EVALUATION OF THE ENERGY INPUT-OUTPUT AND GREENHOUSE GAS EMISSIONS OF RICE PRODUCTION SYSTEMS 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）

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SUMMARY

The general introduction discussed the general status of rice cultivation in the world and in the Philippines. It explained the effect of rice in the lives of Filipino people and its contribution to the economy. The methods and practices of rice cultivation were discussed here. The challenges in attainment of self-sufficiency in rice in relation to the environmental impact of rice cultivation were also explained here. The importance of fertilizer application and the utilization of carabao as draft animal during land preparation and hauling were discussed. The mechanization of rice production was slightly explained, including the rice straw and husk management in the field. Several activities involved in rice production were shown in the figure. The general objective of the dissertation was mentioned.

In Chapter II, the analysis of the energy input-output for different rice production systems in the Philippines was discussed. Energy input and energy output of rice production considering the power source (manual, semi-mechanized, and mechanized) were analyzed using the Philippine national statistical data of 2006-2007 based on life cycle assessment. During analysis, the differences on growing season (wet and dry season) and irrigation methods (irrigated and rain-fed) were also reflected in the data. The energy input-output of rice production in the Philippines was analyzed here. The results separately discussed the dry and wet season data. The results were compared to previous studies on rice energy of other countries. The conclusion of the study was carefully discussed at the end of the study.

In Chapter III, the greenhouse gas emission of rice production system in the Philippines was evaluated based on life cycle inventory analysis. The GHG emissions of rice farming inputs (fertilizer, pesticide, fuel for machines, and irrigation) and carabao were comprehensively quantified. Methane (CH_4) and nitrous oxide (N_2O) emissions from soil processes during rice production were estimated based on 2006 IPCC guidelines. The difference in rice straw management (burning or incorporation) and method of irrigation (irrigated and rain-fed) were also taken into account. All data were based on national surveys conducted in 2006-2007. The global warning potential of methane and nitrous oxide were 21 and 310, respectively. The result discussed the GHG emission of rice production in the Philippines. The emission of

rain-fed and irrigated area was compared towards the discussions. The detailed GHG emission of sources of emission was also discussed here. Several mitigation processes were identified to reduce GHG emission during rice cultivation. The result was compared to the emission of different countries, such as Japan and Italy. The conclusion was discussed by stating some possible mitigation technologies based on the view point of an agricultural engineer.

In Chapter IV, as a mitigation technology, the technical and socioeconomic evaluation of a ride-on tillage implement for the hand tractor was conducted in actual field operation. The status of rice production mechanization was discussed in the introduction. Technical evaluation covered the speed of travel, draw bar pull, rolling resistance, and turning radius of the hand tractor during plowing and harrowing, depth of cut, width of cut, and field efficiency. All data were analyzed using the descriptive statistical analysis. The socioeconomic impact and feedbacks from the farmers who used and observed the ride-on attachment were gathered through structured questionnaire. The economic analysis of the handtractor using a straight line method was also evaluated. The result showed the actual performance of the handtractor with ride-on attachment. The advantages of using the ride-on attachment in relation to field performance, economics were compared to the conventional attachment. The mitigation effect of using the handtractor as replacement of carabao during levee-side plowing was also discussed in this chapter.

In Chapter V, as a mitigation technology, the potential evaluation of a locally-designed wind-pump system for water pumping to irrigate rice crop based on 10-year weather in the Philippines was studied. The weather data were gathered from PhilRice weather monitoring station. A previously installed wind-pump system in Tarlac, Philippines was used for the study. The actual performance of the wind-pump by measuring the water discharge together with the actual wind speed in the area was monitored and analyzed. The 10-year wind speed and rainfall data of the area was analyzed in relationship with the actual data. The result showed that the wind-pump is not capable of irrigating one hectare rice crop. However, it can support rice crop during the rainy season (June-November) if it is combined with the rainfall. The mitigation effect of using the wind-pump system during dry season was also compared to water pumping using diesel engine-pump system.

In Chapter VI, as a mitigation technology, the evaluation of an up-draft rice husk gasifier system for powering rice mills in the Philippines was conducted. The study was aimed to ameliorate the effect of rice husk disposal by small rice mills. Performance of the gasifier was discussed in the results and discussions. The study concluded that the gasifier output was not enough to power a small rice mill. However, by improving the performance of the system, this could be done. If improved and adopted, the gasifier will help rice millers in reducing rice husk waste and at the same time, power their mills. The mitigation effect of using the gasifier was also studied in this chapter.

In chapter VII, the general discussion and conclusion were discussed here. The concluding remarks in each chapter were discussed here. The final message of the dissertation was stated.

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Chapter I

General Introduction

Rice cultivation is highly concentrated in East, Southeast, and South Asia, accounting for 89% of the world's rice production, as well as rice global emission (Yan et al 2003).With a total land area of 154 million, 98% developing countries and only 2% developed countries. It is predominantly a dietary energy source for 17 countries in Asia and the Pacific, America, and Africa accounted to 20% of the world (IRRI 2008). The Philippines devotes more than 33% of its 9.2 million hectares total agricultural land to rice cultivation. In 2007, the Philippines has a total annual rice harvested area of 4,272,889 hectares, with 2,917,012 hectares considered as irrigated rice areas and 1,355,877 hectares as rain-fed rice areas. Based on statistics, rice production placed around 21% of the total agriculture (BAS 2007) and accounts for the 44% share of total caloric intake and 31% of total protein intake of Filipino at a daily supply of 1,161 gram calories per capita (WHO 2008).

Rice is the most important of all agricultural crops because it is the major staple food crop and a way of life for 70% of the total population who are greatly dependent on rice production, processing, distribution, and marketing. The agriculture labor force, comprising12.9 million or an equivalent of 37% of the total labor force, is highly dependent on agricultural production. Farmers, forestry workers, and fishermen ranked second with 17.3% share of the total employed population (BAS 2008).

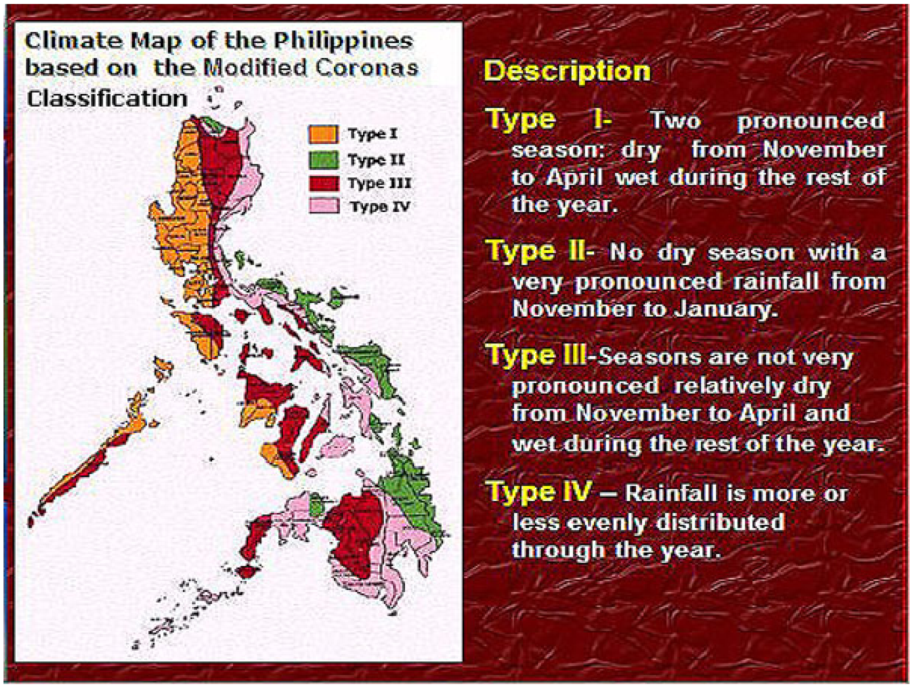
The Philippine population continues to grow at its high rate of 2.04%, requiring more and more rice output to feed the people. At this point, local rice production has not met current local demand, making the Philippines a major importer of rice despite it being a major rice-producing country. Filipinos consume more rice today compared to previous years. Data shows that rice per capita consumption in 2000 substantially increased to 13% in 2009 from 106 kg head^{-1} y^{-1}to 119 kg head^{-1}yr^{-1} (PhilRice 2011). As a result, the level of self-sufficiency in rice decreased from 91% in 1990 to only 80% in 2010 because both population growth and per capita consumption increased faster than rice production. This includes the effect of natural calamities that destroy the crop before harvesting. With an average annual yield of 3,684 kg ha^{-1}, the country's rice supply of around 12 Mt came short of more than 1.7Mt tons for sufficient supply in 2006 (DA 2008).

Table 1. Rice supply and utilization accounts, kg paddy, 2006

Supply	Beginning stock	2,094
	Production	10,024
	Import	1,716
	Gross supply	13,834
Utilization	Seeds	204
	Feeds and waste	652
	Processing	401
	Ending stock	2,253

The climate of the Philippines is tropical and maritime. It is characterized by relatively high temperatures ranging from 25.5 to 33.9ºC, 75 to 86% high humidity with abundant rainfall. The mean rainfall varies from 965 to 4,358 millimeters annually. Rainfall distribution throughout the country varies from one region to another. The tropical cyclone season is from June to December, with the months from July to September having more than three cyclones each month. This coincides with the wet season rice cropping season since farmers are intent to use rainfall for irrigation. The climate in Central Luzon is characterized by two pronounced seasons: dry from November to April with an average rainfall of 193 mm, and wet from May to October with an average rainfall of 1654 mm which permits rice farmers to grow their rice within the period.

Based on the seasonal rainfall distribution, the climate of the Philippines is classified as follows:



Type I- Two pronounced season: dry from November to April wet during the rest of the year.

Type II- No dry season with a very pronounced rainfall from November to January.

Type III-Seasons are not very pronounced relatively dry from November to April and wet during the rest of the year.

Type IV – Rainfall is more or less evenly distributed through the year.

Figure 1. Climate map of the Philippines. (courtesy of PAGASA)

Paddy production meets a total of 16.52 million metric tons in 2007. It was improved due to sustained used of hybrid and high quality inbred rice seeds. The rehabilitation of several irrigation facilities in various rice areas contributed to the improvement of yield. The absence of strong typhoons during the year also boosted paddy harvests. The average farm gate price of paddy was Php11.21 per kg (PhilRice 2008).

A strong emphasis has been given to introducing high-yielding varieties, development of irrigation facilities, and provision of fertilizer loans and subsidies to encourage farmers to produce more yields.

The rate of GHG concentrations is increasing which contributed to changes in the earth's climate (IPCC 2006), hence there is a significant interest in quantifying the GHG sources and sinks of these trace gases. The international community has taken steps to reduce these emissions. The IPCC published new guidelines in the 2006 IPCC guidelines for computing CH_4 emissions from rice fields. Climate change is recognized as an inescapable threat to global development, especially in agriculture which has become the primary source of greenhouse gases (Johnson 2007).GHG emissions from agriculture represents 0.14 of global anthropogenic GHG 0.47 CH_4 emission, and 0.82 N_2O (Boumann 2001, USEPA 2006).Rice fields were identified as an essential source of 40% anthropogenic methane and biogenic emissions, so it is a very challenging task to increase rice production to feed a rapidly increasing population using modern and advanced technologies knowing that more GHG emissions to the atmosphere are produced, causing climate change. Harmonizing production intensification with lower GHG emission levels is a real challenge in the field of rice agriculture.

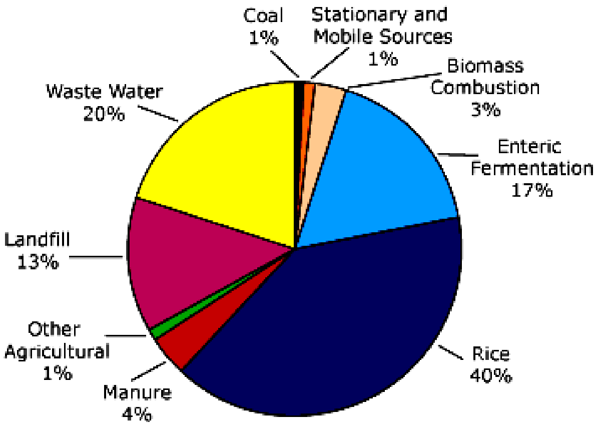


Figure 2. Philippine estimated anthropogenic methane emissions by source, 2005.
Source: 2006 USEPA Report: http://www/epa.gov/nonco2/econ-inv/international.html

In order to increase the yield of rice, more organic or inorganic-based fertilizers must be applied, improved high-yielding variety and disease-prevention chemicals must be used, and rice crops taken good care of, among others. The tremendous utilization of energy from fossil fuel, chemical fertilizers, pesticides, machinery, and electricity during intensive production resulted to remarkably increased GHG emissions which have resulted to unexpected global warming. Thus, GHG emissions are probably the most serious problem of humankind today. There is direct energy required to perform various tasks, such as land preparation, transplanting, irrigation, harvesting, threshing, and transportation of farm input and outputs. On the other hand, indirect energy is the energy used in the manufacture, packaging, and transportation of primary farm inputs as shown in Figure 3.

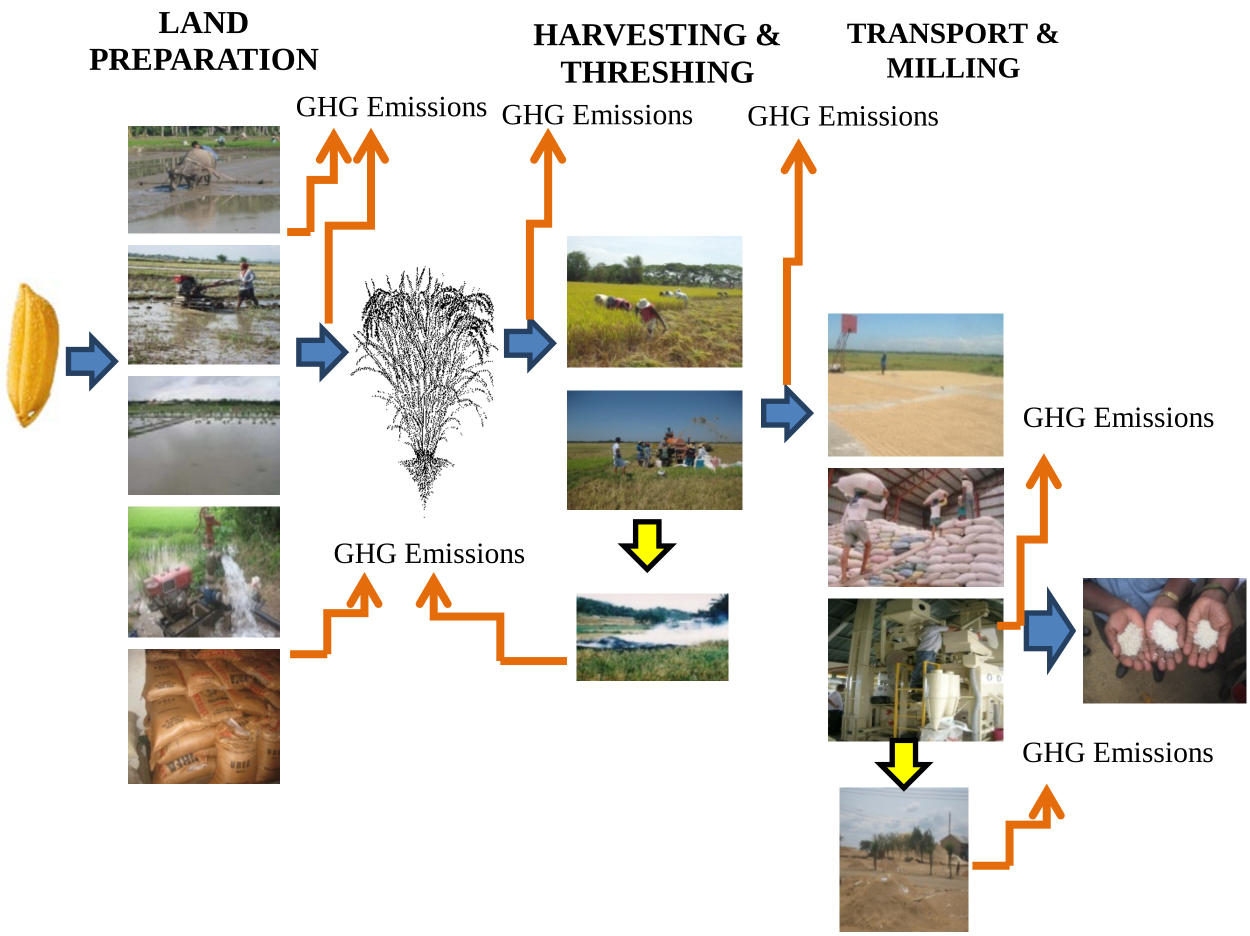


Figure 3. Schematic diagram of the life cycle flow in rice production.

