EVALUATION OF THE ENERGY INPUT-OUTPUT AND GREENHOUSE GAS EMISSIONS OF RICE PRODUCTION SYSTEM IN THE PHILIPPINES AND POSSIBLE MITIGATION TECHNOLOGIES

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博士論文内容要旨

EVALUATION OF THE ENERGY INPUT-OUTPUT AND GREENHOUSE GAS EMISSION OF RICE PRODUCTION SYSTEM IN THE PHILIPPINES AND POSSIBLE MITIGATION TECHNOLOGIES

（フィリピンにおける稲作システムの

エネルギー収支と温室効果ガス排出量の評価、

及び緩和技術の可能性）

ELMER GRANADOZO BAUTISTA

PhD Thesis

ABSTRACT

Evaluation of the energy input-output and greenhouse gas emission of rice production system in the Philippines and possible mitigation technologies

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Chapter 1. Introduction

In the Philippines, rice is the most important crop because it is the staple food and 70% of the population depended on it (Bureau of Agricultural Statistics 2007). Thirty-three percent of agricultural land is devoted to rice (Table 1). Although climate is favorable and rice is planted twice a year, the increasing demand for rice challenges all stakeholders because of natural calamities that resulted to 80% the level of self-sufficiency in 2000. Irrigation water is sustainable during the wet season (June-November) but dry season (December-May) depends on impounded water from rainfall or pumping with engines. The combination of human labor and carabao (water buffalo) is still the prevailing practice in rice production although, mechanical power such as handtractor for land preparation and hauling, and thresher for threshing are becoming popular. These are used depending on farm size, cultural practices, soil conditions, and topography.

To meet the food requirements of a growing population, research and development efforts are pursued to help developing countries in Asia to grow more rice in limited land. As a result, rice production has been intensified. The increased utilization of energy from fossil fuel, chemical fertilizers, pesticides, machinery, and electricity to support intensive rice production has resulted in higher greenhouse gas (GHG) emission, which contributes to global warming that is becoming the most serious problem (Figure 1) of humankind today such as effects of climate change. To come up with a more sustainable and environment-friendly rice production system, it is useful to evaluate the environmental impact and food safety of rice products and processes, or activities throughout its life cycle.

In rice production, direct energy is required in land preparation, irrigation, harvesting, threshing, and transport of farm inputs and outputs. Indirect energy is used in the manufacture, packaging, and transport of primary inputs (Figure 2). Thus, increasing rice production using modern and advanced technologies produce more GHG emission. Furthermore, the rice field is identified as a source of biogenic methane emission.

In this study, the energy input-output and GHG emission of rice cultivation in the Philippines were assessed from the life cycle viewpoints. In the view point of an agricultural engineer who is developing agricultural machine, possible mitigation technologies are recommended based on rice mechanization. But such improvement requires necessary assessment how it contribute to mitigation of GHG emission in rice production. In Chapter 2, the energy input-output of various rice production systems was evaluated. In Chapter 3, I evaluated GHG emissions and discussed possible mitigations with common practices. To mitigate GHG emission and reduce energy input, I examined a ride-on tillage implement for the handtractor (Chapter 4); a locally designed wind-pump system was evaluated based on 10-year weather data (Chapter 5); and evaluated an updraft rice husk gasifier system to power a small rice milling facility (Chapter 6). I elaborated on mitigation of GHG emissions from rice production systems in the general discussions and final conclusions (Chapter 7).

Chapter 2. Analysis of the energy for different rice production systems in the Philippines

The energy input-output analysis is an effective tool to grasp the energy structure of agriculture (Pimentel 1979). In the Philippines, however, it has not been used in agricultural sciences. This study traced and analyzed the energy for different rice productions based on Life Cycle thinking using the 2006-2008 statistical data of the Philippines. Energy inputs included human labor, machinery, animal, seeds, irrigation, fuel, fertilizers, and pesticides. Energy output is milled rice. Rice growing systems in the Philippines were classified based on growing season (wet and dry) and irrigation practices (irrigated and rain-fed) (Table 1). Furthermore, these systems were classified into 3 categories in terms of power sources (manual, semi-mechanized, and mechanized).

The wet season (WS) analysis is shown in Table 2. The average output-input ratios were 4.1 and 3.5 for rice irrigated by canal and pump facility, respectively. The manual system had the highest energy ratio of 4.0 and 4.4; and average energy input of 9,225 and 11,566 mega joules (MJ) ha^{-1}for rice with pumping sets and canal facility, respectively. The analysis during the dry season (DS) is shown in Table 3. The average output-input ratios were 4.5 and 2.7, for channel and pumping areas. Manual system in the channel and pumping had the highest output-input ratio of 3.0 and 4.9, and energy inputs of 10,413 MJ ha^{-1} and 10,483 MJ ha^{-1}. Mechanized rice showed that modern technologies reduced the cultivation cycle but it increased yield potential and total energy inputs.

In irrigated rice conditions, yield was higher during the DS than WS, because more fertilizer was applied. In rain-fed conditions, WS yield was higher than in the DS, because water shortage constrains rice growth. The average output-input ratios of manual, transplanted semi-mechanized, direct seeding semi-mechanized, and mechanized were 4.9, 4.7, 4.4, and 3.9, in that order. The same order was observed in all conditions, except for pumping during the DS when the semi-mechanized systems alter each other's position. The energy input of irrigation and fuel for machine were also high in the dry season. In order to increase rice area, irrigation with engine pump is needed. It may be needed to introduce the use of renewable energy for alternative irrigation such as wind pumping.

In all farming systems, nitrogen, fuel, and seeds contributed around 80% of the total energy inputs (Figure 3). The output-input ratio of rice production in the Philippines is largely affected by cropping season and pumping for irrigation. The energy ratios in PH were generally higher than those reported from Japan and US (Byrne 2001). These countries have higher yield to almost double comparing to that of the Philippines but energy input on machine, fuel and fertilizer and other inputs are also higher. This is because the power sources for rice production in THE PHILIPPINES still predominantly depend on human labor that results in low energy input.

Chapter 3. Greenhouse gas emission from rice production systems in the Philippines based on life cycle inventory analysis

In the Philippines, the latest national inventory of greenhouse gas (GHG) emissions from rice production was submitted to the UNFCCC using data of 1994. In my study, the same emissions were more comprehensively assessed based on LCIA (Life Cycle Inventory Analysis) using Philippine National Statistics data of 2006-2007. The GHG emissions of farm inputs (fertilizer, pesticide, fuel for machines and irrigation) including water buffalo from seedbed preparation to harvesting and threshing, and methane (CH_4) and nitrous oxide (N_2O) emissions from soil processes were estimated based on 2006 IPCC guidelines (Figure 2). Because the rice production area in this country is mostly dichotomized into either irrigated or rain-fed areas and cultivated twice a year (Table 1), I used different emission factors for the soil processes in each area.

