions from rice fields for selected cultivation practices in SEA

Rice Methane | N_2O Emission | GHG Emission from Rice Field



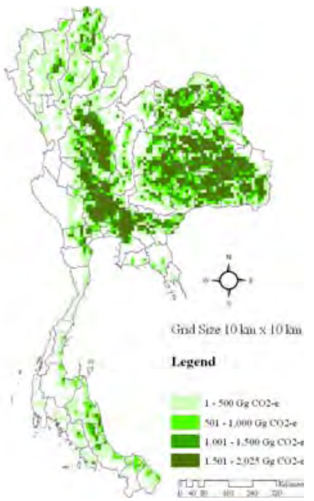
Grid Size = 10 km x 10 km

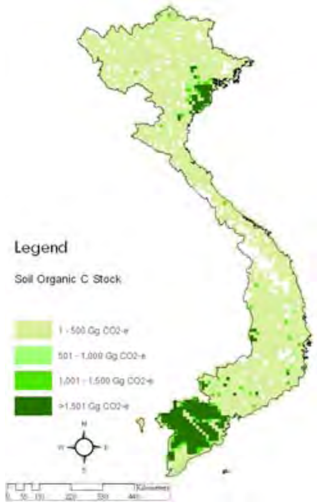
Activity III: GIS maps of GHG emissions from rice fields for selected cultivation practices in SEA



Grid Size = 10 km x 10 km

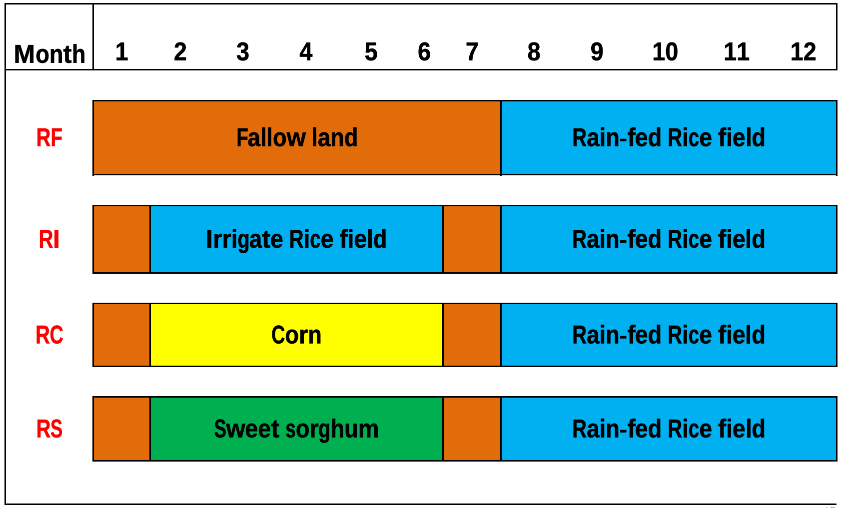
Activity III: GIS maps of carbon stock of rice fields in SEA



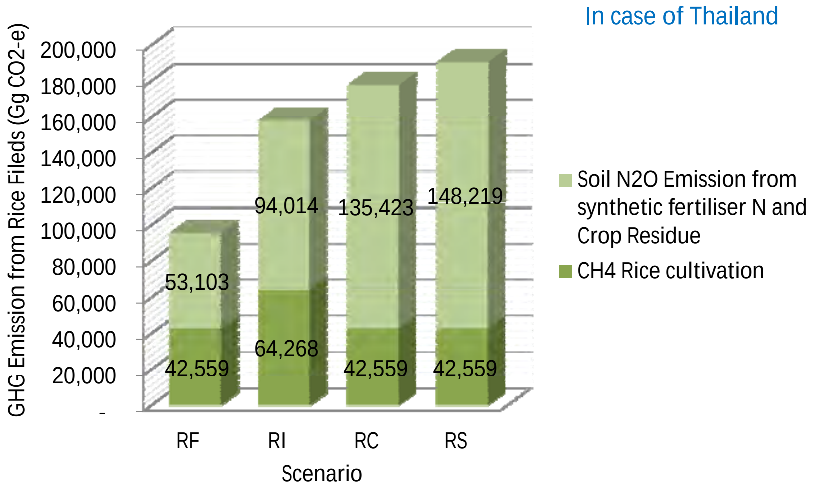


Activity III: GIS maps of carbon stock of rice fields in SEA

Activity III: Assessment of potential mitigation options based on different cropping (rotation with energy crop)