As rice is grown and harvested, it consumes the nutrients available in the soil which could be replaced by fertilizer application. Anything depleted from the soil during rice cultivation needs to be replaced through application of required fertilizers. Depletion of soil nutrients of the soil due to intensive rice cultivation would require supplemental fertilizers, either organic or inorganic, to attain higher yield per unit area of land. Fertilizers are important factors in modern-day agriculture and are essentially responsible for the increase in rice yields. They allow crops to be planted even in low fertile soil. Using fertilizers enables farmers to produce more yields in smaller areas. Therefore, it is a very important element in worldwide food production. Without applying fertilizer to the soil, farmers are required to utilize larger lands to produce the same yield as that of fertilized land.

The commercially manufactured inorganic fertilizers for rice are formulated with varying nutrient compositions. Inorganic fertilizers can be made from single-to multi-nutrient content at several concentrations. Main fertilizer nutrients that are indicated by percentage are nitrogen, phosphorous, and potassium with minimal amount of micro-nutrients.

A study by Smil (1999) found that the global use of fertilizers in 1950 has substantially increased to 23 times more nitrogen (N), almost eight times more phosphorus (P), and >4 times more potassium (K) by 1999.Nitrogen fertilizer is a significant concern as >50% of applied N is either lost through leaching or released into the atmosphere as N gases including nitrous oxide (N_2O). The more urea fertilizer was applied, the higher CH_4 emission proportionately increases (Lindau 1991). Studies showed that from 1990 to 2002, N_2O emissions from N fertilizer increased by 18.7% into 444 mt CO_2e (Vergel 2007), while the energy consumed was increased to about 45% (Helsel 1992). Similarly, worldwide use of pesticides has also increased to an average 3% per year from 1993 to 2003, resulting in substantially increased GHG emissions (Vlek 2003). In the Philippines, irrigated rice applied an average fertilizer rate of 72-18.6-11 NPK using the locally available fertilizer 108 kg urea, 26 kg ammonium sulfate, 39 kg ammonium phosphate, and 77 kg complete, while rain-fed rice applied at the rate of 55.3-18.6-10.8 NPK using 75 kg urea, 18 kg ammonium sulfate, 39 kg ammonium phosphate, and 77 kg complete.

These factors really challenge the capability of farmers and researchers to produce more rice and at the same time reduce GHG emission (Wassmann 2009) to cope with food supply demands. In order to deal with these challenges, the factors involved in rice production must be carefully examined. Several studies suggest that increasing fertilizer application at optimum rate will meet the maximum yield of rice. Lowland rice cultivation was proven to produce more grain compared to upland but GHG emission was also higher (Wassmann 2000). The use of fossil fuel by machinery during land preparation, irrigation, harvesting, and hauling is also a contributor to GHG emissions in rice production (Maraseni 2009). There are alternative renewable energy technologies that can be used in rice production but it needs further studies to evaluate its suitability to specific rice cultivation conditions. The traditionally used carabao during land preparation and hauling of input were also being investigated with regards to GHG emissions. All of these are key factors that need to be studied to come up with higher rice yield with considerably low GHG emissions.

Rice cultivation consumes more water compared to other grain crops (Tuong 2005). With land preparation alone, it requires 200 mm to prepare lowland rice. This further increases to 500-

600 mm if preparation is longer for up to 30 days. A total of 1,240 mm is an average water requirement for irrigated rice (Yoshida 1981). Rice water requirement varies from 400 mm in heavy clay soils with shallow ground water to 2000 mm in coarse textured soils (Bouman 2001). The emissions from irrigation systems were also not negligible because of transport and manufacture of pumps (Maraseni 2007). The interdependence of irrigation water and rice production and the GHG emission and irrigation system need to be studied. Rice is grown under flood condition, its unique semi-aquatic nature allows it to grow productively in places no other crop could exist. However, it is also the reason for the emission of the major greenhouse gas (GHG), methane. Methane emissions from rice fields are predominantly influenced by the water regime and organic inputs (Thanawong 2013), but also soil type, weather, tillage management, residues, fertilizers, and rice cultivars (Wassmann 2009, Neue 1997). Intermittent irrigation or late flooding of rice paddies can greatly diminish the seasonal emission of CH4 compared with continuous flooding (Smith 2004).

The United Nations Framework Convention on Climate Change requires all signatories to develop and periodically update national inventories of anthropogenic emissions. Most signatories have submitted their national communications using 1994 as the base year, and Annex I countries have submitted their national inventory reports on an annual basis (Yan 2009). Using the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and country-specific activity data, the emission of CH_4 from global rice fields was estimated at 25.6 Tg a^{-1}, with a 95% certainty range of 14.8–41.7 Tg a^{-1}(Yan 2005).

The carabao (water buffalo) population in the world is actually more than 170 million heads in 2003: 161 million (95.83%) could be found in Asia. In the Philippines, there are about 3.2 million carabaos, 99% belong to farmers with limited resources, low income, and little access to other income opportunities (Borghese 2005). The carabao is especially suitable for preparing rice fields and is a good source of milk as well. Carabao milk has been proven to be richer in fat and protein compared to dairy cows (Tripaldi 2003, Barile 2002). The carabao is very important to the farmers' daily living. It could be a draft animal without the use of fuel, a source of fresh milk, carabeef (carabao's meat), and hide. In 1990, the highest consumption of carabeef was observed in Asia with an average of 18 kg/head per year. Farmers in the Philippines still depend on the carabao for land preparation and hauling activities.

Figure 4. The carabao (water buffalo)
during field leveling.

Labor productivity is higher in highly mechanized farming cultures like Japan compared to that of Philippine farms which are only 25-65% efficient because they use human labor. There are 52 man-days per hectare of human labor consumed during rice production, including operations from land preparation to drying of paddy. Most of the rice production operations are manually done, except for the use of local power tillers and threshers and imported knapsack sprayers. Locally developed and manufactured machines prevail in the market because of higher adaptability to local conditions. They are easier to repair and maintain because of the availability of spare parts. They require a lower investment cost compared to imported machines. Although manufacturers are still dependent on imported engines, bearings, and other transmission elements, the said local mindset has resulted to wider adoption of local machines, leaving behind imported products.

The Regional Network for Agricultural Machinery (RNAM) classified the Philippines as low mechanization level with only about 50% mechanized production operations (RNAM 2008). Several reasons are: low buying power of farmers, abundance of rural labor and, hence, low wages, very small landholdings per farmer, high cost of machines and government policies not favorable to mechanizing agriculture. The energy consumed associated in fabrication of machinery in agriculture in the world was about 51%. Future studies would be aimed to measure the GHG emission of locally produced machines in the Philippines.

Figure 5. The locally manufactured hand tractor during plowing.

The depletion of fossil energy and the associated environmental impacts are the two main reasons that lead to research exploring the use of alternative energy sources in all sectors. Rice by-products such as rice husk and straw are still considered a type of waste in the Philippines. The impact of climate change by rice cultivation could be reduced through the use of residues, such as rice straw and rice husk. Rice straw which was assumed to be equal to the amount of actual paddy yield is customarily burnt in the field. Farmers are aware of some beneficial recycling processes, such as decomposition and incorporation, paper making, and mushroom production. However the process takes a very long time which hampers the succeeding season planting schedule. Land preparation with rice straw causes difficulties; it requires more energy as well that results to higher operation costs.

Rice straw content	% dry matter
N	0.5-0.8
P	0.16-0.27
K	1.4-2.0
S	0.05-1.0
Si	4-7.0
Silica	5.0

Figure 6. Rice straw left in the field.

Burning was considered to be the most economical and convenient way to dispose of rice straw, but apparently, this practice generates an environmental hazard because of the smoke and particles produced during open field burning. The alternatives for disposing rice straw are limited by its great bulk, slow degradation in the field, and harboring of rice diseases. At any rate, the rice straw must be disposed of in order to make way for the next crop. It is necessary for rice straw to be burned or removed from the field before land preparation as it increases drudgery, energy requirements, and amount of fuel for land preparation. Incorporating it to the soil or just burning it had been the major practices for removing rice straw in the Philippines.

Figure 7. Rice straw burnt in the field.

Open field burning not only removes necessary nutrients for rice production but also creates a health hazard to the populace, environmental degradation, and air pollution. For every one ton of rice straw removed from the field, about 5.8 kg of Nitrogen per hectare, 1.6-2.7 kg P_2O_5 per hectare, 14-20 kg K_2O per hectare, around 0.5-1 kg of Sulfur per hectare and 40-70 kg Silicon per hectare are removed (Doberman 2002). Incorporating 6 t ha^{-1} rice straw to the field increases CH_4 emission by 2.1 times when applied before transplanting and 0.8 times when applied the season before (Yan 2005). Rice straw production in the Philippines was about 10.15M t of fresh straw with an energy potential as renewable fuel of 141.8 PJ (Gadde 2009); however, the energy potential in theory may be different from realizable energy due to its abnormal distribution in the field.

Rice husks are also not properly disposed. Majority of these wastes are dumped in places near and/or in the river banks, side of the roads, hilly areas, and other vacant places. The introduction of rice husk stove and gasification processes did not affect the total amount of rice husk because of very low adoption of the technologies.

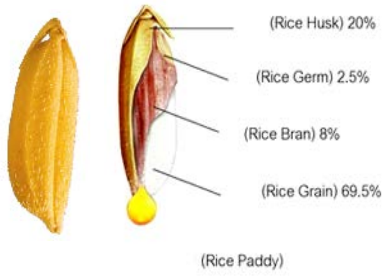


Figure 8. Parts of rice husk.

Rice husks are defined as renewable energy resource which can mitigate greenhouse gas emissions. Converting rice husks into heat, steam, gas, or liquid fuels would benefit those countries that have limited conventional energy resources. The use of rice husks and straw by the energy sector would eliminate local environmental problems, such as rice husk dumping and open field burning. It would also highlight the benefits of GHG reduction to the community and environment. Although, a study showed that the production of biofuel from biomass sources were not able to reduce fossil fuel consumption (Xunmin 2009), the production of bioenergy can cause higher environmental impact than fossil fuel if significant emissions from land use change are not avoided (Cherubini 2009). The present low price of electricity and the lack of sufficient incentives for renewable energy are apparent limitations to draw interest of stakeholders.

This study assessed the energy input-output and GHG emissions carried out during rice cultivation in the Philippines. Possible mitigation processes specifically to reduce environmental impact had been evaluated. Several important rice production activities, such as land preparation with handtractor, leveling with carabao, manual transplanting, irrigation, fertilizer application, harvesting, threshing, rice milling, sun drying, and hauling of produce had been assessed. It also suggests techniques on how to reduce GHG emissions using rice straw and rice husk management.

In Chapter II, the amount of input and output energy of rice production in the Philippines, as well as the output-input ratio, were evaluated using the life cycle thinking. The energy inputs for transplanted and direct-seeded systems considering the mechanization level were comparatively estimated. The environmental impacts of the use of such energy sources as animal and machine power were analysed. Furthermore, rice productivity for each production condition was measured, and activities contributing to the major energy share of rice production were individually identified.

In Chapter III, the GHG emissions from rice cultivation was comprehensively assessed using life cycle inventory analysis. It is a very important procedure to assist stakeholders in rice to identify potential mitigation processes in rice production. Knowing the specific source of emissions will lead to a better understanding on the mitigation measures of its environmental impact and will be a basis in formulating better management practices. Therefore, this paper aims to comprehensively quantify GHG emissions from the current Philippine rice production practices from seedling production up to harvesting and postproduction based on lifecycle inventory analysis.

In Chapter IV, the study tested the performance of the ride-on tillage implement for the hand tractor. It enhanced the capability of locally manufactured handtractors and brought more convenience for operators. It includes evaluation of the field performance in terms of field efficiency, speed of travel, draft force, field capacity, working width, fuel consumption, turning radius, and some related parameters. With the enhanced capacity of local hand tractors, it is a good alternative source of energy during land preparation and hauling of farm inputs and output in place of carabao that emits higher GHG emissions. It also aims to assess users' feedback on the design and acceptability of the ride-on tillage implement during actual utilization in the field. Mitigation effect was also evaluated comparing the conventional handtractor and the ride-on attachment.

In Chapter V, a study was carried out to assess the capability of the locally-designed wind-pump system to irrigate rice production in a rain-fed area in the province of Tarlac, Philippines. The potential of the wind-pump system to irrigate rice was also evaluated using 10-year weather data. The wind-pump system was aimed to become an alternative source of irrigation water for rice fields to reduce the use of fossil fuel in the rain-fed areas. Irrigated rice received 2-3 times water at the field level and is thus a major target for the development of water-saving irrigation technologies (Toung 2005). The mitigation effect of using the wind-pump system was evaluated. It was compared to water pumping during rice cultivation using diesel engine in the dry season.

In Chapter VI, the technical performance of the PhilRice up-draft RH gasification system was examined as a possible alternative source of energy for operation of single-pass rice milling factories in the Philippines. The potential of the up-draft RH gasification systems to power village rice milling factories was also discussed in this study. The mitigation effect of using the gasifier system was also evaluated. Sources of GHG emissions, such as electricity from the grid and disposal of rice husk, were discussed here.

In Chapter VII, the discussion and conclusion describes the importance of the study in rice production in the Philippines. The contribution of assessing the energy input-output in modernization and possible advancement of rice farming are also given importance. The effect of GHG emissions of rice production is also discussed together with the possible mitigation effect that should be done to reduce such environmental impact of rice. The positive effect of introducing more mechanized activities or advanced rice cultivation methods in the Philippines is also discussed in this section. The mitigation effects brought by using the handtractor for land preparation; locally-designed wind-pump system to irrigate rice production during the dry season and simple design up-draft gasifier system for powering a small rice mill; are also discussed here. In conclusion, the overall information delivered by this study regarding improvement of rice production in the Philippines is discussed.

Chapter II

Analysis of Energy for Different Rice Production Systems in the Philippines

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2.1. INTRODUCTION

Rice is a staple food in the Philippines. It is one of the most important crops that supplies more than 45% of the total daily calorific requirements of Filipinos with an average consumption of 118.6 kg per year (BAS 2008). Considering the Philippine population in 2007, this was equivalent to 10.50 million tons rice. Despite the schemes of the government to increase rice production, the country still imports more rice as it did in 2008. This is due to the growth in consumption requirement caused by an increase in population (2.03%) higher than the rice production potential (1.23%) (DA 2008).

Rice is planted and harvested twice in a year in the Philippines. The first season commences in December and finishes in May, and the second season is from June to November. Usually, during the first cropping season, there is no rain, so it is called the dry season. During the dry season, crop irrigation is done by gravitational water and water-impounding facilities, which are managed by the National Irrigation Administration, or by engine-driven pumps to draw water from underground. The second rice cropping season is during the rainy season which is called the wet season. During this period, irrigation typically depends on precipitation throughout the growing season of the year. Tropical typhoons are common natural disasters for crops in the rainy season, while water scarcity is frequently encountered during the dry season.

Rice production in the Philippines is labor intensive. The amount of human labor employed in every stage of rice production is substantially higher than the machines used. The agriculture sector approximately uses 37% of the total labor forces (BAS 2008). There are three basic sources of available power in the Philippines: human labor, animal, and mechanical. The use of these powers usually depends on farm size, cultural practices, soil conditions, and topography. Carabao (water buffalo)-drawn implements, such as ploughs and harrows, are still widely used in a number of places, while power tillers are mainly used in semi-mechanized regions for land preparation and transportation. Axial-flow threshers are commonly used in most of the regions. Manual transplanting of 15-30 day old seedlings is still common. Human labor as the prime source of energy constitutes an average 56.53% of the total energy inputs because of cultural and economic constraints (RNAM 2008).