The GHG emission of rice cultivation in the Philippines was about 13.3 Tg CO_2eq yr^{-1}, which was about 40% from agriculture (UNFCCC 1999). Irrigated and rain-fed rice emitted about 3,920 kg and 1,381 kg CO_2 eq. ha^{-1} $year^{-1}$, respectively (Table 4). Soil processes, mainly CH_4 emissions, comprised the highest among sources (Table 5), which are similar to findings in other countries. The emission of carabao was found to be very high compared to handtractor emission even if carabao is only 25% in land preparation. The emission of diesel fuel for irrigating rice field was also high in the dry season. Emission of rice in the Philippines is still lower than those of Italy and Japan (Table 6) because of lesser fertilizer application rate and dependence on animal-human labor.

To reduce emissions from soil processes, the technology on alternate wetting and drying or mid-season drainage is recommended. The use of handtractor in place of carabao is also recommended to reduce emissions from enteric fermentation and carabao's manure emission, which was bigger than that from handtractor. Handtractor is more advantageous in terms of workability as well as mitigation of GHG emission compared to carabao. Mechanize rice farming could save time, increase efficiency of farm inputs, increase yields, and help farmers but its contribution to GHG emission in rice production needs to be contained.

Chapter 4. Mitigation technologies: technical and socioeconomic evaluation of a ride-on tillage implement for the handtractor

Handtractor, a small walk-behind machine made of chain and sprocket, became most popular in rice production because of its versatility, made from locally available materials and easy to fabricate. The technical performance of a ride-on tillage implement was evaluated under actual field conditions, while the socioeconomic aspect was taken through structured questionnaire to gather feedback on its acceptability. The mitigation effects on the use of ride-on attachment were also evaluated.

The new ride-on implement (Figure 4a) to the handtractor was used in levee-side plowing, ride-on plowing, ride-on harrowing, and ride-on leveling at a field capacity of 0.7, 3.57, 3.72, 3.70 and 3.2 ha h^{-1}, in that order. It can accomplish one major land preparation operation such as levee-side plowing, which was previously done only by carabao (Figure 4b). The total time needed to prepare a hectare of rice field was reduced from 22 hours to 17 hours only (Table 7). One half-hectare could be completely prepared within an 8-h day with side plowing-9%, plowing-34%, 1st harrowing-22%, 2nd harrowing-13%, and leveling-22% (Figure 4c).

Farmers who used the new ride-on implement said they experienced more advantages, and even faster than the old attachment. They were satisfied with the investment cost and the safeness of field operation. Economic analysis showed that a handtractor with rice-on attachment generated more income per year compared to conventional attachment. The ride-on tillage implement can generate a net income of Philippine Peso 39,528 per year. The investment cost could be returned in 1.9 years after having prepared 57 ha.

The ride-on implement substantially improved the performance of the handtractor thereby making land preparation shorter, compared to the conventional implement. The handtractor with ride-on attachment can do the levee-side plowing. The improved ride-on attachment could reduce GHG emissions to 42% per hectare by replacing the conventional attachment in land preparation and carabao during levee-side plowing (Figure 5).

Chapter 5. Mitigation technologies: potential evaluation of a locally designed wind-pump system for water pumping to irrigate rice crop based on a ten-year weather data in the Philippines

Windmills for water pumping and electricity generation have become an important point of interest in the world today because it reduces fuel for machine by using the naturally available wind. This study examined the actual performance of a locally designed wind-pump system installed in Tarlac, Central Luzon, Philippines (Figure 6); and evaluated its potential using a 10-year (2004-2013) weather data. The daily wind speed in relation to wind pump power was monitored every 5-10 minutes in the study site from April-July, 2012. Based upon the monitored data of wind speed and power of the wind-pump system, the discharge of the wind pump system was analyzed and came up with a functional relationship in term of a formula. The potential of the wind pump system then was estimated based from an average 10-year wind speed (Figure 7) and rainfall data (Figure 8). It showed that water is available for rice crop is enough if it is combined with rainfall during rainy season in May-Sep (Figure 9). Water pump by wind pump system is supplemental irrigation to rice crop. During the second cropping season in Dec-Mar, there was no rainfall, however, wind is available which can be used by wind pump to pump water for irrigation. Thus, the wind-pump system in this study has a limited potential for irrigating rice fields under the weather conditions in Central Luzon. It is best to explore a more suitable use of the present system such as drip irrigation for vegetables.

However, the wind pump could reduce fuel consumption of a diesel engine pump for irrigation as indicated in Chapter 2 (Figure 2). It was estimated that 13% of irrigation water per hectare during dry season may be supplied with the wind-pump system. In terms of GHG emission due to combustion of diesel oil, 141 kg CO_2eq. could be reduced per ha (Figure 10).

Chapter 6. Mitigation technologies: evaluation of an updraft rice husk gasifier system for powering village rice mills in the Philippines

In the Philippines, the tremendous quantity of rice husk (RH) produced by rice millers poses a variety of potentially harmful consequences to humans and the environment (Figure 11). This study evaluated the performance of the RH updraft gasification system to possibly ameliorate the problem of RH disposal and potential mitigating effect on rice production.

The system comprises a gasifier reactor (internal volume, 1.44m^3), scrubber, condensers, filter, gas storage unit, and an internal combustion engine coupled to an electric generator (Figure 12). Based on a RH consumption rate of 78 kg h^{-1}, the conversion rate of RH to carbonized rice husk (CRH) was 18% by weight. The average temperature during gasification was 780℃. With engine speed of 1.920 rpm, the system generated 13 kWh^{-1} at 173–240 V (Table 8).

The capacity of a typical small rice mill (Figure 13) was about 1t h^{-1} which required 30 kW of electricity for operation. The updraft rice husk gasifier system was technically fitted to the small rice mill. However, the power output of the gasification system in this study was insufficient to operate the rice mill. However, reassessment study indicated that it may be technically feasible if modified. Given these improvements, and if adopted by rice millers in the Philippines, the RH updraft gasification system might provide the electricity needed for rice milling facilities and a way to ameliorate the disposal of rice husk by rive miller.

The present gasifier system might still have some role for mitigation of GHG emissions from milling facilities. Assuming that the system is introduced into a small milling facility (8 ton rice grains are milled per day) where all disposed rice husk is burnt, the gasifier could reduce both electricity and rice husk disposal because part of the rice husk would be used for gasification. It was estimated to mitigate 43% of GHG emissions in terms of CO_2 eq. emission per facility per day (Figure 14).

Chapter 7. Conclusion

For a more sustainable rice production in the Philippines, it is necessary to grasp the energy inputs and GHG emissions of rice cultivation and to develop mitigation technologies. In this study, the energy input-output and GHG emissions of rice production in the

Philippines were comprehensively quantified from the lifecycle viewpoint. Likewise, some mitigation technologies, from an agricultural engineer's viewpoint, were evaluated.