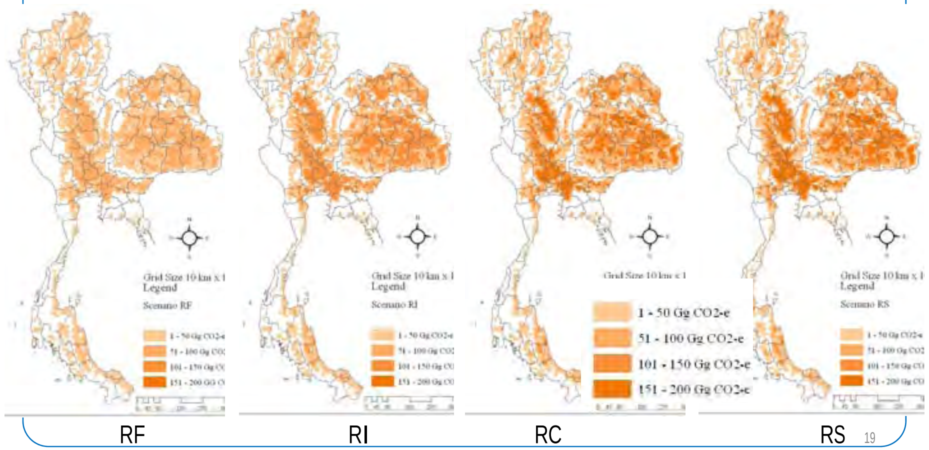


Activity III: Assessment of potential mitigation options based on different scenarios

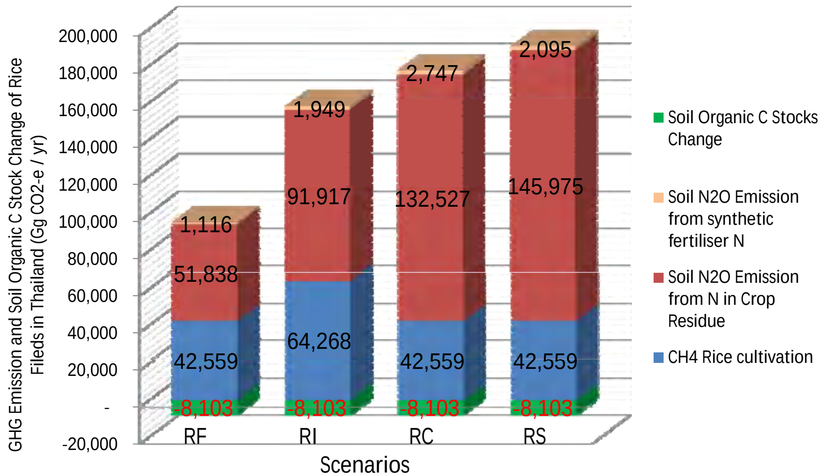


Activity III: Assessment of potential mitigation options based on different cropping (rotation with energy crop)

Assessment of total GHG emission mitigation options based on different scenarios



Activity III: Assessment of potential mitigation options based on different cropping (rotation with energy crop)



Appendix 9

List of young researchers involved in the project

1. Ms Kanittha Kanokkanjana
Affiliation: The Joint Graduate School of Energy and Environment
Address: King Mongkut's University of Technology Thonburi, 126 Pracha-Uthit Road, Bangmod, Tungkru, Bangkok, Thailand
Email: kkanittha@yahoo.com

Involvement in the project:

- Review of rice cultivation practices and use of energy crops for rotation in SEA
- Design of questionnaire on rice cultivation practices
- Preparation and participation to Expert Meeting on "State-of-the-Art of Rice Cultivation Practices in South-East Asia"
- Preparation of poster "Rice Cultivation and Potential Areas for Rotation with Energy Crops in South-East Asia"
- Preparation and participation to Training Workshop on "Capacity Building on Estimation of GHG Emissions from Rice Fields-The Application of DNDC Model"
- Preparation and participation to the Capacity Building Workshop on "Strategic rice cultivation with energy crop rotation in SEA: A path toward climate change mitigation in the agricultural sector"

"These project activities have enabled me to further develop my scientific knowledge and to gain experience in terms of international communication and coordination of activities. These are good experiences which will be very useful for my work in the future."