Recently, technological progress has enabled multi-cropping per unit area. The adoption of modern technologies, such as modern high-yielding rice varieties, appropriate machinery, and fertilizers, has generally enhanced soil productivity. However, these schemes have increased the energy input per unit area. The maximization of energy input requires careful attention, because it leads to an increase in production costs. The utilization of technology should be appropriately evaluated to ensure a high energy-efficient production. Hence, it is very important to evaluate the energy efficiency and productivity of rice production.

The amount of input and output energy and the output-input ratio of rice production in the Philippines were evaluated using Life Cycle thinking. The effects of the impact of the use of such energy sources as animal and machine power were analysed. Finally, rice productivity for each production condition was measured, and activities contributing to the major energy share of rice production were identified.

2.2. MATERIALS AND METHODS

All data used were taken from the results of surveys and experiments by the Philippine Rice Research Institute, the International Rice Research Institute, and the Bureau of Agriculture Statistics conducted in the Philippines from 2006-2008. The inputs, such as human labor, machinery, irrigation, diesel fuel, chemical fertilizers, pesticides, irrigation water, and electricity were considered. In terms of outputs, rice yield and husk were evaluated.

Rice-growing systems were classified on the basis of power sources into manual, semi-mechanized, and mechanized. The energy inputs of each system were evaluated for both growing seasons (wet and dry seasons), as well as irrigation practices (irrigated and rain-fed conditions). The manual system uses man and animal power, except for milling operation. The semi-mechanized system uses locally available machines for direct seeding and transplanting. The mechanized system uses all locally available machines for rice production. All inputs were transformed into energy terms by using the appropriate conversion factors. Statistical analysis was carried out using the factorial experiments, and the results were compared using Tukey`s post test.

2.2.1.Human labor

According to recent United Nations Food and Agriculture Organization (FAO) statistics, while the world has an average per capita consumption of 2,700 cal d^{-1}, the Philippines has an average per capita consumption of 2,280 cal d^{-1} (Allen 2003). Pimentel (1979) notes that 68% of human energy was consumed for 8 hours of work per day, 21% for other activities (6 hours), and 11% for rest (10 hours)**.**

From data on average body weight, age, and daily activities, human labor energy coefficient of 0.65 MJ $person^{-1}\ h^{-1}$ was obtained by the World Health Organization. A similar study was carried out by Samootsakorn (1982),by which a coefficient of 0.65 MJ $person^{-1}\ hr^{-1}$ was derived and used to convert hours of labor into energy. A systematic approach for estimating an adult energy requirement, based on a calculation of the basal metabolic rate, was employed in this paper. The following formula was used to calculate human energy input:

$$\text{HLIE} = \frac{\text{CIF} \times 68\% \text{ x TW}}{8 \text{ h d}^{-1}} \times \text{CF} \qquad (1)$$

Where: HLIE = Human labor input energy, MJ ha^{-1}
CIF = Calorie intake of a Filipino, 2280 cal d^{-1}
CF = Conversion factor, 239,000 calorie MJ^{-1}
TW = Time of work per ha, h ha^{-1}

2.2.2. Irrigation methods

Water is one of the most essential inputs in rice production. Previous studies showed that rice requires a substantial amount of irrigation water more than other cereals. Rice experiments of the International Rice Research Institute (IRRI) in the Philippines proved that water productivity for direct-seeded and transplanted rice was 1.01 and 0.69 kg m^{-3}, respectively (Cabangon 1994; Boumann 2001). This indicates that a hectare of rice having an average yield of 4 tons consumes around 3,960 m^3 of water during one cropping season in direct-seeding and 5,797 m^3 in transplanted farms.

Rice production activities

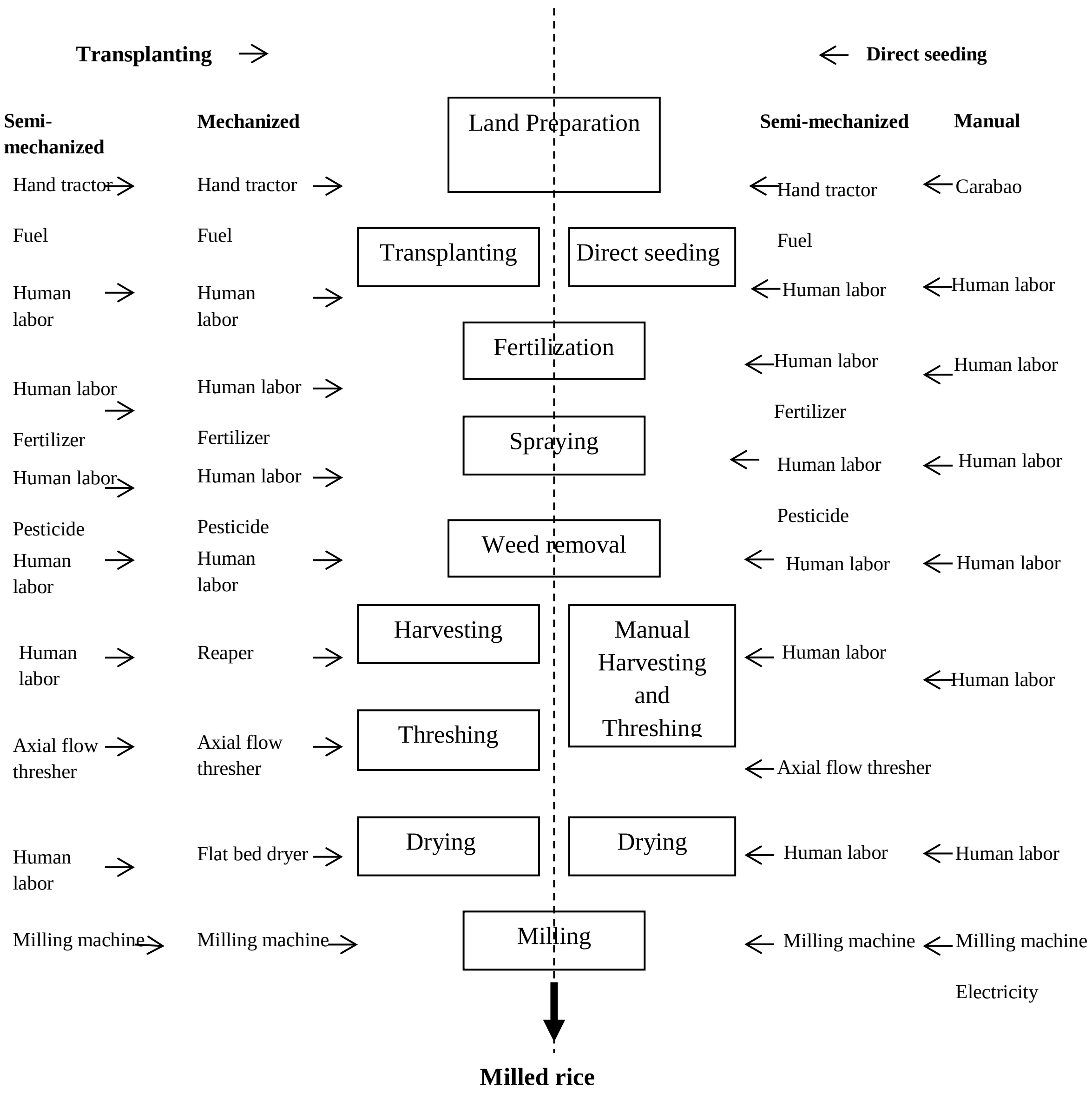


Figure 9. Classification of rice production activities.

Farms with pump-set facilities pump the same amount of water to irrigate the crops during the dry season. Farmers use a 7-12 hp diesel engine coupled to a centrifugal water pump to raise water from underground sources or to pump it from a river. Farmers in the irrigated areas use gravitational irrigation water supplied by dams and water-impounding facilities, which collect water during the rainy season. As irrigation water comes from natural sources during the rainy season, the energy input is normally neglected.

In this paper, the irrigation energy input was computed according to the following formula:

$$IIE = IEE \times VWH \qquad (2)$$

Where: IIE = Irrigation input energy, MJ ha^{-1}
IEE = Irrigation energy equivalent per unit water used (0.615 MJ m^{-3})
VWH= Volume of water required per ha, m^3 ha^{-1}

Table 2. Energy equivalents with their corresponding authors.

	Energy equivalent used, MJ/unit	Authors
Human labor	0.8 MJ/h	(Pimentel 1992, Umar 2003, Samootsakorn 1982)
Machinery	109 MJ/kg	(Pimentel 1992, Kalk 1996, Umar 2003)
Fuel	47.78 MJ/l	(Umar 2003, Safa 2002)
Nitrogen	80 MJ/kg N	(Pimentel 1992, Tippayawong 2003, Chamsing 2008)
Phosphorus	14 MJ/kg P	(Pimentel 1992, Esengun2006, Samootsakorn 1982)
Potassium	9 MJ/kg K	(Pimentel 1992, Esengun 2006,Samootsakorn 1982)
Seeds	16.75 MJ/kg	(Pimentel 1979, Rutger 1980, Intravichai 1998, Saunders 1979)
Paddy yield	12.36 MJ/kg	(Pimentel 1979)
Irrigation	0.615 MJ/m3 water	(Pimentel 1979, Ozkan2003, Esengun 2006)
Insecticide	101.2 MJ/kg insecticide	(Pimentel 1992, Esengun 2006)
Herbicide	238 MJ/kg herbicide	(Pimentel 1979, Esengun 2006, Hulsbergen 2001)
Transportation	0.22 MJ/kg rice	(Tippayawong2003)
Drying	4.6 MJ/kg water	(Thompson 1981)
Electricity	12.36 MJ/kWh	(Pimentel 1992, Esengun 2006)

2.2.3. Fuel

The majority of engines used in rice production are diesel. When burned, diesel typically releases approximately 38.6 MJ L^{-1} when complete burning has occurred (Safa 2002; Allen 2003; ASTM2008). However, a higher diesel energy coefficient 47.78 MJ L^{-1} was reported by Pimentel (1979), Esengun (2006), and Umar (2003). The energy input of diesel fuel was calculated by the following formula:

$$FIE = DEC \times AFC \qquad (3)$$

Where: FIE = Fuel input energy, MJ ha^{-1}
DEC = Diesel energy coefficient, 47.78 MJ L^{-1}

AFC = Amount of fuel consumed, $l\ ha^{-1}$

2.2.4. Machinery

The total lifetime energy cost of machinery is estimated by aggregating the costs of raw materials, fabrication, spare parts, and maintenance. Pimentel (1992) argued that the average demand energy for equipment is equal to 109 MJ kg^{-1}. This value was similarly obtained from steel production energy 62.8 MJ kg^{-1}, fabrication, and assembly energy 8.4 MJ kg^{-1}, and repair and maintenance energy 37.7 MJ kg^{-1} (Doering 1980; Fluck1985).

The main machinery considered in this paper were two-wheel tractors (commonly called a power tiller) which were used for land preparation, reapers, axial–flow rice threshers, and medium-size rice mills. The machinery energy input was calculated by the following formula:

$$MIE = \frac{MEC \times MW}{LM \times EFC} \qquad (4)$$

Where: MIE = Machinery input energy, MJ ha^{-1}
MEC = Machine energy coefficient, 109 MJ kg^{-1}
MW = Machine weight, kg
LM = Life of machine, 9600 h
EFC = Effective Field Capacity, ha h^{-1}

2.2.5. Carabao and its manure

Rice production activities such as land preparation and transportation still depend on carabao power, especially in areas under deep mud, rain-fed condition, and in places where the machines are not available. The Philippine carabao weighs around 700-800 kg and has an estimated energy input of 20,000 kcal d^{-1} or 3.49 MJ h^{-1}, which is similar to that of oxen (Pimentel 1979).

Using this assumption, the following formula was used to compute the energy input of a carabao:

$$CIE = CEC \times DW \qquad (5)$$

Where: CIE = Carabao Input Energy, MJ ha^{-1}
CEC = Carabao Energy Coefficient, 3.49 MJ h^{-1}
DW = Duration of work, h ha^{-1}

2.2.6. Pesticides

There are two main ways to eradicate weeds during rice production: chemically, by using herbicides and manually by labor. The application of herbicides is mostly used in irrigated areas because of the massive effect on various kinds of weeds, while manual weeding prevails in non-irrigated areas of the country.

According to Esengun *et al.* (2006), the production of insecticides and herbicides consume approximately 101.2 MJ L^{-1} and 238 MJ L^{-1}, respectively. Almost similar values were suggested by Pimentel (1992), Anon (2004), and Hulsbergen *et al.*(2001). Therefore, this amount of pesticide energy input is adopted in this paper.

The energy input of pesticides was computed using the following formula:

$$PIE = PEC \times APA \tag{6}$$

Where: PIE = Pesticide input energy, MJ ha^{-1}
PEC = Pesticide energy coefficient: 101.2 MJ kg^{-1} for insecticide or 238 MJ kg^{-1} for herbicide
APA = Amount of pesticide applied, kg ha^{-1}

2.2.7. Fertilizers

Inorganic fertilizers are widely used in the Philippines. Manual application of fertilizers is the most common. Rice experts recommend the multi-split application method, such as: basal (1/3 N, 100% P, and 50-100% K), topdressing during the vegetative (1/3 N), and reproductive stages (1/3 N, 50% K) to keep the nutrient requirement throughout the life of the plants (IRRI2008; PhilRice 2008). In this paper, only three major nutrients—N, P and K—were considered.

Energy requirements for the production and transportation of commercial chemical fertilizers are 80 MJ kg^{-1}, 14 MJ kg^{-1} and 9 MJ kg^{-1} for N as anhydrous ammonia, P as normal super phosphate (P_2O_5), and K as muriate of potash (K_2O), respectively (Samootsakorn, 1982). Approximately the same amount of energy for N is also estimated by Pimentel (1992), Chamsing *et al.* (2008) and Tippayawong *et al.* (2003). Regarding P and K, a similar result was obtained by Pimentel (1979), Esengun *et al*. (2006).

The energy input of nutrients N, P and K was calculated using the formula:

$$NIE = NEC \times ANA \tag{7}$$

Where: NIE = Nutrient input energy, MJ ha^{-1}
NEC = Nutrient energy coefficient, 80 MJ kg^{-1} for N 14 MJkg^{-1} for P or 9 MJ kg^{-1} for K
ANA = Amount of nutrient applied, kg ha^{-1}

2.2.8. Transportation

In this study, transportation of rice from the farm to the farmer's house (2-10 km by hand tractor), and from the farmer's house to the local rice mill (5-50 km by 10-wheeler truck) was considered. Samootsakorn (1982) found that each kilogram of rice transportation using a 10-wheeler truck (125 horse power, 8 tons, 445 km distance) resulted in a coefficient of 0.22 MJ kg^{-1}. The same amount is reported by Tippayawong *et al. (*2003).

Similar estimates were applied in this paper; however, the ratio of distance (67/445) is used. Here, 67 km means average round trip distance (50 × 2/3 × 2 = 67 km). To compute the energy input of transportation, the following formula was adopted:

$$TIE = TEC \times \text{Conversion factor} \times RYP \qquad (8)$$

Where: TIE = Transportation input energy, MJ ha^{-1}

Conversion factor = 67/445

TEC = Transportation energy coefficient, 0.22 MJ kg^{-1} for paddy

RYP = Rice yield per ha, kg ha^{-1}

2.2.9. Drying of paddy

Due to abundant solar energy in the tropics, the drying of rice paddy is commonly done on multipurpose sidewalks. Rice is evenly distributed over the sidewalk and is frequently turned manually by human labor.

Thompson (1981) suggested that 2,000 Btu of energy is required to remove one pound of water (or 4.6 MJ kg^{-1} water) from the grain. The amount of moisture to be removed from the grain (from 26% MC to 14% MC) during drying is about 140 kg ton^{-1}paddy. Moreover, Leniger (1975) estimated that 4-10 MJ kg^{-1} of evaporated water is required when using hot air dryers. Based on these estimations, the energy input during rice drying was computed as follows:

$$DPIE = DPEC \times 140\text{ kg } H_2O\text{ ton}^{-1}\text{ rice yield} \times RYP \qquad (9)$$

Where: DPIE = Input energy of paddy drying, MJ ha^{-1}

DPEC = Energy coefficient for paddy drying, 4.6 MJ kg^{-1} water removed

RYP = Rice yield, ton ha^{-1}

2.2.10. Electricity

Electricity is the usual source of energy used for milling. Although four-cylinder diesel engines were also used occasionally, the electricity was considered as the major power source during milling in this study. Leniger (1975) found that 43 kWh (154 MJ) energy was required to mill 1 ton of rice using an electric motor. So, electricity input energy was computed by multiplying the given energy modulus to the final weight of rice after drying.

$$EIE = EEC \times \text{weight of dry/weight of fresh} \times RYP \qquad (10)$$

Where: EIE = Electricity input energy, MJ ha^{-1}
Weight of dry/weight of fresh =0.86
EEC = Electricity energy coefficient, 154 MJ ton^{-1} dried rice
RYP = Rice yield, ton ha^{-1}

2.2.11. Rice seed energy

The amount of rice seeds used per hectare is dictated by the growing method. Transplanting of rice includes the raising of seedlings over 15-30 days on a seedbed and manually pulling them a day before or during the transplanting schedule. On the average, a farmer uses 40-80 kg of seeds per hectare. Direct seeding by a drum seeder put the seeds in rows and consumes 80-120 kg of seeds per hectare (PhilRice 2008), while manually spread direct-seeding uses up to 150 kg of seeds per hectare.