The amounts of energy input and output of rice in the Philippines were analyzed (Chapter 2). Irrigated rice with mechanized system had apparently higher energy input compared to manual because of higher farm inputs application and fossil fuel used. The use of more fertilizers, high-yielding rice varieties, pesticides, and farm machinery increased the energy input that resulted in reduced cultivation cycle and higher yield potential. However, it also increased the rice production energy input that resulted in a lower output-input ratio especially in the dry season when irrigation water was needed to be pumped. Rice cultivation in transplanted semi-mechanize for both WS and DS is favourable in terms of energy input-output ratio. Fuel for irrigation was very high during the dry season.

In Chapter 3, GHG emissions from rice production in the Philippines were evaluated based upon life cycle inventory analysis, because the country has only limited information on such emissions. The present work confirmed that a large proportion of GHG in rice production is CH_4 from soil processes. Irrigated rice was proven to have higher GHG emissions compared to rain-fed rice. Emission from carabao (water buffalo) had substantial amount of methane during enteric fermentation. Yet, results showed that GHG emissions in the Philippines were still lower than those of Japan and other temperate countries, perhaps due to less fertilizer application and utilization of essential farm inputs, and less fossil fuel by mechanization.

In Chapters 4, 5, and 6, possible technologies for mitigating GHG emissions in the rice production system were investigated.

I successfully improved the ride-on tillage implement, a simple modification to the handtractor attachment, which eased all major land preparation operations in rice production and has been accepted by farmers. Levee-side plowing, which was only done by carabao before, can be performed by the implement. The ride-on attachment was also proven to mitigate GHG emission when it replaces the conventional attachment. Moreover, a substantial amount of GHG was mitigated if the activity of carabao during land preparation will be replaced by handtractor. This indicates that this invention may be not only a good alternative in terms of working efficiency but also a good mitigation technology of GHG emissions by replacing the carabao.

In Chapter 5, the locally designed wind-pump system was evaluated according to its performance and theoretical output using the 10-year weather data. The system would be an alternative for irrigating rice without fossil fuel in the rain-fed areas in the Philippines. Under the weather conditions in Central Luzon, however, the wind pump system could play only a supplemental role in irrigating rice crop. I found that large amount of GHG emission may be mitigated when it is used during the dry season.

Utilization of biomass is also another option for mitigating GHG emissions. In Chapter 6, the performance of the updraft gasifier was evaluated. The gasifier did not have an enough power for a 1 t h^{-1} rice mill, but would be technically feasible if properly modified. Given these improvements, RH updraft gasification systems might provide the electricity needed for local milling facilities (Figure 13). In terms of GHG emission, the gasifier system was proven to mitigate GHG emission due to reduced electricity supplied by the grid. It also reduced the GHG emission during open field burning of rice husk. If rice husk is use for the gasifier, lesser RH is being disposed, so lesser GHG emission is emitted.

The comprehensive assessment of the energy input-output of rice production based on life cycle thinking led us to a recommendation of improving production that helps protect the environment and mankind. In the present work, I as an agricultural engineer evaluated possible mitigation with some improvement of agricultural machines and facilities. I found that these were effective to mitigate GHG emissions to some degree.

Thorough evaluation of each rice production process gave us some insights on how to reduce environmental stress and possibly suggest options to improve it. Self-sufficiency of rice in the Philippines could still be possible to attain without so much worry of increased GHG emissions by following the recommended improvements in the rice production process.

Tables and Figures

Table 1. Area of rice cultivation and yield in the Philippines [a].

Water management	Season [b]	Area (ha)	Yield (t ha^{-1})	
Irrigated	Dry season	1,336,045	4.18	**4.21**
	Wet season	1,580,967	4.23	
Rain-fed	Dry season	467,935	2.46	**2.93**
	Wet season	887,942	3.18	
Total		**4,272,889**	3.8	

[a] Available online at http://countrystat.bas.gov.ph/selection.asp

[b] Dry season: December–May, Wet season: June–November

Table 2. Energy input-output of rice during wet season, MJ ha^{-1}.

	Channel (irrigated)				**Pumping (rainfed)**			
	Transplanted		**Direct-Seeded**		**Transplanted**		**Direct-Seeded**	
	Mechanized	**Semi-mechanized**	**Semi-mechanized**	**Manual**	**Mechanized**	**Semi-mechanized**	**Semi-mechanized**	**Manual**
Inputs								
Human labor	321	358	318	694	321	358	318	694
Machine/animal	265	262	263	474	265	262	263	474
Fuel	2,839	2,643	2,643	0	2,839	2,643	2,643	0
Nitrogen	5,817	5,817	5,817	5,817	4,682	4,682	4,682	4,682
Phosphorus	255	255	255	255	238	238	238	238
Potassium	105	105	105	105	95	95	95	95
Seeds	1,114	1,114	1,937	2,513	1,114	1,114	1,937	2,513
Insecticide	51	51	51	51	51	51	51	51
Herbicide	238	238	238	0	238	238	238	0
Transportation	116	116	116	116	85	85	85	85
Drying	2,257	0	0	0	1,646	0	0	0
Electricity	543	543	543	543	396	396	396	396
Total input	13,921	11,501	12,284	11,566	11,969	10,160	10,944	9,225
Outputs								
Paddy yield	50,367	50,367	50,367	50,367	36,734	36,734	36,734	36,734
Ratio O/I	3.6	4.4	4.1	4.4	3.1	3.6	3.4	4.0

Table 3. Energy input-output of rice during dry season, MJ ha^{-1}

	Channel (irrigated)				Pumping			
	Transplanted		Direct-Seeded		Transplanted		Direct-Seeded	
	mechanized	Semi-mechanized	Semi-mechanized	Manual	mechanized	Semi-mechanized	Semi-mechanized	Manual
Inputs								
Human labor	321	358	318	694	321	358	318	694
Machine/animal	265	262	263	474	265	262	263	474
Fuel	2,182	1,986	1,986	0	2,182	1,986	1,986	0
Nitrogen	5,721	5,721	5,721	5,721	3,607	3,607	3,607	3,607
Phosphorus	255	255	255	255	165	165	165	165
Potassium	90	90	90	90	62	62	62	62
Seeds	1,114	1,114	1,937	2,513	1,114	1,114	1,937	2,513
Irrigation	0	0	0	0	3,565	3,565	2,435	2,435
Insecticide	51	51	51	51	51	51	51	51
Herbicide	238	238	238	0	238	238	238	0
Transportation	137	137	137	137	83	82	82	82
Drying	2,288	0	0	0	1,322	0	0	0
Electricity	550	550	550	550	331	331	331	331
Total input	13,211	10,761	11,544	10,483	13,305	11,821	11,474	10,413
Outputs								
Paddy yield	51,047	51,047	51,047	51,047	30,752	30,752	30,752	30,752
Ratio O/I	3.9	4.7	4.4	4.9	2.6	2.6	2.7	3.0

Table 4. GHG emissions from rice production in the Philippines.