2. Ms Nittaya Cha-un
Affiliation: The Joint Graduate School of Energy and Environment
Address: King Mongkut's University of Technology Thonburi, 126 Pracha-uthid Rd, Bangmod, Thungkru, Bangkok, Thailand
Email: nidchaun@gmail.com

Involvement in the project:

- Work in activity 2 of the project: Long-term monitoring of GHG emission and soil carbon dynamic from rice cultivation and utilization energy crops for rotation
  - Review of rice and crop cultivation in Thailand, also crop rotation and its potential to improve soil carbon storage, mitigation of GHG emissions, and economic potential for farmer
  - Set up of crop experiments at KMUTT's Ratchaburi Campus during 2010 - 2012
  - Collection and analysis of biomass, soil and gas samples from rice and energy crops (corn and sorghum) over two years
- Work in activity 4: Long-term soil carbon dynamics assessment of sustainable low carbon cultivation using process model
  - Processing of climate, soil and crop management data from activity 2
  - Simulation using DNDC model to analyze carbon storage and GHG emissions from energy crop in rotation with rice
  - Validation, sensitivity and uncertainty analyses of DNDC results

- Speaker for Training Event on: Estimation of GHG Emissions from Rice Fields - The Application of DNDC Model
- Participation to Capacity Building Workshop on: Strategic rice cultivation with energy crop rotation in SEA A path toward climate change mitigation in the agricultural sector

"My involvement in the APN project enabled me to develop and improve my scientific skills and knowledge. The training and workshop events organized as part of the project provided me with useful experiences including communicating with other scientists at the international level and establishing good connection with other countries in the region. This project gave me a great experience overall and has been very useful for me and my work in the future."

3. Mr Uday Pimple
Affiliation: The Joint Graduate School of Energy and Environment, KMUTT, Thailand
Address: King Mongkut's University of Technology Thonburi, 126 Pracha-Uthit Road, Bangmod, Tungkru, Bangkok, Thailand
Email: upimple@jgsee.kmutt.ac.th, upimple@gmail.com

APN project involvement:
- DNDC modeling
- Data analysis and processing
- Tutor for capacity building programs

"Working with APN project was a privilege. It was wonderful experience, and made me even more interesting to study climate change issues in Southeast Asian countries. In my 8 months participation I was able to spend many hours to discuss various issues about greenhouse gases emission from rice paddy and possible mitigation option using field experiments as well as modeling approach with Dr Sirintornthep Towprayoon (Project leader), Dr. Sebastien Bonnet (Project manager and Research scientist) and experts from Japan, which helped me to strengthen my knowledge on current situation of greenhouse gas emissions from paddy field in Southeast Asia. Also the various capacity building programs helped me to improve technical skills required to deal with climate change issues and gave me opportunity to communicate with various experts from all South East Asian countries. In future I am really looking forward to work with APN team again."

4. Dr Agapol Junpen
Affiliation: The Joint Graduate School of Energy and Environment,
Address: King Mongkut's University of Technology Thonburi, 126 Pracha-Uthit Road, Bangmod, Tungkru, Bangkok, Thailand
Email: akjp@hotmail.com

Involvement in the project:
Work in the Activity III: Capacity assessment of GHG emissions and soil carbon stock from sustainable cultivation practices in SEA.

"The project enabled me to gain further understanding and knowledge on the following 3 aspects: (1) The assessment of the capacity of C budget in term of emissions and soil carbon stock of rice fields in

SEA, (2) The development of GIS based maps of GHG emissions from existing and sustainable cultivation practices, and (3) The assessment of potential mitigation options based on different scenarios."