The energy equivalent for rice seeds is 16.74 MJ kg^{-1}(Pimentel 1992). Similar values were obtained and used by Rutger (1980), Intaravichai (1998), and Sahr *et al*. (2004).

The rice seed energy input was calculated as follows:

$$RSEI = RSEC \times RYH \qquad (11)$$

Where: RSEI = Rice seed energy input, MJ ha^{-1}
RSEC = Rice seed energy coefficient, 16.75 MJ kg^{-1} of seeds
RYH = Rice seed used per ha, kg ha^{-1}

2.2.12. Paddy yield energy output

The rice yield data for the year 2006 were obtained from Philippine Rice Research Institute. According to the data, the rice yield was almost higher in dry season as compared to wet season. As available data differentiate only between irrigated and rain fed yields during dry and wet seasons, they are adopted in this paper on a per season basis. In the calculations, the energy equivalent of 12.36 MJ kg^{-1} suggested by Pimentel (1979) was adopted.

The following formula was used to calculate the rice yield energy output:

$$RYEO = RYEC \times RYH \qquad (12)$$

Where: RYEO = Rice yield energy output, MJ ha^{-1}
RYEC = Rice yield energy coefficient, 12.36 MJ kg^{-1}
RYH = Rice yield per ha, kg ha^{-1}

2.3. RESULTS AND DISCUSSIONS

2.3.1. Wet Season

Result shows that during the wet season, the total energy input of the mechanized system for both irrigated (13,921 MJ kg^{-1}) and rain fed (11,969 MJ ha^{-1}) systems were the highest among rice growing systems. This result confirms the fact that the utilization of modern technologies to increase system productivity leads to an increase in energy input during rice production as well. Highest energy input came from fertilizer most especially by Nitrogen followed by seed energy input.

Table 3. 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

The manual system possesses the lowest total energy input, which results in the highest output-input ratio among the systems if a similar yield is attained. The high output-input ratio of the manual system reveals that man/animal energy-based production would lead to a higher productivity than a man/machine-based one but had lower actual yield.

Human labor energy input obviously became higher in the manual production system but fertilizer and seeds energy contributed the highest input. However, the semi-mechanized system that applied direct seeding had a smaller energy input (318 MJ ha^{-1}) compared to transplanting (semi-mechanized, 358 MJha^{-1} and mechanized, 321 MJha^{-1}) because a considerable amount of human labor was engaged during transplanting (72.7 man-hha^{-1}), while direct seeding used only 20 man-hha^{-1}.

Seed energy input was apparently high for direct seeding, especially for manual system (2,512 MJ ha^{-1}), because farmers put to use more seeds to compete against weeds and diseases during the early stage of rice growth. On the other hand, transplanting requires less seed input. Energy input of seeds contributed 8%, 9.7%, 15.8%, and 23.9% of total energy inputs for mechanized, transplanted, and direct seeding in semi-mechanized, and manual, respectively. The decreasing trend of energy input from the mechanized to the manual system signified the decreasing efficiency of seedlings at the early stage of rice growth.

The average output-input ratios (excluding rice husk energy output) of the wet season (3.9) and dry season (3.6) rice production systems in the Philippines were considerably higher than that of Bangladesh (2.8) (Iqbal, 2007), Japan (2.8) (Pimentel 1992), and the United States (2.2). The higher output-input ratio in the Philippines indicated that the utilization of farm inputs were lower and so, even if the energy output of the developed countries were almost doubled, the resulting ratio became higher. These output-input ratios are further increased to around 113% if the rice husk energy output is considered.

The energy input of N contributed approximately 50% of the total energy input in all systems. High-yielding rice varieties require a significant amount of N (even higher in other countries) to replenish the soil nutrients depleted due to intensive rice production. Fuel energy input accounted for an average of 23% of the total energy input in the mechanized systems.

It shows that N occupied more than half (55.1%) or around 58% (when all fertilizers are included) of the total energy input into the manual system. These energy inputs provided higher yield potentials, leading to more productive rice systems compared to the conventional ones. In the manual system, when fertilizer was not applied, the seed become the dominant energy input, hence, the total energy input becomes 59%, less than that of intensified agriculture. Drying was done by a mechanical dryer in mechanized system that utilized fuel, while the other systems utilized solar drying.

The results showed that nitrogen accounts for the highest amount of energy input in this system as well. Fuel, drying, and seed energy inputs also made a considerable contribution to total energy input, but these technologies reduced the cultivation period and increased the possibility of a higher yield potential as compared to traditional systems. The increased amount of fossil fuel energy input was apparent in mechanized farming.

2.3.2. Dry season

The results showed the list of energy inputs and outputs for dry season. Results indicated that the mechanized systems had the highest total energy input for both farms with pump facilities (13,305 MJ ha^{-1}) and farms with canal facilities (13,211 MJ ha^{-1}) compared to the manual system (10,483 MJ ha^{-1} for canalled and 10,413 MJ ha^{-1} for pumped).

Table 4. 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

Although all modern technologies have been applied to the mechanized system, it still possesses a higher human labor input as compared to semi-mechanized direct seeding. The manual system was fully based on human energy (694 MJ ha^{-1}).

Channelling practices consumed N more than pumping did, probably because farmers practicing channelling were confident about producing a higher output. This was mainly due to the availability of irrigation water, which does not require the energy input of pump and engine. However, pumping uses a substantial amount of irrigation water energy input from machines and fuel (2,435 MJ ha^{-1} for direct seeding and 3,565 MJ ha^{-1} for transplanting) during the dry season. When water is pumped, the energy output-input ratios were decreased to 36%, 48%, 40%, and 39%, for direct seeding semi-mechanized, transplanted semi-mechanized, manual and mechanized systems, respectively. In this study, irrigation water for channelling was neglected because it is supplied by dam and water-impounding ponds, which collect water naturally during the rainy season. The energy output-input ratio of pumping (4.83-6.17) was significantly smaller than that of channelling (8.25-10.39), because pumping produced a smaller rice energy output.

Herbicide energy input (238 MJ ha^{-1}) was the same in all systems except for the manual, which purely employed hand tools (240 man-h ha^{-1}) for weed control. The output-input ratio of the manual system was the highest. This signified that using a man/animal-energy system leads to a higher output-input ratio as compared to man/machine-based systems taking into account that the production output is similar for both systems in one climatic condition.

Result shows the energy input for the channelling system in descending order for the dry season. N was the highest contributor to the total energy input in all the systems. The table indicates that fertilizers were the primary factors for attaining the higher yield. The semi-mechanized systems for both direct seeding and transplanting methods followed similar patterns of energy input.

The mechanized system had almost the same characteristics as the semi-mechanized one, except for drying energy input (17.3 MJ ha^{-1}), which was second after N energy input (43.3 MJ ha^{-1}). Drying energy input was considered only for the mechanized system, due to its utilization of flatbed dryer during paddy drying. Regarding the manual system, similar to the above-described systems, N energy input (54.6%) was the highest contributor to the total energy input. This was followed by seeds (23.97%), human labor (6.6%), electricity (5.2%), machines/animals (4.5%), phosphorus 2.4%), transportation (1.3%), potassium (0.85%), and insecticides (0.5%).

Due to water scarcity during the dry season, water pumping with engine was a must which contribute a substantial amount to input energy (30%) including the increase in fuel (17%). This resulted to the reduction of energy ratio to about half. A higher energy ratio does not mean attaining a favourable rice production but indicated lower energy input which usually resulted to lower yield. As a fact, Japan and US who are enjoying a very high yield had lower energy ratio compared to this study because of higher energy input on machine and fuel.

2.4 CONCLUSION

Results showed that utilization of inputs such as fertilizers, high-yielding rice variety, pesticides, and farm machinery increased the total energy input of rice production in the Philippines. The output-input ratio became lower because the energy input substantially increases during mechanized farming. The energy input of irrigation needs to be reduced so the wind-pump system was introduced to be an alternative for water pumping to reduce fossil fuel during dry season.

The energy input of electricity used during rice milling is also needed to be reduced because of its apparently high value. The potential of the RH up-draft gasifier system could be evaluated to generate electricity for rice mills and to ameliorate the GHG emissions cause by disposal of RH.

Chapter III

Greenhouse Gas Emissions of Rice Production Systems in the Philippines Based on Life Cycle Inventory Analysis

3.1. INTRODUCTION

Climate change, as an outcome of human activities, has been described as the biggest threat to humanity, which can be stabilized through reducing greenhouse gas (GHG) emissions responsible for temperature increases. The Philippines will probably be one of the regions to be most affected by climate change as it has been severely experiencing natural calamities, such as floods, typhoons, and droughts. These phenomena will become more devastating in the tropics than in other climatic zones (UNFCC 1999). With the effects already being felt, immediate action to protect the environment is needed.

Agriculture, especially rice cultivation, is very important to the Philippine economy. It comprises around 13% of GDP and employs 35% (12.9 million) of the total labor force (FAOSTAT 2012). The Philippines is among the world's top 10 rice producers. Rice cultivation occupies 34% of its total agricultural area of 12.64 million hectares, the largest area of any crop (CountrySTAT 2007). Despite attempts to self-sustainability in rice, production in the country still struggles to meet the demands of the rapidly growing population (2% annual growth) as it imported1.5million tons of rice in 2012 (IRRI 2012). To increase rice production, cultivation needs to be intensified. This situation would inevitably increase the use of fertilizer, agro-chemicals, fuel, and other production inputs, and so GHG emissions also increase(FAO 2014; Maraseni 2009).The Philippine national inventory of GHG emissions in agricultural activities has been submitted to the UNFCCC using 1994 data (UNFCC 1999). It is important to quantify the GHG emissions from rice production, which is the largest production in the Philippines based on national statistics.

GHG emissions from rice production have been estimated based on lifecycle inventory analysis in Japan (Hokazono 2012; Harada 2007; NIAES 2003) and other countries, such as India (Pathak 2005), Italy (Blengini 2009), and Thailand (Kasmaprapruet 2009). In terms of cultivation environments and agricultural practices, rice production in the Philippines is different from those in temperate countries such as Japan. In the Philippines, most rice fields are cultivated twice a year for rice. A large proportion of the field remains under rain-fed conditions. Methane, one of the main GHGs emitted through anaerobic decomposition of organic matter in submerged rice fields, is emitted less in rain-fed rice fields than in irrigated ones (Wassmann 1994). Although mechanization of rice production is becoming the norm, the carabao, a domesticated water buffalo, is still widely used as draft animal for plowing and harrowing. The carabao is a ruminant and emits methane through enteric fermentation. Rice straw burning is the most popular rice straw management practice in the Philippines (Lasco 2002). Burning rice straw in the field is proven to be the fastest, most economical, and easiest way of helping eradicate diseases but may cause environmental and health hazards.

Assessing GHG emissions from rice cultivation is vital to help identify potential mitigation processes. Knowing the key sources of emissions will help in understanding the mitigation measures and pave a way to formulate better management practices. Therefore, this paper aims to comprehensively quantify GHG emissions from Philippine rice production practices from land preparation to harvesting based on lifecycle inventory analysis. Possible mitigation technologies were evaluated to reduce GHG emissions related to rice production.

3.2. MATERIALS AND METHODS

3.2.1. Rice production system in Philippines

In the Philippines, the production area can be classified into irrigated or rain-fed areas. Rice is usually cultivated twice a year. During dry season, however, cultivation area is limited, especially in rain-fed areas. Table 5 shows the irrigated and rain-fed rice fields and yields in 2006-2007 (CountrySTAT 2007). The following analyses were made for the areas shown in the table.

Table 5. Area of rice cultivation and yield in the Philippines.[a]

Water management	**Season**[b]	**Area (ha)**	**Yield (t ha^{-1})**	
Irrigated	Dry	1,336,045	4.18	4.21
	Wet	1,580,967	4.23	
Rain-fed	Dry	467,935	2.46	2.93
	Wet	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-April, Wet season: May-November

3.2.2. System boundaries

This study exclusively covered the GHG emission of all rice production activities in the farm. The system boundary included seedbed preparation, land preparation, transplanting, crop care, harvesting, and threshing (Figure 10). In the Philippines, harvested rice is usually preserved as grain and milled immediately before consumption. Milling process was therefore not included in this study.

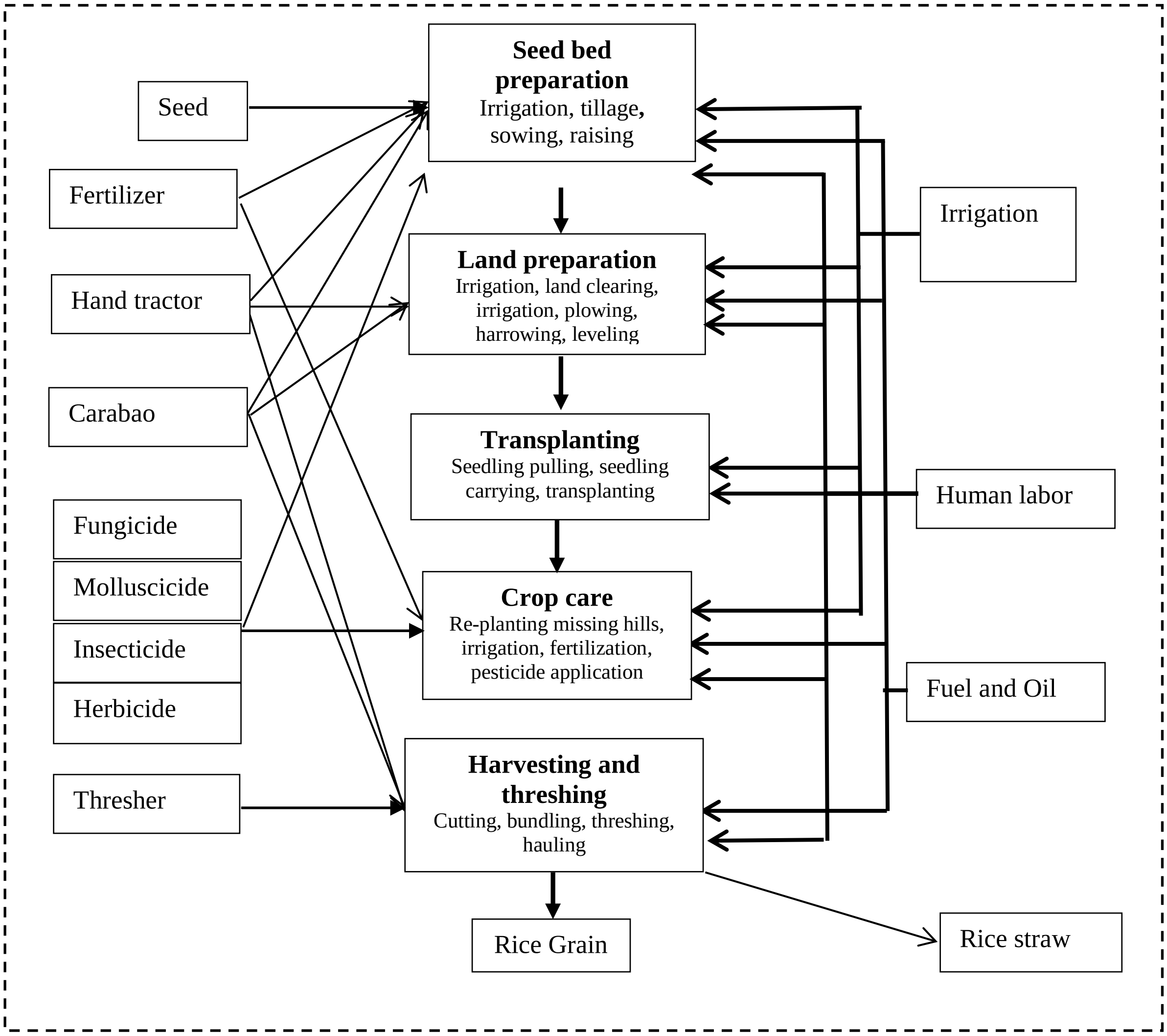


Figure 10. System boundary of rice production in the present study.