	Total kg CO_2 eq. yr^{-1}	**kgCO_2 eq. ha^{-1} yr^{-1}**
Irrigated areas	1.14×10^{10}	3.92×10^{3}
Rainfed areas	1.87×10^{9}	1.38×10^{3}
Total	**1.33×10^{10}**	**3.11×10^{3}**

Table 5. GHG emissions from rice production in the Philippines.

	kg CO_2 eq. ha^{-1}		**kg CO_2eq. kg $grain^{-1}$**	
	Irrigated	**Rainfed**	**Irrigated**	**Rainfed**
CH_4 emissions from soil	3,625	1,141	0.861	0.389
CH_4, N_2O from carabao	50	50	0.012	0.017
N_2O from N fertilizer applied	105	79	0.025	0.027
Fertilizers	99	74	0.024	0.025
Pesticides	5	2	0.001	0.001
Fuel for irrigation and machinery	6	5	0.001	0.002
Manufacture of threshers	13	13	0.003	0.004
Manufacture of handtractors (power tiller)	17	17	0.004	0.006
Total	**3,920**	**1,381**	**0.931**	**0.471**

Table 6. GHG emissions from rice production in various countries.

Country	**Emissions per kg brown rice (kg CO_2 eq.**	**Emissions per area (kg CO_2 eq.**	**Conditions**	**Sources**
Italy	2.76	19,000		Blengini and Busto 2009
Japan	1.46	6,300	Conventional farming	Hokazono 2012
Japan	1.58	7,000	Environment-friendly farming	Hokazono 2012
Japan	2.0	7,000	Organic farming	Hokazono 2012
Philippines	0.93*	3,990	Irrigated	Present study
Philippines	0.47*	1,445	Rainfed	Present study

*grain weight

Table 7. Comparison between handtractor with conventional and ride-on attachment.

	Handtractor with conventional attachment	**Handtractor with ride-on attachment**
Field performance		
Field capacity, had^{-1}	0.7	0.5
Total time per ha, hha^{-1}	22	17
Economic analysis		
Income generated, P y^{-1}	84,000	105,000
Cost of machine, P	71,600	74,000

Table 8. Up-draft RH gasification operation and performance data.

	Average value^{a}
Rice husk (RH)	
RH consumption rate, kg h^{-1}	78
Conversion rate, RH to CRH^{a}, %	18
Temperature	
Reactor temp, °C	780
Gas temp, °C	39
Operating efficiency	
Engine operation, rpm	1950
Electric generator operation, rpm	1242
Power output^{b,} , kW/h	13
Generated voltage^{c}, V	173–240

[a] Amount of carbonized RH produced from input RH.
[b] Average power generated using producer gas.
[c] Voltage measured from generator output.