3.2.3. GHG emissions

The GHG emissions from farming inputs (fertilizer, pesticide, fuel for machines, and irrigation) and carabao; and methane (CH_4) and nitrous oxide (N_2O) emissions from soil were estimated based on IPCC guidelines (2006). Upon estimation, difference in rice straw management (burning or incorporation) was also taken into account. Activity data and GHG emission factors of the above items were gathered from the Philippine surveys of 2006-2007 (CountrySTAT 2007) and other references (FAOSTAT 2012).GWP of CH_4 and N_2O were 21 and 310, respectively. The total GHG emission of rice production in the Philippines was calculated in terms of global warming potential (GWP) using the following formula:

$$GHG_r = \sum(GHG_{rc} + GHG_f + GHG_{cm} + GHG_{fuel} + GHG_{rs} + GHG_p + GHG_{mach})$$

Where: $GHG_{r\,=}$ the total GHG emission of rice production system in the Philippines, kg CO_2 eq.
$GHG_{rc\,=}$ the GHG emission during rice cultivation, kg CO_2 eq.
$GHG_{f\,=}$ the GHG emission of fertilizer production and applied, kg CO_2 eq.
$GHG_{cm\,=}$ the GHG emission of carabao enteric fermentation and its manure, kg CO_2 eq.
$GHG_{fuel\,=}$ the GHG emission of fuel used for machines, kg CO_2 eq.
$GHG_{rs\,=}$ the GHG emission of rice straw management, kg CO_2 eq.
$GHG_{P\,=}$ the GHG emission of pesticides, kg CO_2 eq.
GHG_{mach}= the GHG emission of machine, kg CO_2 eq.

3.2.3.1. GHG emission from soil during rice cultivation.

Methane (CH_4) emission from soil was estimated by using the emission factors for irrigated and rain-fed areas according to IPCC guidelines (2006). Irrigated areas were considered to be water flooded from land preparation to before harvesting time, while rain-fed areas depended on rainfall and was dry for sometimes. Rice straw management is crucial in terms of CH_4 emission. In the Philippines, 95% of rice straw was burnt in the field after harvest (Gadde 2009) because burning is considered the fastest and most economical way of disposal. On the other hand, when rice straw is not burnt but incorporated into soil, it increases CH_4 emission in the next cultivation period. The present study assumed that 95% of straw is burnt in the rice fields irrespective of water management.

The adjusted emission factors were 1.3 kg $CH_4d^{-1}ha^{-1}$ for irrigated and 0.35 kg $CH_4d^{-1}ha^{-1}$ when rice straw is not incorporated into soil, and 2.08 kg $CH_4d^{-1}ha^{-1}$ for irrigated and 0.51 kg $CH_4d^{-1}ha^{-1}$ for rain-fed when rice straw is incorporated into soil. The CH_4 emissions were computed by multiplying the adjusted emission coefficients to total harvested area for 120 days for a cropping period (Yoshida 1981). The GHG emissions of irrigated and rain-fed areas were separately computed and summed up for national level. Although rice cultivation practices vary among the regions of the country, computations were based on actual rain-fed and irrigated rice areas only. All other conditions were assumed to be similar for all areas. The following formula was used:

$$GHG_{rc} = \sum(((EF_i \text{ x } A_i \text{x } 0.95) + (EF_{rf} \text{ x } A_{rf} \text{x } 0.95)) + ((EF_{i+s} \text{ x } A_i \text{x } 0.05) + (EF_{rf+s} \text{ x } A_{rf} \text{x } 0.05))) \text{ x } t \text{ x } 21$$

Where: GHG_{rc} = the total GHG emission from soil during rice cultivation, kg CO_2 eq.
EF_i and EF_{rf} = Emission factors of irrigated and rain-fed rice without rice straw, respectively.
EF_{i+s} and EF_{rf+s} = Emission factors of CH4 from irrigated and rain-fed rice, respectively.
t = cultivation period of rice, 120 days per season
A_i and A_{rf} = Area of rice field under irrigated and rain-fed, respectively, ha

3.2.3.2. GHG emissions from fertilizers

Although fertilizers can be organic (decomposed organic matter)or inorganic (made of simple, inorganic chemicals or minerals), only inorganic fertilizers that supply nitrogen, phosphorus, and potassium were included in this paper. In 2005 alone, approximately 978,000 tons of fertilizers were used for Philippine agriculture. Around 60% of the total fertilizers had been utilized for rice and corn production (Wassmann 1994). The emission factors for production of chemical fertilizers were estimated with each component of N, P, and K, respectively (Lal 2004). The amount of nitrogen, phosphorus, and potassium were separately calculated from the four commonly applied fertilizers to rice in the Philippines: urea (46-0-0), ammonium sulfate (21-0-0), ammonium phosphate (16-20-0), and complete (14-14-14) fertilizers. Furthermore, N_2O emissions of N fertilizers applied to paddy soil were computed by multiplying the N_2O coefficient of the nitrogen content to the amount of nitrogen applied in rice production and the rice field area (IPCC 2006). The following formula was used:

$$GHG_f = \sum((EF_a \text{ x } AF) \text{ x } 310 + (EF_p \text{ x } AF))$$

Where: GHG_f = the GHG emission of fertilizer applied, kg CO_2 eq.
EF_a and EF_p = Emission factor of N_2O due to N fertilizer application and production of NPK fertilizers, respectively
AF = Amount of fertilizer applied to rice production, kg

3.2.3.3. GHG emission from pesticides

Pesticides include insecticides, herbicides, fungicides, and various substances used to control pests. Since the national survey presented the total amount of pesticides as a whole (herbicide and insecticide), emission factor for production and application of pesticides was assumed as the average of the insecticide and herbicide at 5.5kg CO_2 kg^{-1}(Lal 2004). The pesticide emission was computed by multiplying the actual amount of pesticide used in rice production to the specific emission factor and total harvested area. The following formula was used:

$$GHG_{ac} = EF_{ac} \text{ x } A_{ac}$$

Where: GHG_{ac}= the GHG emission of pesticides, kg CO_2 eq.
EF_{ac} = Emission factor of pesticides, g CO_2 kg^{-1}
A_{ac}= Amount of pesticides used in rice production, kg

3.2.3.4 GHG emission from carabao (working water buffalo)

In the Philippines, many rice growing areas still depended on carabao power for land preparation and hauling of inputs and paddy during harvesting. It is a very important substitute to expensive machines not appropriate in specific field conditions such as deep mud and inaccessible farms. Carabaos are specifically raised to primarily serve as draft animals[1] for almost the entire rice production areas. Therefore, GHG emissions from carabaos were included in rice production. Carabao, along with cattle and sheep among others, are ruminant herbivores that can digest plant-based food and emit CH4 through enteric fermentation. Carabao manure is also a source of CH4 emission.

In 2007, the carabaos in the Philippines were counted at 3.36 million [4]. Based on national statistics, the rental cost of animals was 25% of machine rental (CountrySTAT 2007). It was assumed that the rental costs were reflected by dependency of carabao or machine in rice farmers and that 25% of the land was solely managed by carabao. A native Philippine carabao could plow at the speed of 0.5ms-1 and area of 2,500m^2 in 8 hours (Garillo 1987), indicating that a carabao can manage two ha of land by two harrowing and one leveling within the 20-day land preparation period in every crop-growing season. Based on the above information, the number of carabaos involved in rice production was estimated. The following formula was used to compute for the GHG emission of carabaos:

$$GHG_{cm} = \sum((EF_c \text{ x } C) + (EF_m \text{ x } C)) \text{ x } 120 \text{ days/crop x } 21$$

Where: GHG_{cm} = the GHG emission of carabao enteric fermentation and its manure, kg CO_2 eq.
EF_c and EF_m = Emission factor of carabao enteric and its manure, respectively.
C = number of carabao involved in rice production

3.2.3.5. GHG emission of diesel fuel used by machinery

Data on farmer's expenditure for fuel in rice production is only available. In this paper, all fuels used for water pumping, land preparation, and threshing were considered as diesel. Its amount was estimated from the expenditures in the national survey conducted in 2006. The following formula was used in the computation:

$$GHG_{fuel} = EF_d \text{ x } A_d \text{ x NCV}$$

Where: GHG_{fuel}= the GHG emission of fuel used by machinery, kg CO_2 eq.
EF_d = Emission factor of diesel oil, tC TJ^{-1}
A_d = Amount of diesel used by machinery, L ha^{-1}
NVC = Net calorific Value, TJ t^{-1}
In 2006, the price of diesel oil was 34.46 Philippine Pesos.

3.2.3.6. GHG emission for manufacturing farm machineries

This paper considered the two-wheeled hand tractor (commonly called as power tiller) weighing 286kg including plow and harrow accessories for land preparation, and it became 500kg if its trailer was included during hauling of farm inputs and paddy harvest (Bautista 2010). Results of national survey in 2006 showed that 6.6 days are needed to plow and prepare a hectare of rice field before transplanting and 1.6 days to haul farm inputs and yield using a handtractor. Machineries for land preparation and hauling of farm inputs were estimated at 75% compared to that of carabao.

The most commonly used axial flow thresher weighing around 505kg having a capacity of 2-3t h^{-1} was also considered in this study. The thresher needed 2.9 days to thresh a hectare of rice field. GHG emission factor 12.8kg CO_2 eq. kg^{-1} of farm machinery (Maraseni 2009) was used for both power tiller and axial flow thresher since local data were not available. A life span of the machines was considered to be 12,000h. To calculate the GHG emission of power tiller and axial flow thresher, the following formula was used:

$$GHG_{mach} = \sum((EF_{mc} \text{ x } W_{mc \text{ x}} T_u)/(LS))$$

Where: GHG_{mach}= the GHG emission of machine, kg CO_2 eq.
EF_{mc} = Emission factor of farm machinery, kg CO_2 kg^{-1}
W_{mc}= Weight of machine, kg

T_u= Total time of operation, h ha^{-1}
LS = Life span of machine, h

3.2.3.7. GHG emissions due to burning of rice straw

After harvest, rice straw burning in field may be the fastest and most economical way of disposal. It was found out that 95% of rice straw in the Philippines was burnt in the field (Gadde 2009)which was also considered in this study. The weight of rice straw left in the field was approximately similar to that of the grain yield so this study adopted the paddy yield of national survey in 2007 to represent the weight of rice straw. Burning of rice straw emits approximately 2.7g CH_4kg^{-1} straw (IPCC 2006). The following formula was used to calculate the emission of rice straw burning, by adopting combustion factor,0.8, for agricultural residues (IPCC 2006).

$$GHG_{sm}= \sum((EF_{CH4} \text{ x } SA_{sm} \text{ x } 0.8 \text{ x}0\ .95 \text{ x } 21)$$

Where: GHG_{sm}= the GHG emission during rice straw burning, kg CO_2 eq.
EF_{CH4} = Emission factor during straw burning, kg CH_4 kg^{-1}
SA_{sm} = Amount of straw burnt, kg

Table 6. Sources of activity data and emission factors.

	Sources of GHG emissions during rice production	**Data and sources**	**Emission factors**	**Source**
Non-CO_2 GHG	Irrigated rice cultivation w/ straw amended after harvest		2.08 kg CH_4d^{-1} ha^{-1}	IPCC 2006
	Rain-fed rice cultivation w/ straw amended after harvest		0.51kg CH_4d^{-1} ha^{-1}	IPCC 2006
	Irrigated rice cultivation w/o straw amended		1.3 kg CH_4d^{-1} ha^{-1}	IPCC 2006
	Rain-fed rice cultivation w/o straw amended ^{d}		0.35 kg CH_4d^{-1} ha^{-1}	IPCC 2006
	Rice straw burning		2.7 gCH_4kg^{-1}	IPCC 2006
	Fertilizer application, N	248kgNha^{-1} (Phil Statistic 2006)	0.003 kgN_2O-N kgN^{-1}	IPCC 2006
	Carabao enteric emission	364,627 head (irrigated) & 169,485 head (rain-fed)(Phil Statistic 2006)	55 kg CH_4yr^{-1} $head^{-1}$	IPCC 2006
	Carabao manure emission	364,627 head (irrigated) & 169,485 head (rain-fed)(Phil Statistic 2006)	3 kg $CH_4yr^{-1}head^{-1}$	IPCC 2006

CO_2 from fossil energy	Fertilizer production, N	248 $kgNha^{-1}$ (Phil Statistic 2006)	1.3 $kgCO_2$ eq. kgN^{-1}	Pathak 2007
	Fertilizer production, P	66 kg Pha^{-1} (Phil Statistic 2006)	0.2 $kgCO_2$ eq. kgP^{-1}	Pathak 2007
	Fertilizer production, K	39 $kgKha^{-1}$ (Phil Statistic 2006)	0.2 $kgCO_2$ eq. kg K^{-1}	Pathak 2007
	Pesticide (assumed average of insecticide and herbicide)	2.3L (irrigated), 2.1L (rain-fed)(Phil Stat 2006)	5.5 $kgCO_2$eq. kg^{-1}	Lal 2004
	Diesel oil	34 L irrigated, 12 L rain-fed (Phil Statistic 2006)	20.2 tC TJ^{-1}	IPCC 2006
	Manufacturing of farm machinery, (handtractor and axial flow thresher)	286 kg handtractor&acc.,500kg handtractor w/ trailer, 505kg thresher (Bautista 2010) 6.62 day land prep, 1.62 day hauling, 2.93 days threshing, (Phil Stat 2006) Lifespan12000h (Maraseni 2004)	12.8 kg CO_2kg^{-1}	Maraseni 2009

3.3. RESULTS AND DISCUSSIONS

3.3.1 GHG emission of rice production in the Philippines

Results showed that the total GHG emission of rice production in the Philippines was 13.3 Tg CO_2 eq. yr^{-1}, comprising of 3,920kg CO_2 eq. ha^{-1} $crop^{-1}$ in irrigated area, and 1,381kg CO_2 eq. ha^{-1} $crop^{-1}$ in rain-fed area (Table 7). These corresponded to 1.19 kg CO_2 eq. kg brown $rice^{-1}$and 0.62 kg CO_2 eq. kg brown $rice^{-1}$, respectively.

Table 7. GHG emissions of rice production in the Philippines.

	Total $kgCO_2eq.\ yr^{-1}$	**kg CO_2 ha^{-1} yr^{-1}**
Irrigated area	1.14×10^{10}	3.92×10^{3}
Rain-fed area	1.87×10^{9}	1.38×10^{3}
Total	$\mathbf{1.33 \times 10^{10}}$	$\mathbf{3.11 \times 10^{3}}$

Rice production from irrigated areas in the Philippines was 74% of the total rice production, while GHG emission from the irrigated areas was 11.4 Tg CO_2 eq. yr^{-1}, which was 86% of the total GHG emission. On the other hand, rain-fed areas produced 26% of the total rice production, while GHG emission from the rain-fed areas was 1.87 Tg CO_2 eq. yr^{-1}or 14% of the total GHG emission.

Table 8 shows GHG emission from each source. The largest proportion of the emission was derived from soil processes, such as CH_4 and N_2O emissions from soil followed by emission from fertilizer utilization. GHG emission through soil processes in rain-fed area was 33% of that in irrigated areas by area basis, or 47% by grain weight basis. Emission from carabao was 50kg CO_2 eq. ha^{-1}irrespective of water management practices. Emissions from fertilizer, fuel, and other farming activities were 140kg CO_2 eq. ha^{-1} $crop^{-1}$ in irrigated area, while 111kg CO_2 eq. $ha^{-1}crop^{-1}$was emitted in rain-fed area. These are much lower than those reported in temperate countries such as Japan because of limited used of farm inputs.

Table 8. GHG emissions of rice production in Philippines.

	kg CO_2 eq. ha^{-1}		**kgCO_2eq kg $grain^{-1}$**	
	irrigated	rain-fed	irrigated	rain-fed
CH_4 emission 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 machines	6	5	0.001	0.002
Manufacturing of threshers	13	13	0.003	0.004
Manufacturing of handtractors	17	17	0.004	0.006
Total	**3,920**	**1,381**	**0.931**	**0.471**

Table 9 shows GHG emission of rice production system in other countries. This clearly shows that GHG emission was much lower in the Philippines than those in other temperate countries. Although their system boundary in references included rice milling process, a proportion of CO_2 emission for rice milling process is very small (Hokazono 2012). Lower GHG emission in the Philippines is mainly due to much lower use of fertilizer, agro-chemicals, fuel, and other inputs such as machinery compared to other countries.

Table 9. GHG emissions of rice production in various countries.

Country	**Emission per brown rice** (kgCO_2 eq. kg^{-1})	**Emission per area** (kgCO_2 eq. ha^{-1})	**Conditions**	**Sources**
Italy	2.76	19,000		Blengini2009
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*	3,922	Irrigated	Present study
Philippines	0.47*	1,445	Rain-fed	Present study

*Grain weight

Increasing rice productivity in the future will mean increased inputs. In turn, this may increase GHG emission in area basis. However, if the increase in yield is comparable with the increase in inputs from fossil sources, the GHG emission per rice grain might be kept at the same level.

3.3.2. Mitigation of CH_4 and N_2O emission from soil processes

A major source of GHG emission in rice production system comes from soil processes. It is therefore primarily important to mitigate the emission from soil. Irrigated areas in the country are expected to increase to meet with the increased demand in food for faster increasing population. This may cause further increase in CH_4 emission from irrigated rice fields. Various mitigation options (Corton 2000), such as alternate wetting and drying as occurred in rain-fed areas should be adopted as farmers' practices. Emission of rain-fed condition was apparently lower due to limited supply of water but also had lower yield (Wassmann 1994). It will be more important, especially in the Philippines, to satisfy both increasing rice productivity and mitigating GHG emission.

3.3.3. Land preparation and hauling operation

Based on current number of carabao (534,111 heads per year) used in rice field cultivation, carabao produced 50kg CO_2 eq. ha^{-1} which was also not negligible. The total rice production emission with carabao was 13.3 Tg CO_2 eq. per year while replacing carabao with handtractor resulted to 13.1 Tg CO_2 eq. per year. There was a total of emission saving of 0.2 Tg CO_2eq.

without carabao involved in rice production in the Philippines. The corresponding field operation using carabao could actually be replaced by agricultural machinery.

Since the carabao has always been in the field even during farm operation downtime, the emitted GHGs even during non-working period are also considered. Carabao emits CH_4 even during rest period while the handtractor's emission is zero. Handtractors prepare the rice field much faster than the carabao. Handtractors could also shorten time of work such as land preparation thereby reducing emission from soil organic decompositions between works. Thus, alternative use of hand tractors for land preparation and hauling in place of carabao can mitigate 3.7Mg CO_2 eq. emission. Such activities as hauling of paddy, plowing, and harrowing of field could be accomplished by using a handtractor which can totally replace the carabao during rice production.

However, in terms of conservation of traditional farming practices, the carabao may not be simply replaced by agricultural machines. Carabaos are sources of fresh milk and serve as draft animals for low income and less fortunate farmers in the country side. It is needed to study the significance of draft animals, such as the carabao, in sustainable agricultural system.

3.3.4 Straw management

Straw management greatly affects CH_4 emission from soil. The present status of straw management in the Philippines as adopted in the study is that 95% of straw is burnt. This may be beneficial in terms of mitigation of CH_4 emission from soil with 5.3 Gg CO_2 per year and for pest management. In terms of soil nutrient management, organic matter decomposition under tropical climate conditions is so fast that accumulation or maintenance of soil organic matter by incorporating straw may not be expected (Javier 2002). Therefore, even though rice straw is burnt, retuning of ash containing minerals such as potassium and phosphorus into field may contribute to maintain soil fertility. However, burning of straw may cause serious environmental and health hazards. In fact, the local governments in Japan request farmers not to burn rice straw in the fields after harvest.

3.4. CONCLUSION

GHG emissions of rice production in the Philippines were comprehensively quantified by considering irrigation methods and cropping season. The results of this study could be used to recommend mitigation processes in rice production. Such mitigation processes are as follows:

Mitigating the effect of microbiological process and fertilizer utilization by adoption of intermittent irrigation or alternate wetting and drying or mid-season drainage is recommended. Previous studies proved that such irrigation practices are effective in reducing GHG emissions.

Carabao could be replaced by handtractor, since the former emits more GHG emission than the latter. An improved ride-on attachment would be an additional advantage to a comfortable operation of the handtractor which also lessens emissions by increasing work rate. The ride-on attachment to the handtractor was evaluated to reduce GHG emission of the handtractor.

Since irrigation of rain-fed areas was critical during the dry season, the wind-pump system would become an alternative for irrigation. This study evaluated the performance of the wind-pump system to possibly irrigate rice crops during dry season.

Although, rice milling is outside the system boundary of this study, the disposal of rice husk by rice millers contributed to substantial GHG emission. To reduce the effect of RH disposal, the RH up-draft gasifier was evaluated to generate electricity for the rice mill as well as ameliorate RH disposal.

Chapter IV

Mitigation Technologies

Technical and Socioeconomic Evaluation of a Ride-On Tillage Implement for the Hand Tractor

4.1. INTRODUCTION

Since the 1970s, different hand tractor models from other countries were introduced in the Philippines. One of these was the gear-type transmission system that was very efficient in transmitting power. However, this type of hand tractor did not become popular because of very high investment cost and the limited work it could accomplish. Moreover, the spare parts were not available in the local market, making it difficult to repair in case of damage or wear.

The local hand tractor design modified by the International Rice Research Institute based on the Landmaster model is still popular these days. Although it requires more power to operate, it requires lesser investment cost. The IRRI-designed power tiller was modified by local manufacturers over time and was eventually replaced with box-type casing, enlarged chains and sprockets, increased size with wider cage wheels, bigger engines, and longer handles to facilitate easy maneuvering. The commonly used engine is 6-8 hp diesel engines, although gasoline engine (10-16 hp) is also used. Common attachments of conventional handtractor are disc plow, comb harrow, and trailer (Mahmud 1977).

Turning the hand tractor during operation requires the full power of the operator. The operator needs to exert substantial effort to turn it at the corners of the field. Despite this feature, the hand tractor is still the most popular rice production machine today because of its versatility. It can be fabricated using locally available materials and requires minimum skills to assemble. The plow assembly can be changed to a harrow from the hitch point to complete all harrowing activities including final leveling the field. The hand tractor also allows for on-road operation. By hitching a trailer, the hand tractor can be used as a means of transportation. It is used to transport people, seeds, fertilizers, produce, and other production inputs.

Mechanization of land preparation finally took off in the early 1980s. The use of the power tiller, now locally known as *kuliglig* after the more popular Lakas Kuliglig brand in Central Luzon in the 1970s, rose from 14 per 1,000 ha to approximately 20 per 1,000 ha by 1990.

Irrigated areas tend to be more highly mechanized with more than one power tiller per 10 ha of rice land, while the less favorable area continue to rely on animal power (De Padua 2004).

Machine operation is labor-intensive which requires the operator to walk about 70 km to prepare a hectare of his rice field. On top of that, the farmer is also prone to feet injury while walking in the mud due to the presence of sharp objects. The golden apple snails pose risks not only to rice plants but also to the operator's feet during field operations. Recent machine developments focused on operator's comfort. Machines must be ergonomically designed to ensure the operator's safety and comfort requirements. A well-designed machine should promote the general welfare of the operator that includes lighter muscle load, shorter working hours, and operator-friendly devices.

Mr. Val A. Lugto, a hand tractor fabricator in Guimba, Nueva Ecija, developed a ride-on implement. He used the existing harrow design to fabricate a ride-on attachment (Fig. 11a). According to operators, the varying elastic deflection of the leaf spring while moving was greatly annoying. It also created instances of imbalance, which made the operator uneasy during operation.

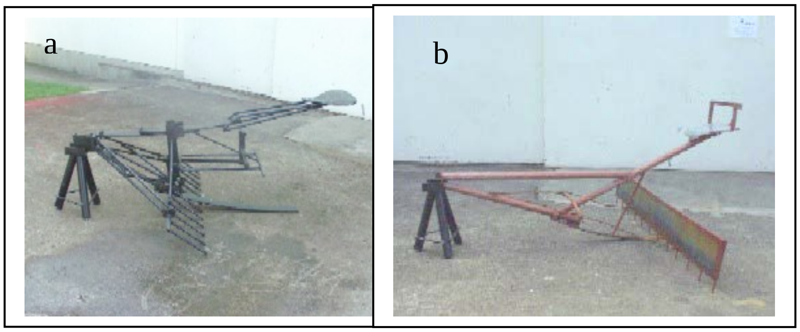


Figure 11. The a) Val's Hand tractor attachment and b) unidentified manufacturer models.

Another unidentified fabricator developed a ride-on attachment prototype (Fig. 11b). The implement was very light and simple; however, activity was focused only on harrowing operation.

The Philippine Rice Research Institute (PhilRice), in collaboration with Mr. Lugto, developed a new prototype by combining features of Val model and the locally fabricated one. The research output came up with an attachment to the hand tractor that can plow and harrow the field while the operator is riding. Eventually, it was developed into a multipurpose attachment that can accomplish all major tillage operations. This attachment offered an easier utilization of the handtractor compared to the previous design and will be promoted to be a mitigation technology to replace the carabao in rice cultivation activities. It further shortens the land preparation time thereby lowering the GHG emission due to lesser time of soil physical manipulation.

The study evaluated the performance of the ride-on tillage implement for the hand tractor. It included an evaluation of the field performance in terms of field efficiency, speed of travel, draft force, field capacity, working width, fuel consumption, turning radius, and some related parameters. It also assessed users' feedback on the design and acceptability of the ride-on tillage implement. The GHG mitigation effect of the ride-on implement was also evaluated.

4.2. MATERIALS AND METHODS

4.2.1. Technical evaluation

Before the test, the researcher as well as the operators, familiarized themselves with the construction and operational feature of the implement to assess the actual performance and evaluate its suitability in view of limitations of time, soil type, material, and manpower. Upon the manufacturer's recommendation, all required adjustments were done and preliminary field trials were conducted to keep the machine at its best working condition. It was also ensured that the testing operator was fully familiar with the actual operation of the machine.

Technical evaluation covered the speed of travel, draw bar pull, rolling resistance, and turning radius of the hand tractor during plowing and harrowing, depth of cut, width of cut, and field efficiency. All data were analyzed using descriptive statistical analysis.

4.2.1.1 Test plot

The test was conducted in Maligaya, Science City of Muñoz, Nueva Ecija, Philippines. Weed density of each plot was at a moderate level of 100 plants per square meter. The test plots with an average area of 776 m^2 were submerged with irrigation water three days before the actual data gathering. Soil physical properties were determined through laboratory analysis at the PhilRice soil laboratory. Water depth of 2–5 centimeters was maintained during land preparation operations.

4.2.1.2. Soil drop test

A fabricated brass, drop type penetrometer, 47 cm long and weighing 143 grams was used to determine the soil hardness. The cone base diameter was 33 mm and 38 mm height with apex angle of 47^o. The penetrometer was raised to one meter above the soil surface, and then carefully dropped. Reading was determined from the graduation on the stem of the penetrometer.

4.2.1.3. Cone index

Cone index profile of the soil relative to working depth was determined using a cone penetrometer. The Japanese-made Daiki 60 soil cone penetrometer was used. The pressure readings were automatically recorded on the sheet at a corresponding soil depth. Several points along plot subdivisions were measured at random.

4.2.1.4. The engine and handtractor transmission

The Japan-made RK 80 KUBOTA diesel engine was used during the test. It had a maximum output of 8 hp at 2,400 rpm. The transmission used was a JV Ocampo hand tractor. The speed ratio from the top sprocket to the cage wheel axle was 1:9 using a double groove pulley of 30.5 cm diameter. The overall height and length were 110 cm and 255 cm, respectively, while the handle was 70 cm long. The cage wheel was 50 cm in diameter and 52 cm in width, producing a total hand tractor width of 120 cm, including that of the transmission. The total weight of the transmission including all accessories was 286 kg.

4.2.1.5. Speed of travel

The speed of travel is the unit distance travels per unit time. Two poles were placed at 20 m apart at the long side of the field to serve as base point of measurement, while another two poles were placed on the opposite side of the field creating an imaginary line between the adjacent poles.

4.2.1.6. Effective working width

The effective working width was determined by measuring the actual width of cut during operation. This was done by first, measuring a 1 m distance from the unplowed portion of the field. After each pass, the remaining unplowed soil was again measured leaving the actual width of cut during plowing. The procedure was also used for harrowing operation but the first measurement was increased to 2 m.

4.2.1.7. Draft or pull force

The draft or pull force is the amount of force that a hand tractor requires to pull an implement. A strain-gauge type dynamometer was used to measure the forces.

A strain-gauge type dynamometer was attached to the front of the hand tractor where the implement was also mounted. Another auxiliary tractor pulled the implement through the dynamometer. The auxiliary tractor pulled the implement-mounted tractor with the latter tractor in neutral gear but with the implement in operating position. The draft within the 20 m distance was read. On the same field, the implement was lifted out off the ground and the draft was measured in similar setting. The difference was equal to the draft of the implement.

4.2.1.8. Working depth

The working depth was measured by putting a ruler at the plow sole. Since the plow sole was not always leveled, the tip of the foot rule was positioned at relatively the same point in each pass.

4.2.1.9. Turning radius

The turning radius of the hand tractor with the ride-on tillage implement was determined using different engine rpm. Measurement was done after five meters from the start at the center of the field. This allowed the operator to adjust the speed of travel at normal condition. The radius was measured at the center of the inscribed circle.

4.2.1.10. Soil inversion

Soil inversion was quantitatively expressed as the ratio of the number of weeds or stubbles of last crop left on soil surface before and after operation. A square metal frame having 50 cm sides was used to count weed or crop stubble.

$$F = \frac{Wp - We}{Wp} \times 100$$

Where: F = Indicator for soil inversion; ratio of weed or crop stubble being filled up
Wp = number of weed or crop stubble before operation per unit area

We = number of weed or crop stubble exposed on the surface after operation.

4.2.1.11. Fuel consumption

In measuring the fuel consumption, the engine tank was first filled up at full capacity before the operation of every test plot. The fuel tank was refilled after measuring the volume to replenish the tank. The diesel fuel replenished was carefully measured with a graduated cylinder which was equal to the consumed fuel per plot.

4.2.1.12. Effective field capacity

The effective field capacity was measured as the ratio of total area finished with the unit real time of doing work. The time lost for every turning, loading, and unloading the machine, adjustment, and machine trouble was recorded. However, in calculating the effective field capacity, the time of refueling the engine was not accounted since in some cases refueling within small field was unnecessary (AMTEC 2003).

The time for rectifying machine trouble varied widely due to various factors and it significantly affected the effective field capacity, which is calculated as follows:

$$\text{Effective field capacity} = \frac{\text{Area covered (ha)}}{\text{Total time (min)}}$$

4.2.1.13. Theoretical field capacity

The theoretical field capacity depends on the full operating width of the machine and the average travel speed in the field. It represents the maximum possible field capacity that can be obtained at the given field speed when the full operating width of the machine is being used. The theoretical field capacity was calculated using the following formula:

Theoretical Field Capacity = SWE

where: S = average speed
W = full width
E = efficiency, %

4.2.1.14. Field efficiency

Field efficiency is the ratio of effective field capacity and the theoretical field capacity of the machine. This was affected by the time lost in the field and the failure to utilize the full working width of the machine.

4.2.2. Socioeconomic Evaluation

4.2.2.1. The social feedbacks

Using a structured questionnaire, the socio-demographic profile of the farmer-respondents was determined. This includes personal data, respondents' knowledge on the machine owned and operated, machine/s they can afford to buy, their previous experiences on farm machines, and others. .

The field performance of the ride-on tillage implement was evaluated in comparison with the hand tractor with conventional attachments. Respondents were also asked regarding design modification and expectations from the implement.

The advantages and disadvantages were enumerated in the questionnaire. Among the criteria cited were the machine's timeliness of operation, price preference of the implement, safety of use, labor required during operation, capacity, and ease of use. Respondents were given an opportunity to rate the ride-on tillage implement based on the above criteria using numerical ratings from 1-5 (1-outstanding, 2-very satisfactory, 3-satisfactory, 4-fair, and 5-poor).