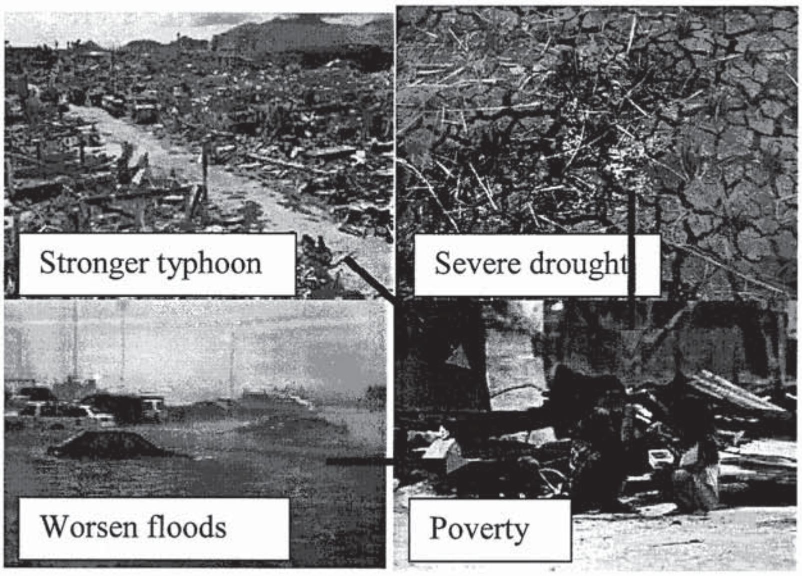


Figure 1. Effects of climate change to the Philippines

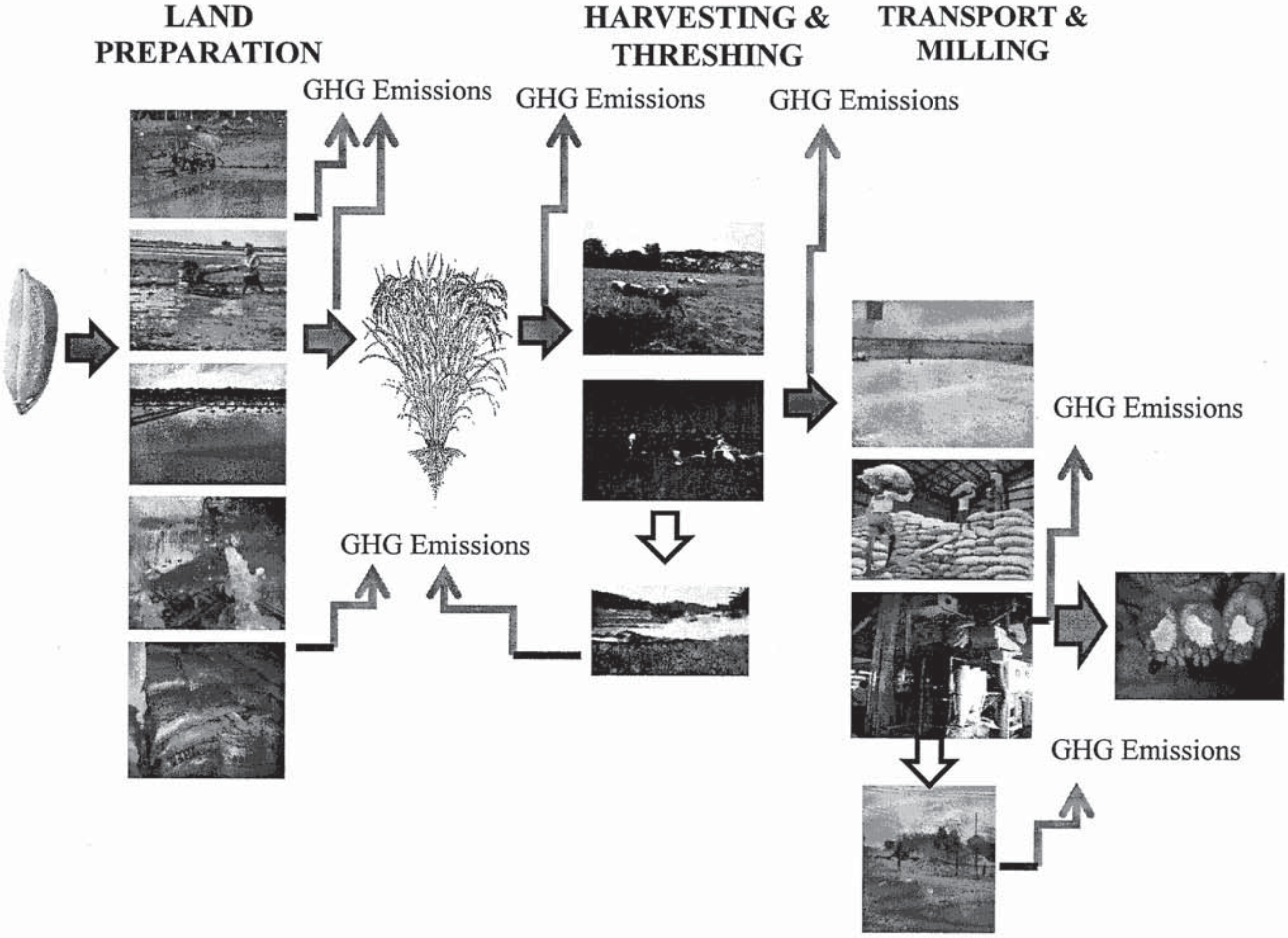
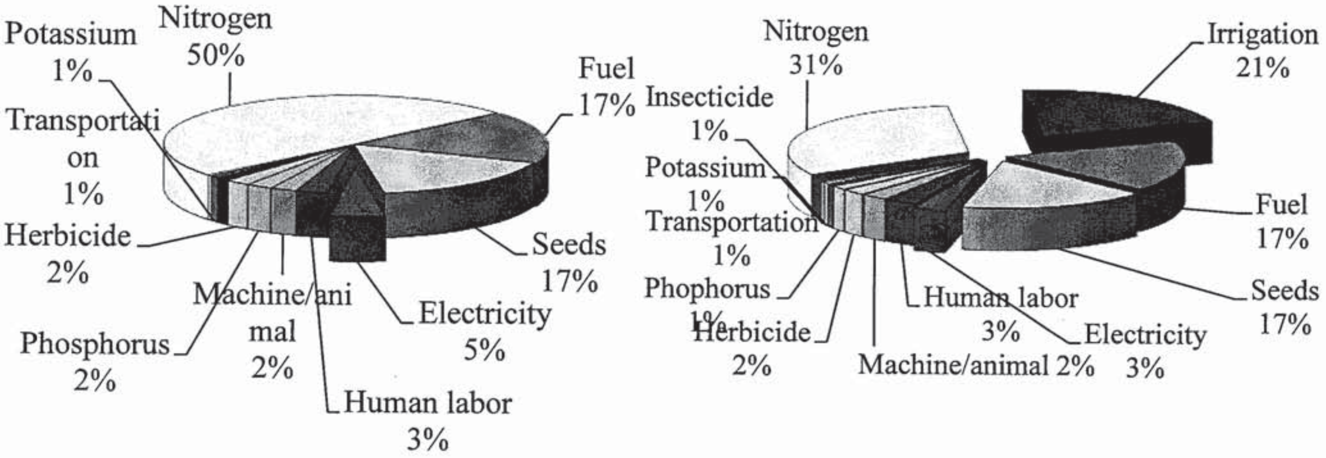


Figure 2. Flowchart of rice production in the Philippines.



(a) (b)

Figure 3. Proportion of various sources of energy input of rice production during dry season: (a) channel (irrigation was supplied by impounded water); (b) pumping (irrigation water was pumped using diesel engine)

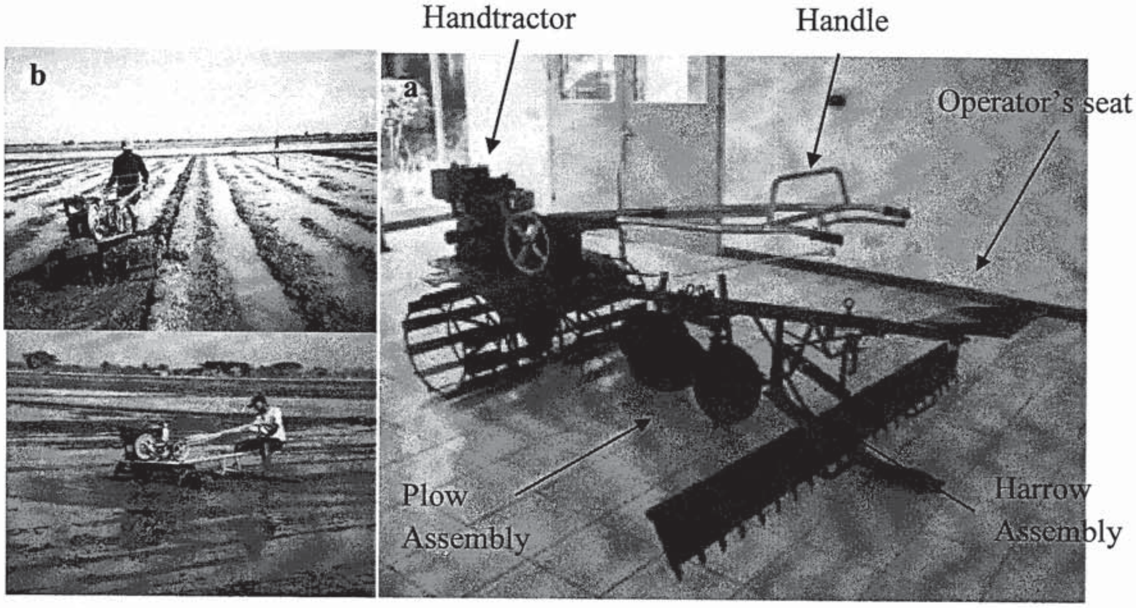
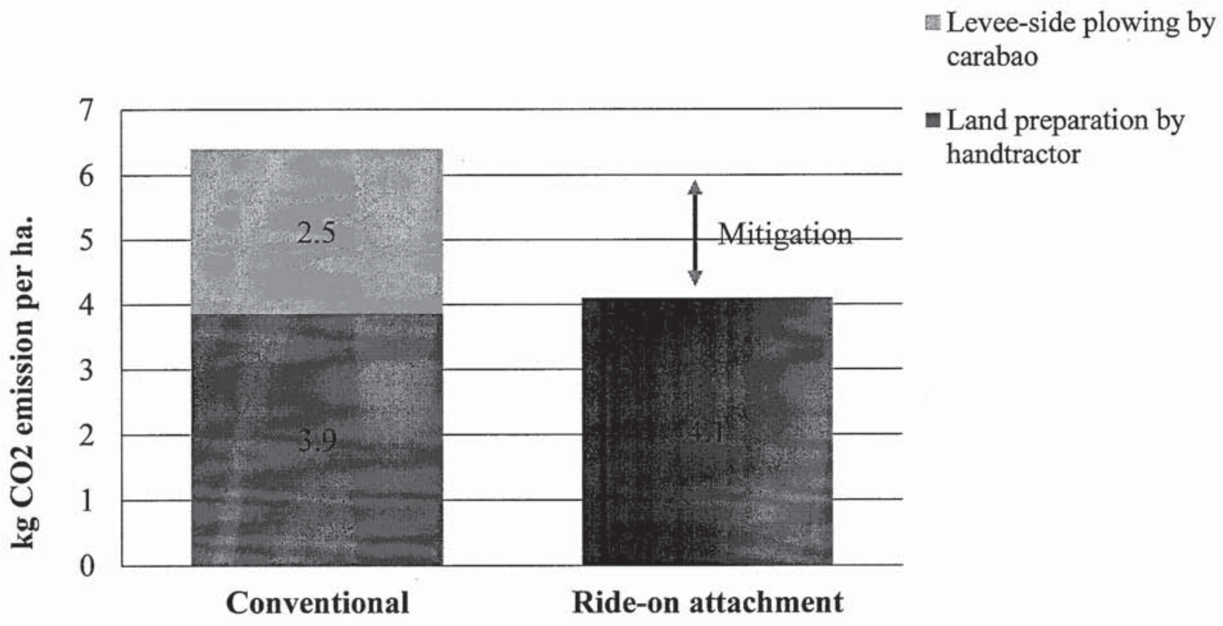