4.2.2.2. Economic analysis

The cost of the ride-on tillage implement was evaluated based on the materials used and the cost of producing the unit. The ride-on tillage implement was compared with the conventional land preparation method in terms of economic value. The unit cost of each system was determined from machine dealers.

1. Depreciation Cost

$$\text{Depreciation} = \frac{P - S}{N}$$

Where: P = Purchase price
S = Salvage price normally 10% of P
N = Total life in years

2. Interest on Investment

$$\text{Interest} = \frac{P + S}{2} \times \frac{r}{100}$$

Where: r = interest rate (12 %)

3. Repair and Maintenance

Actual expenses of using a machine increase with time. Repair and maintenance are the machine cost invested to keep its high quality performance. The method of average repair and maintenance per year was adopted to simplify calculation.

$$\text{Repair} = P \times \frac{m}{10}$$

Where: m = repair and maintenance rate (5% IC)

4. Hourly Fixed Cost

Hourly fixed cost was obtained by dividing annual fixed cost by operating time in hours per year. Fixed cost comprised of the depreciation of the machine and the interest on investment.

5. Variable Cost

Variable cost per hour was considered using the actual test data. Variable costs comprised the cost of fuel of the engine during actual field operation; the cost of oil and lubricant which was assumed at 3% of fuel cost; the salary of the operator per day; and the cost for repair and maintenance assumed at 5% of the investment cost.

4.3 RESULTS AND DISCUSSIONS

4.3.1 Technical Evaluation

4.3.1.1. Description of the ride-on tillage implement for the hand tractor

The exploded view of the ride-on tillage implement and the complete assembly attached to a hand tractor are shown in Figures 12 and 13. Including accessories such as two-bottom disc plow, rear furrow wheel, operator’s seat and harrow, , it had an overall weight of 65 kg.

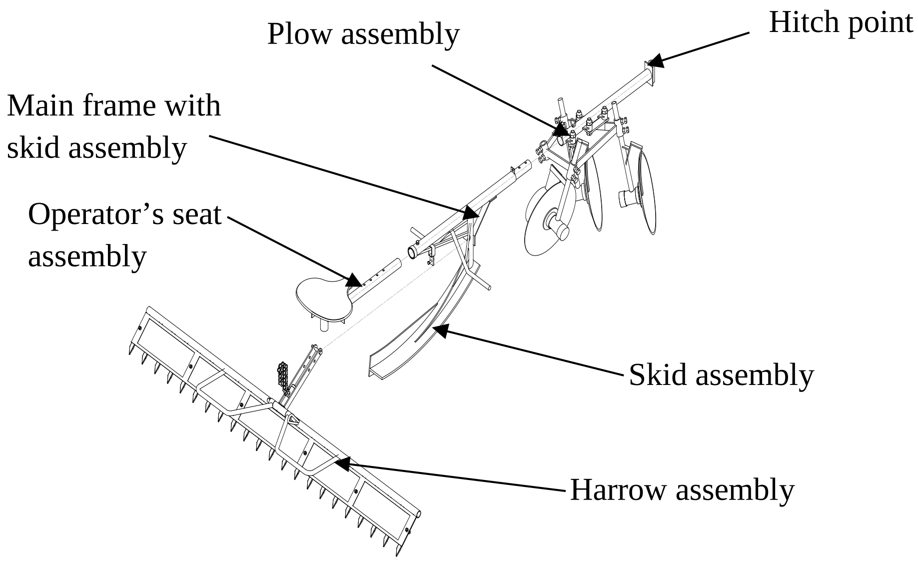


Figure 12. Exploded view of the ride-on attachment for handtractor

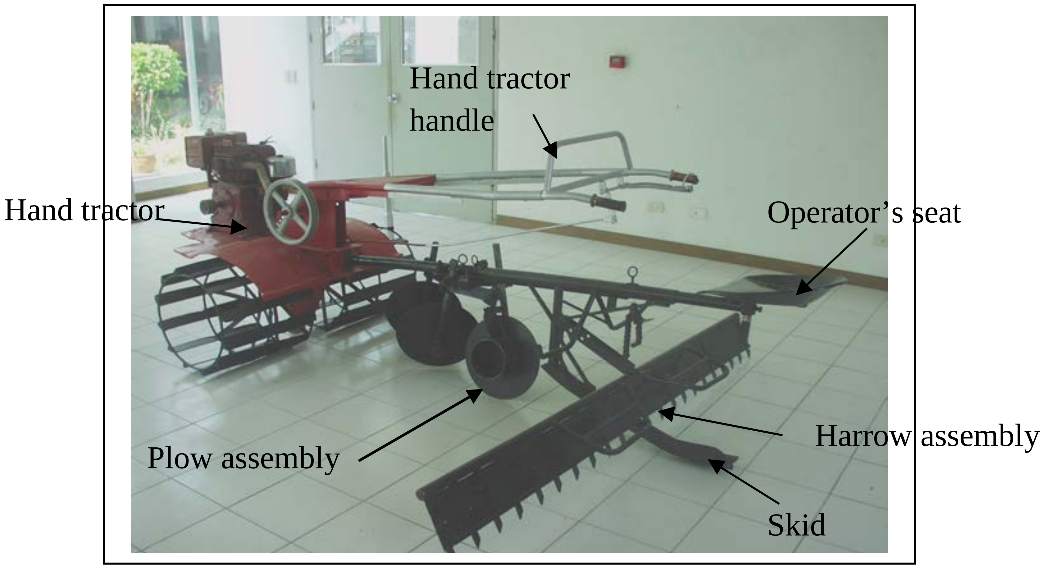


Figure 13. The new ride-on tillage attachment.

The operator’s seat assembly. The operator’s seat could be adjusted up or down and closer or further from the hand tractor. The height and length of the seat should be adjustable because handle dimensions vary according to the hand tractor model.

The seat pad 32 x 35 cm^2 was made of metal plate with bent sidings. The up-and-down adjustment was made of a square bar secured by bolts and nuts placed at the bottom of the seat.

The length adjustment was made of a telescopic pipe at the end of the mainframe. Four pinhole adjustments set at 5 cm apart were located on the mainframe to facilitate several length adjustments to ± 20 cm.

Harrow assembly. The harrow assembly consisted of the following components:

- Harrow fix - connected with bushing from the main frame. A pair of 5 mm x 3.5 cm flat bar placed 5 cm apart was connected to the mainframe allowing the harrow to move up/downward and swing sideways. The depth adjuster was a hand tractor chain (RC 60) hung by bolt and nut on the upper portion.
- Comb-harrow - made of 17 x 17 x 3 mm x 20.5 cm long angular bar. The angular bars having pointed ends were welded on a 33 mm diameter pipe x 220 cm long at 10 cm apart.
- Footstep - made of 20 mm diameter pipe bent at 23 cm apart from the main pipe positioned at 37^o from the peg tooth.
- Pin - made of a solid 20 mm diameter round bar with ring at its end to permit manual disassembly of the harrow.
- Leveling plate- made of a GI # sheet 18 with 220 cm x 15 cm dimensions reinforced with five vertical flat bars along its length.

Plow assembly. The plow assembly was connected to the main frame using five pieces bolts and nuts. It possessed four round holder bushings for the discs and rear furrow wheel. The other bushing was designed to hold the disc for side plowing. The holder bushings had the following dimensions: 29 mm inside diameter, 75 mm long, and 6 mm thick. Each bushing was equipped with 1.5 cm x 4 cm bolts and nuts to secure the discs and rear furrow wheel.

Disc plow. The disc plow is similar to the traditional discs used by farmers, except for the round shaft that holds the discs. The disc is a 5 mm thick high carbon steel plate with 64 cm radius of curvature and 35.5 cm diameter along flat surface. The main shaft is a

29 mm diameter and 41 cm long. The discs were placed 33 cm away from the hitch point and 40 cm apart with tilt and disc angle of 20^{o} and 40^{o}, respectively.

Rear furrow wheel. The rear furrow wheel is composed of a 5 mm thick flat metal sheet with rounded plate which is 168 mm in diameter and has a width of 107 mm. The rounded plate on the flat disc controls the penetration of the wheel to the soil. The main shaft was 29 mm in diameter solid shaft and 46 cm long. To counteract the force created by the discs, a tilt angle of 10^{o} to the left was established. The rear furrow wheel was also set at 15^{o} from vertical position towards the rear.

Hitch point assembly. The hitch point is the link between the implement and the transmission. Although, manufacturers do not use a standardized hitch in making their own transmission, the design for the implement can fit in all models.

Mainframe assembly. The main frame is 48 mm in diameter and 150 cm long. It holds all the components of the implement. There is a disconnection point at the center to separate the plow assembly for walking and side plowing. The second part holds the skid, operator's seat, and the harrow assembly. A vertically welded member with 35 mm diameter and 280 mm length holds the skid assembly. A bushing placed at the end part of the frame was designed to secure the harrow assembly. A 2 cm round bar was also placed to serve as footrest of operator.

Skid assembly. The skid is made up of a 100 mm wide x 10 mm thick x 83 cm long leaf spring. A 5 cm wide and 5 mm thick flat bar was welded on the left side of the skid to counteract the thrust force during plowing.

4.3.1.2. Soil resistance test

Results showed that as soil depth increased, the unit soil resistance also increased. At 5 cm soil depth, the average pressure reading was 1.4 kg cm^{-2}. At 10 cm soil depth, the soil resistance increased to 2.4 kg cm^{-2}. A similar trend occurred at 15 and 20 cm soil depths, in which soil resistances were 3.9 and 7.8 kg cm^{-2}, respectively.

4.3.1.3. Soil analysis

The soil was classified as Maligaya clay having 7% sand, 37% silt and 56% clay. It is classified as clay textured soil with a basic component of 48% solid, 3% air, and 49% liquid. The porosity, organic content, bulk density, and true density are 52, 1%, 1.5, and 3, respectively.

4.3.1.4. Soil drop test

Figure 14 shows that soil hardness before plowing had a minimum and maximum of –8.9 cm and –3.0 cm, respectively. On the other hand, the minimum and maximum values after harrowing were –12.0 cm and –8.5 cm, respectively. The average values before and after was –4.6 cm and -10.2 cm, respectively. This revealed that the soil was already softened before plowing and the hardpan had been formed after harrowing.

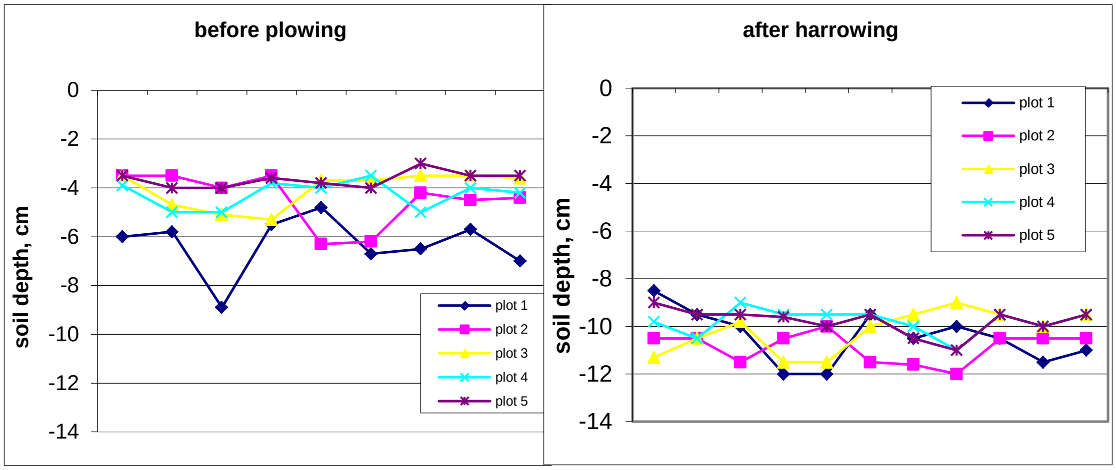


Figure 14. Soil hardness test before plowing and after harrowing.

4.3.1.5. Field performance test results

The results of the test showed that the side plowing capacity was the highest among field operations if area is considered as a basis of computation. On the other hand, low ride-on plowing capacity was greatly affected by numerous headland turns and the width of cut during field operation.

The field efficiencies were practically the same among the field operations because of insignificant operation time loss. The travel speeds of all operations exceeded the normal walking speed of man because of less effort exerted in each operation. The operator was not required to walk behind the hand tractor therefore the effort was concentrated only to maneuver

	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 10. Comparison between handtractor with conventional and ride-on attachment.

the machine at headland. However, the side plowing efficiency was below the walking speed of man due to the difficulty of aligning the cage wheel at the edge of the dike.

4.3.1.6. Levee-side plowing

Figure 15 shows the actual levee-side plowing using the ride-on tillage implement. The average speed of travel during side plowing is 2.4 km h^{-1}. The cutting disc during side plowing was adjustable up to 40 cm width depending on the soil characteristic and capacity of the operator. The side plowing efficiency was 92%. It was calculated using 0.7 ha h^{-1} effective field capacity and a theoretical field capacity of 0.8 ha h^{-1}. The engine consumed 1.2 liters of diesel fuel to side plow one hectare in a single pass operation.

Data showed that side plowing using the ride-on tillage implement can finish a hectare in 1.4 h of continuous operation or an equivalent of 5.6 ha within an 8-h day operation.

Figure 15. Levee-side plowing.

All factors relative to the performance of the ride-on tillage implement during side plowing were not significantly different at 95% confidence level from those of the conventional hand tractor, except for the faster travel speed, and higher wheel slip.

4.3.1.7. Ride-on plowing

Figure 16 shows the actual operation of ride-on plowing. The average travel speed during ride-on plowing was 3.6 km h^{-1}. The travel speed was slightly faster than the walking speed of a farmer. The speed of travel was influenced by the hardpan and other soil characteristics.

Figure 16. Ride-on plowing operation.

The average working width was 52.9 cm. The cutting width could be increased or decreased depending on soil characteristics as influenced by the performance or capacity of the engine. The average efficiency during ride-on plowing was 85%. The performance efficiency was significantly affected by the width of cut and the time loss during operation. With this high plowing efficiency, it was observed that ride-on plowing could finish one hectare in five hours of continuous and uninterrupted operation using 4 l of diesel fuel, while the conventional hand tractor consumed 6 l to finish 1 ha in 8 hr.

Results showed that the travel speed and field efficiency of ride-on tillage implement were not significantly different at 95% confidence level from that of the conventional hand tractor. However, the ride-on tillage implement's field capacity was significantly higher and its operational cost was significantly lower. The fuel consumption of the ride-on plowing operation was also significantly lower.

4.3.1.8. Ride-on harrowing

As shown in Figure 17, the operator could ride while harrowing. The average travel speed during ride-on harrowing was 3.7 km h^{-1}.

Figure 17. Harrowing operation.

The average effective working width was 189 cm. The average efficiency of the implement during ride-on harrowing was 85%. The performance efficiency was significantly affected by the overlap of passes during operation. The riding harrow can cover 3.3 ha in 8 h of continuous operations with a fuel consumption of 3.3 l h^{-1}.

Analysis showed that the field efficiency was significantly lower and wheel slip was significantly higher at 95% confidence level than those of the conventional hand tractor. However, these did not affect the cost of operation of the machine. The faster travel speed of the ride-on tillage implement despite higher wheel slip might have been the cause of higher engine rpm.

The travel speed during cross harrowing using the ride-on harrow was not significantly different at 95% confidence level from that of the conventional hand tractor. The field capacity and operation cost, however, were significantly higher in favor of the ride-on tillage implement. Nevertheless, the field efficiency was significantly higher and fuel consumption significantly lower in favor of conventional hand tractor.

4.3.1.9. Ride-on leveling

Figure 18 shows the leveling operation. The average travel speed during leveling was 3.2 km h^{-1}. The average working width was 186.4 cm, which was influenced by the overlap in each pass. The average efficiency during ride-on leveling was 84%. The performance efficiency was reduced significantly by the overlapping of passes. Considering this value of performance efficiency, the ride-on leveling could finish one hectare in 3.3 h. The increase in frequency or time of ride-on harrowing consequently resulted in the decrease in leveling time. The machine consumed 2.3 l of diesel fuel to level one hectare.

Figure 18. Leveling operation.