Figure 4. Handtractor with attached ride-on tillage implement: a) Overview of handtractor with attachment, b) levee-side plowing, c) leveling (photos courtesy of PASJ)



Handtractor with conventional attachment needs carabao to do levee-side plowing levee-side

Handtractor with ride-on attachment can do levee-side

Figure 5. Comparison of GHG emission of handtractor with different attachments.

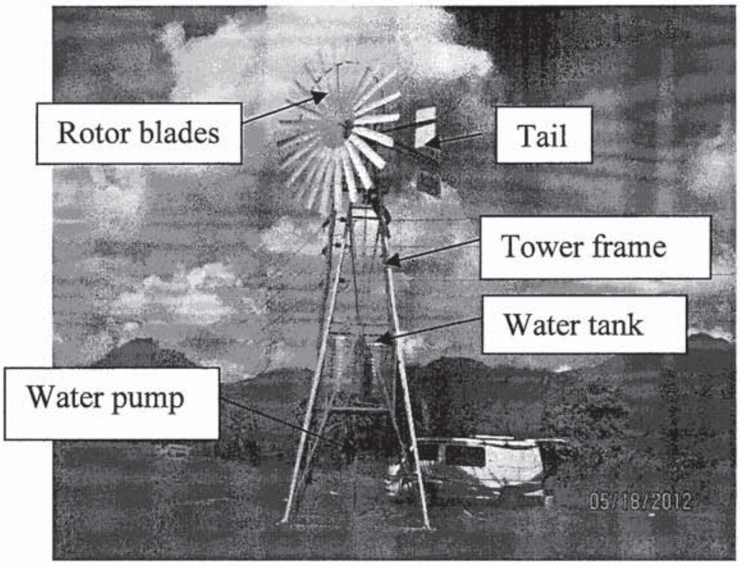


Figure 6. The wind pump system and its parts.

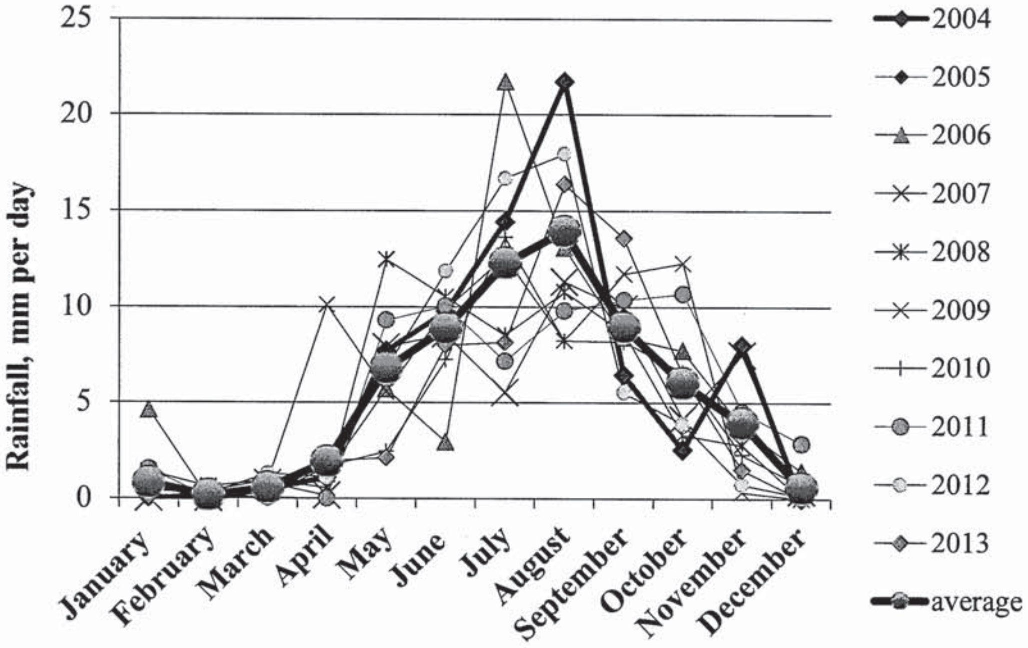


Figure 7. The 10-year average daily rainfall at PhilRice weather station.

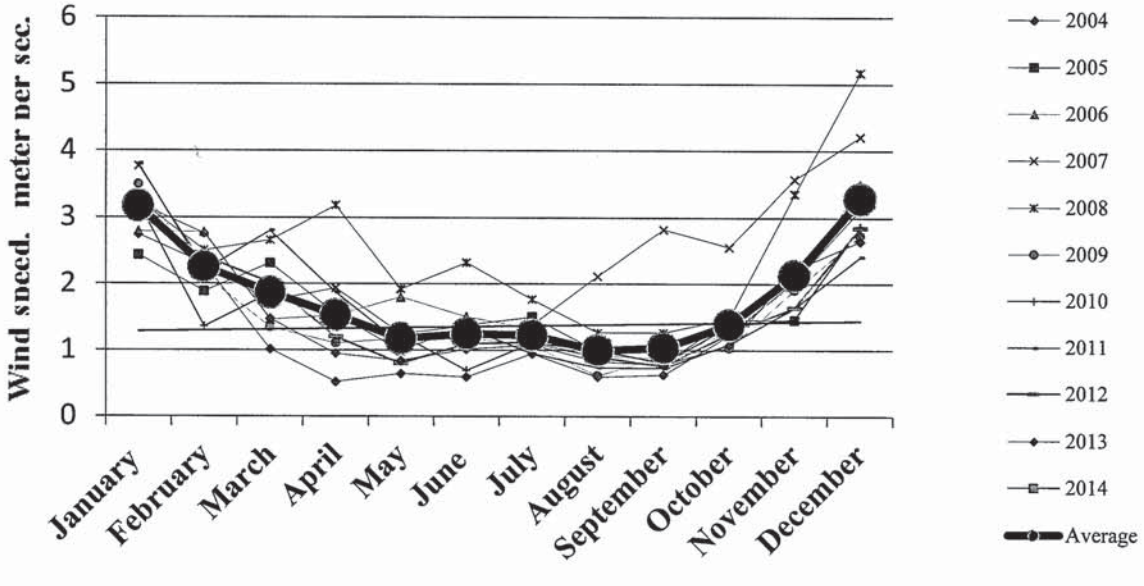
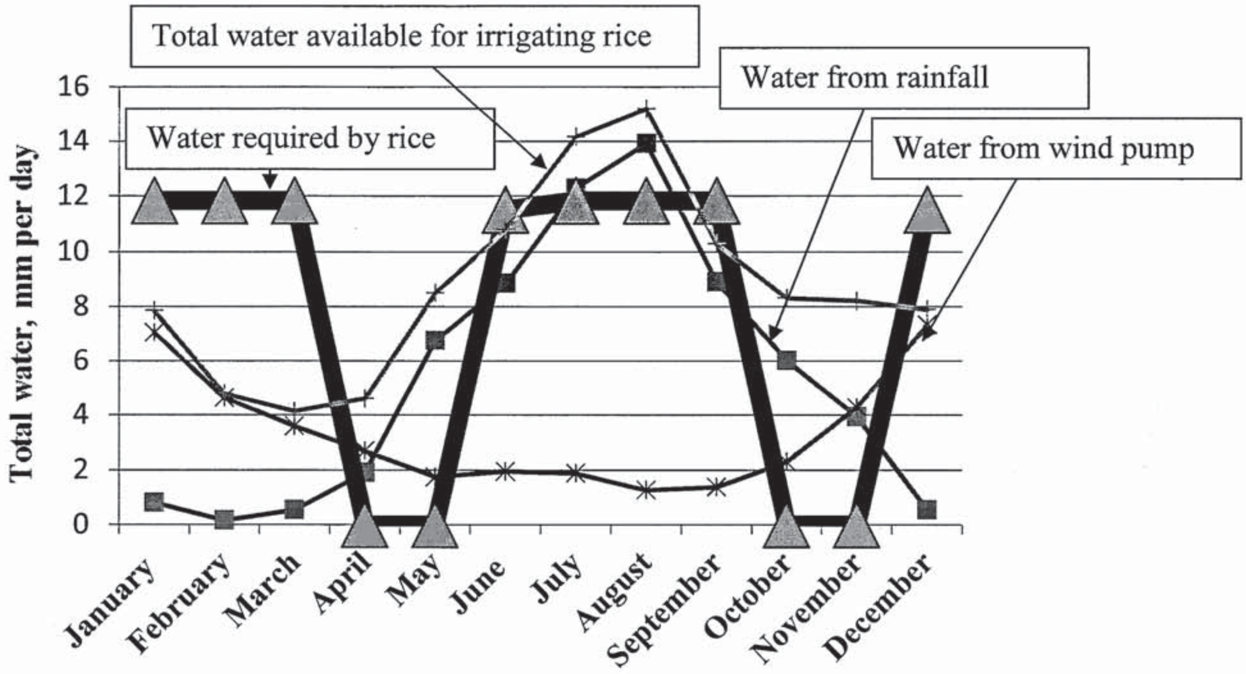


Figure 8. The 10-year average daily wind speed at PhilRice weather station.



Wind pump can irrigate 0.25 ha rice field

Figure 9. Rice crop water supply analysis.

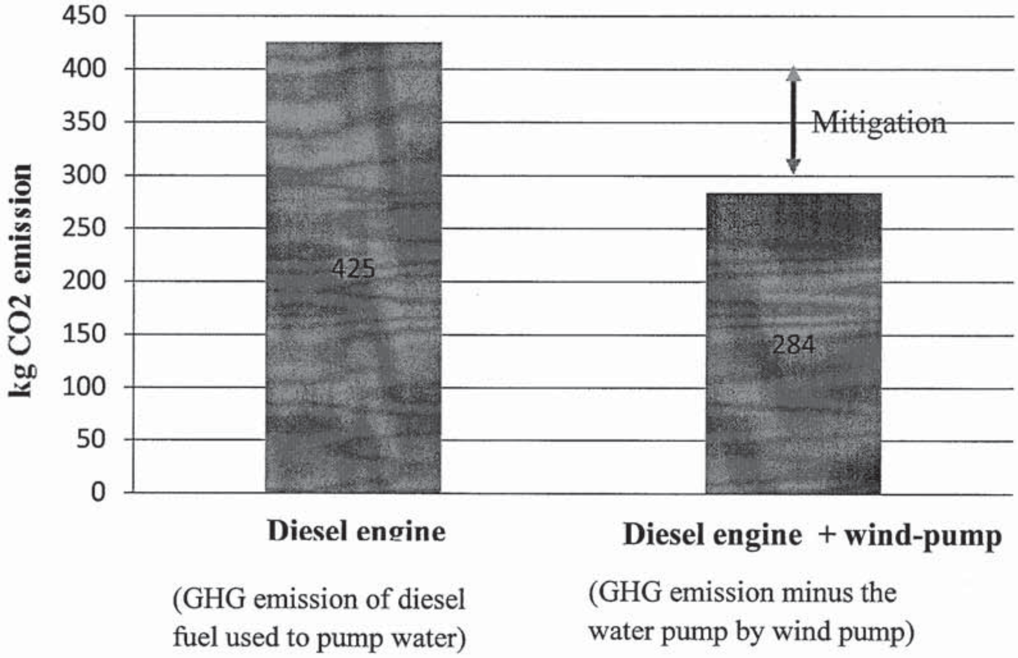


Figure 10. GHG emissions during water pumping for irrigation using full diesel engine and diesel engine + wind-pump system.

Figure 11. Traditional disposal of rice husk in the Philippines: a) at the back of a rice mill; b) along roadside.

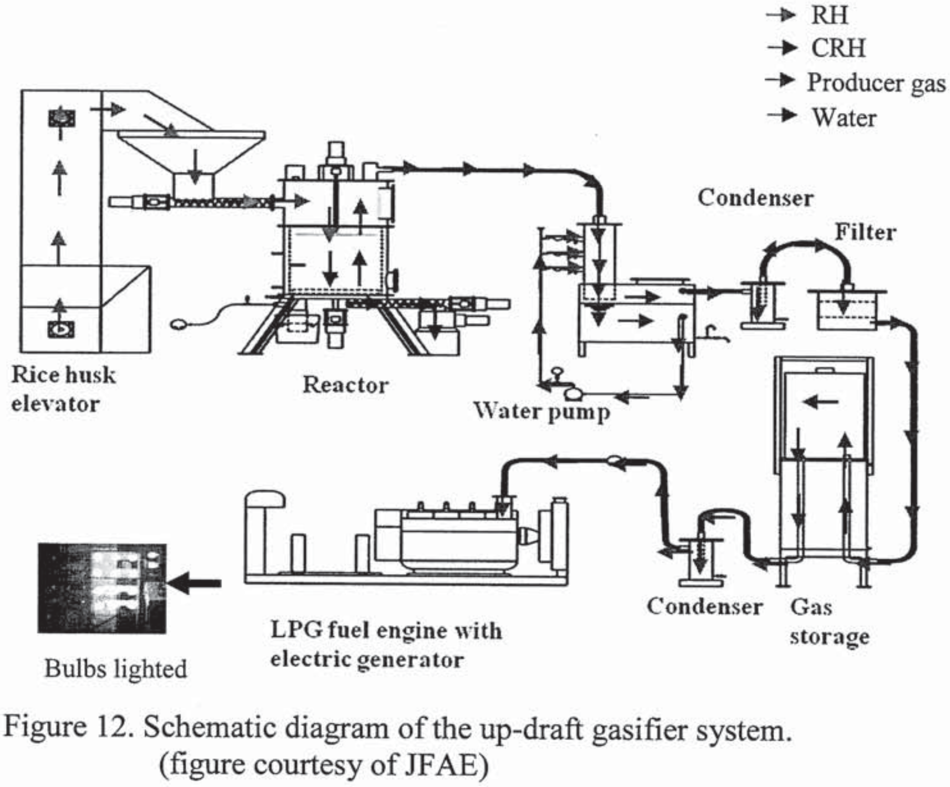
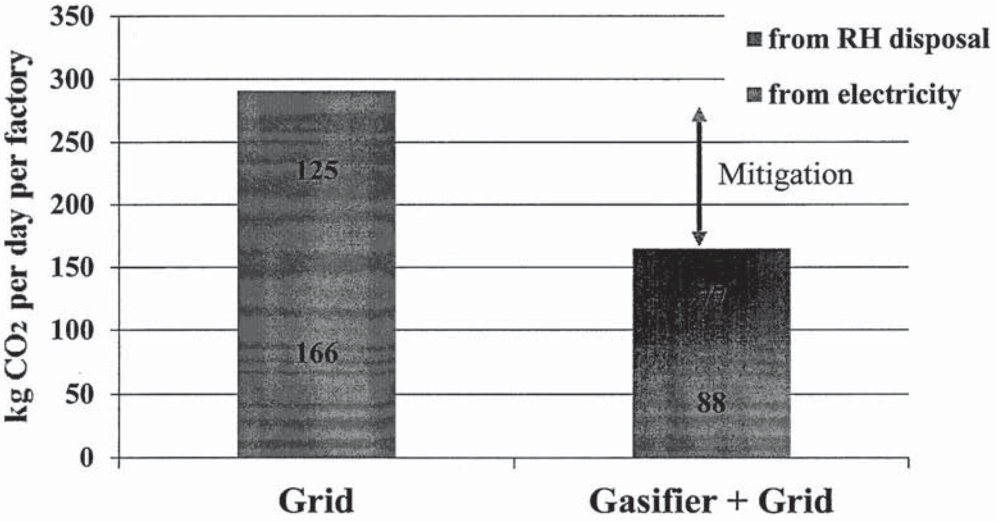


Figure 12. Schematic diagram of the up-draft gasifier system. (figure courtesy of JFAE)

Figure 13. Single-pass village rice mill in Nueva Ecija province, Central Luzon, Philippines



GHG emission of grid equal to total electricity needed by a rice mill and RH disposal is equal to emission of rice husk during open field burning

	RH for gasifier	RH for disposal
Grid, kgd^{-1}	0	1600
Gasifier + grid, kgd^{-1}	625	976

Figure 14. GHG emissions of an 8 t h^{-1} rice milling factory with full power from grid versus Gasifier + grid. (RH disposal means all rice husk left after power generation)

論文審査の結果の要旨及び担当者

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学位論文題目	EVALUATION OF THE ENERGY INPUT-OUTPUT AND GREENHOUSE GAS EMISSIONS OF RICE PRODUCTION SYSTEM IN THE PHILIPPINES AND POSSIBLE MITIGATION TECHNOLOGIES（フィリピンにおける稲作システムのエネルギー収支と温室効果ガス排出量の評価，及び緩和技術の可能性）

論文審査の結果の要旨

フィリピンでは、人口増を支えるために稲の増産が求められており、肥料・農薬・農業機械等の投入エネルギーの増大によって、生産量は増加しつつある。その一方で、稲作に由来する温室効果ガス（GHG）排出の増加などの環境負荷が増大していることが危惧されている。

そこで、本研究では稲作におけるエネルギー収支を調査した。その結果、窒素肥料に由来するエネルギー投入の割合が大きく、また乾期のポンプ灌漑の場合には、ポンプの燃料に由来する投入割合が大きいことが明らかになった。

次に、播種から収穫までのGHG排出量をライフサイクルインベントリ分析の手法により算定した。その結果、GHG排出量にもっとも大きな割合を占めるのは水田土壌からのメタン、亜酸化窒素の排出であった。フィリピンにおいては役畜として水牛が耕起等に広く利用されているが、水牛の反芻により排出されるメタンの割合が、農業機械、農薬などよりも高く、無視できない排出源であることが初めて明らかにされた。

稲作におけるGHG排出削減に向けて、各種の農業用機械について、そのGHG排出削減への効果を調べた。

乗用型アタッチメント付きハンドトラクターは、これまでのハンドトラクターより作業効率が高く、水牛でしかできなかった作業も可能とするものであり、そのことによって、耕起・代かき作業の効率化のみならず、GHG排出量を削減できることが明らかにされた。

灌漑用のポンプに用いる燃料に由来する負荷を削減するために、自然エネルギーである風車ポンプについても検討した。風車の能力は低かったが、補助的に用いることによって、灌漑用ポンプの燃料に由来するGHGを削減することができると考えられた。

籾すり過程で発生するもみ殻の多くは環境中に廃棄され、問題となっている。そこで、もみ殻ガス化発電の能力をフィリピン稲研究所に設置した機器を用いて評価した。その結果、今回試作した機器の発電能力は期待したほど高くなかったが、補助的に利用することによりもみ殻廃棄を削減し、精米工場の電気使用量を大幅に削減できることが明らかになった。

以上のように、本研究は、これまで精査されてこなかったフィリピン稲作のエネルギー収支、GHG排出量を明らかにし、各種の農業機械の改良等が稲作におけるGHG削減に寄与できることを初めて明らかにした研究である。このように、本論文は博士（農学）を授与するにふさわしいと判断した。