The fuel consumption and wheel slip of ride-on tillage implement were significantly higher at 95% confidence level than those of the conventional hand tractor. The field capacity and efficiency of the ride-on tillage implement including the operation cost, however, were not significantly different from those of the conventional hand tractor. The degree of levelness was analyzed by comparing the undulation of the field before and after leveling. Results showed that 83% of the measurement after leveling had no significant difference.

4.3.1.10. Turning radius

During plowing, the hand tractor with ride-on tillage implement could turn at 152.8 cm radius at 1,485 engine rpm (2.7 km h^{-1}). At a faster rate of 2,016 rpm (3.6 km h^{-1}), the machine could turn at 180 cm. Furthermore, at 2,217 engine rpm (3.96 km h^{-1}), it could turn at 172 cm radius. The overall average radius of turn during plowing was 168.cm.

During ride-on harrowing, the turning radius was 139 cm using 1,756 engine rpm (2.93 km h^{-1}). It could turn at 133 cm at 2,217 engine rpm (3.7 km h^{-1}) and 135 cm radius at 2,450 engine rpm (4.1 km h^{-1}). The average turning radius during harrowing was 136 cm. Turns smaller than the radius stated above will result to overturning of the ride-on tillage implement.

4.3.1.11. Rolling resistance

The rolling resistance and drawbar pull were 38% (137 kg) and 30% (108 kg) of the total weight, including the weight of operator, (361 kg), respectively. Since the sum of the rolling resistance and drawbar pull is equal to the traction force, then the actual traction force was 245 kg.

The force necessary to pull the ride-on tillage implement and the operator was 145 kg. Thus, the power required from the hand tractor when traveling at 3.0 km h^{-1} was 1.6 hp. Actually, the readily available power from the hand tractor with 8 hp was 2.7 hp. Therefore, the hand tractor had an extra available power for use during field operations.

4.3.2 Socioeconomic Evaluation

4.3.2.1. Social Feedbacks

4.3.2.1.1 Socio- demographic profile. The 30 respondents have a family with an average of 5 members. Rice farming is their primary source of income. Fifty-three percent (53%) were able to reach college. Forty-three percent (43%) have other sources of income aside from farming. The average age was 48 years old, 70% were 40 years old and above, and 30%, below 30 years old. Majority of them (87%) owned an area of less than 3 hectares while the rest owned more than 3 hectares. Eighty-three per cent (83%) owned the land they were tilling and 16%

were tenants. All of them have experience in farming with 16.6 years on the average. Only 7% of the respondents or two were not able to plant two times a year. Thirty percent (30%) of the respondents used water pumps during second crop season. However, the average yield was relatively high with 103 cavans per hectare.

4.3.2.1.2 Current methods used. Eighty percent (80%) of the respondents owned at least one unit hand tractor, only 20% had no hand tractor, and 3% still had four-wheel tractor. All respondents used the hand tractor to plow and harrow their field. However, there were 36% who used the carabao to side plow and level their field. They used the conventional method in 15.5 years of farming because they could not afford to buy other superior machines. Twenty-seven percent (27%) employed their own family members as sole farm labor, whereas 57% used purely hired labor, and 16% used both family and hired labor.

4.3.2.1.3. Comparing conventional method and ride-on tillage implement. More than half of the respondents (53%) said the hand tractor was the best choice among other land preparation equipment. Others (30%) had no alternative equipment to use, while 16% did not answer. Although four-wheel tractors were available in the market, the price was not affordable to ordinary farmers.

4.3.2.1.4. Evaluating the ride-on tillage implement. Ninety percent (90%) of the farmers had seen the ride-on tillage implement through PhilRice field demonstrations. During demonstration, a structured questionnaire was distributed to selected viewers. They were able to compare the conventional method used with the ride-on tillage implement. Sixty seven percent (67%) of the respondents realized that ride-on tillage implement had higher capacity than the conventional method, while 20% said it has the same capacity as the conventional method.

Sixty three percent (63%) of the respondents observed that there is less labor requirement using the ride-on tillage implement while 30% said the same labor is required. The ride-on tillage implement was also rated by 80% of respondents as easier to use, while 3% said it is the same as the conventional method.

Respondents rated the ride-on tillage implement as very satisfactory (1.6) in terms of timeliness of operation. The price was rated satisfactory (3.0) and the safety of operation as very satisfactory (2.1). Since operators were not required to walk in the mud, farmers do not risk having feet injury. The respondents were convinced that fewer workers are needed in accomplishing the same area of work. It was noted during demonstration that the ride-on tillage implement has a higher capacity than the conventional method. It was rated very satisfactory in terms of (1.7) capacity and (1.5) ease of use.

Eighty-seven percent (87%) of the respondents wanted to use the ride-on tillage implement in their field. Ninety seven percent (97%) of them desired to own a unit. However, they suggested that price should be P 5,600 per unit.

4.3.2.2. Economic Analysis

4.3.2.2.1. Variable Cost

The labor and fuel consumptions of the hand tractor with conventional and ride-on tillage implement were almost the same. The variable cost of the conventional method during operation was P 38,338, while that of the ride-on tillage implement was P 40,357 per year. Two operators were used in both systems.

4.3.2.2.2. Fixed Cost

The fixed cost varies as affected by the depreciation costs, interest on investment, and maintenance of each machine. Result showed that the ride-on tillage implement having the biggest investment cost among the land preparation systems, has the biggest fixed cost of P19, 092 per year while the conventional hand tractor and the animal-man method have P18,228 and P4,752 per year, respectively.

4.3.2.2.3. Payback Period

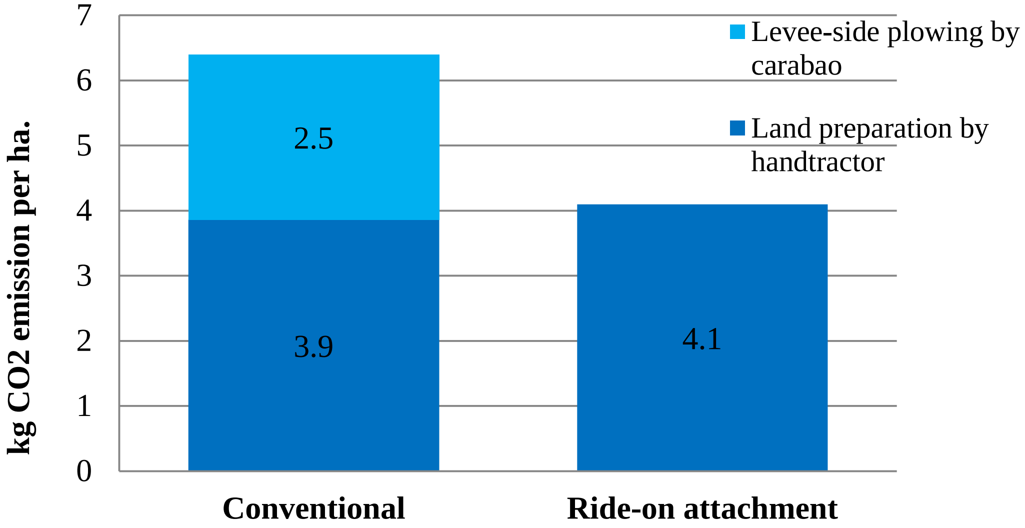
The payback period of the conventional hand tractor is 3.3 years, which required 79 ha to return the investment. The ride-on tillage implement has a payback period of 1.9 years which required 57 ha to recover the investment cost. A farmer with existing hand tractor who bought the ride-on implement could recover the investment cost in 7 days of work.

4.3.2.2.4. Net Income

The net income for owning a unit of ride-on tillage implement is P 39,528 per year. The conventional hand tractor, on-the-other-hand, will give P 21,550 net income per year. There is an additional P 17,978 income when ride-on tillage implement is used. A farmer with existing hand tractor can generate a net income of P62,395 per year.

4.3.2.2.5. Mitigation effect

During land preparation with conventional attachment to the handtractor, levee-side plowing was additionally done by carabao. This combination of carabao and conventional handtractor amounted to 6.4kg CO_2eq per year. With ride-on attachment, the GHG emission was about 4 Gg CO_2 eq per year. There were about 2.3 kg CO_2 mitigated when the conventional handtractor and carabao will be replaced by handtractor with ride-on attachment.



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

Handtractor with ride-on attachment can do levee-side

Figure 19. GHG emission of handtractor with conventional and ride-on attachment

4.4. CONCLUSION

The technical performance and socioeconomic of a ride-on tillage implement was successfully evaluated under actual field conditions and feedbacks were gathered through a structured questionnaire. The ride-on tillage implement can accomplish all major land preparation operations such as: plowing, harrowing, and leveling. It can also be used for levee-side plowing. The newly designed ride-on attachment is a good alternative for preparing the rice field that could shorten time of preparation because of faster performance than the customarily used attachment. It is good replacement to carabao as draft animal which commonly emits more GHG emission from its enteric fermentation and its manure. The capacity of the handtractor was enhanced because it can do levee-side plowing, an operation that could only be done by the carabao. The handtractor was proven to mitigate GHG emission if it will replace the carabao in rice production.

4.5 ACKNOWLEDGEMENT

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Chapter V

Mitigation Technologies

Potential Evaluation of a Locally Designed Wind-Pump System for Water Pumping to Irrigate Rice Crop Based on 10-Year Weather Data in the Philippines

5.1. INTRODUCTION

The interest in renewable energy (RE) sources especially wind energy for electricity generation gained interest towards the end of 20^{th} and beginning of the 21^{st} century. Wind is abundant and free, a natural resource that is important especially in the tropics like the Philippines. Wind energy is socially, industrially, and politically accepted as practically clean and naturally unlimited source. Wind power was used as a source of mechanical energy especially for irrigation as early as 1000 AD by the Europeans.

In 1854, the first windmill with four wooden blades was patented by Daniel Halliday in America (Rao 2011) and more than 6.5 million windmills of this kind were sold in 1880-1935. In 2008, the 12-bladed Kijito wind-pump was also became popular in the US and other parts of the world (Harries 2002). Many windmills are still used today for pumping livestock water and domestic water supplies. These units normally produced maximum power of 1 kW and pump less than 3 m^3 h^{-1} (Clark 1979). However, the discovery of the internal combustion engine and the development of electrical grids caused many windmills to disappear.

In the last decade of 20th century, however, a million windmills were used mainly for water pumping, despite the spread of electric pumps (Fraenkel 1999). In 1996, a small wind pump for manufacture in developing countries was developed (Fraenkel 1996).Some studies were conducted to optimize pumps and windmill design for a given situation (Bragg 2009), for possibility of lifting irrigation water in India (Parikh 1984), Central Nigeria (Clouter 2011), and Turkey (Kedare 1990). A rope wind-pump was also designed in Nicaragua to ultimately reduce cost of fabrication (Ikilic 2010).

Currently, most windmills for water pumping applications have horizontal axis variety, and have multi-bladed rotors to supply high torque required to operate a mechanical pump. In the Philippines, only few windmills are found in the countryside to pump water for household purposes. Since most wind-pumps does not start below 3 m s^{-1} wind and will furl at 12–15 ms^{-}

[1], water output is critically dependent on prevailing wind (Berry 2005) and design of the rotor (Purohit 2007). A wind-powered irrigation system developed in Central Philippine University through a project sponsored by the DOST-PCARRD (Department of Science and Technology-Philippine Council for Agriculture, Forestry and Natural Resources Research and Development) and MoWEC (Mobile Wind Energy Plant) in 1997 for surface and pressurized irrigation (Omara 2004) have shown the technical feasibility and commercial viability. The wind-pump system consisted of 24 blades, horizontal axis rotor windmill with a 10-m tower, a cylinder pump, and water tank. Several windmills of this type was installed at the PhilRice's model farm, two units in Pampanga, four in Quezon, and four in Tarlac which served as demonstration units. The unit installed in Tarlac province was the one considered in this study. The study site has an average wind speed of 4.4 m s^{-1} at 30-meter height and 3.6 m s^{-1} at 10 m height (Elliott et al., 2001). It is located in a rain-fed area where rice crops could be planted only in the wet season.

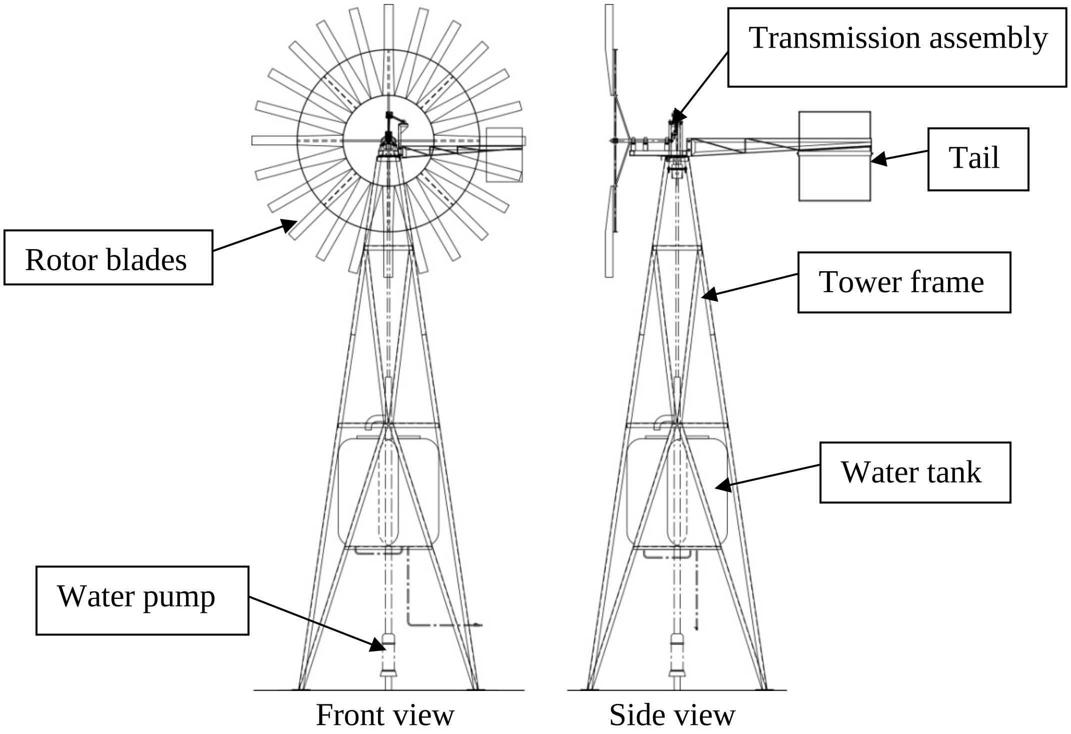


Figure 20. Schematic diagram of the locally designed wind-pump system for water pumping.

This study was carried out to evaluate the performance of a locally designed wind-pump system and specifically to assess the potential water output of the wind-pump system using 10-year (2004-2013) weather data and determine its capacity to irrigate rice fields. Furthermore, the energy input for manufacturing the wind-pump system and the energy output of the pumping were evaluated. The mitigating effect was also computed based on the data computed from the weather data.

5.2 .MATERIALS AND METHODS

5.2.1. Performance of the wind-pump

Site Description

The wind pump system was located in Barangay Magaspac, Gerona, Tarlac, Central Luzon. Specification of the wind pump is shown in Table 11 and is schematically shown in Figure 20. Water table in the area has an average depth of 3 meters from ground surface. There were many shallow tube-wells serving around about 1 hectare per unit as the main source of irrigation water for rice and sugar cane crops in Barangay Magaspac.

Table 11. General specification of the locally designed wind-pump system.

Model	CPU WP – 24450
Rotor diameter	4.5 m with 24 blades
Control mechanism	Side vane and main hinge vane
Tower height	10 m, steel lattice tower type
Installed pump	Cylinder water pump 44 cm diameter
Start-up wind speed	2.2 m s^{-1}
Cut-out wind speed	Indeterminate

Pumping rate

Pumping rate was measured to evaluate capability of the wind-pump system for water pumping in April-July 2012. It was directly recorded by water meter installed at the discharge of the wind-pump with respect to the given wind speed. These parameters were used to calculate water pumping capacity of the wind-pump system based upon an analyzed wind speed data. The relationship of the wind speed data and pumping rate was analyzed and came up with regression analysis equation which was used to derive the estimated wind-pump discharges. Several levels of pumping rate corresponding to wind speed were then determined.

5.2.2. Potential of the wind-pump: Estimation with 10-year weather data

A 10-year daily rainfall and wind speed data from 2004-2013 was acquired from PhilRice weather station. The PhilRice monitoring station is located in Maligaya, Science City of Muñoz, Nueva Ecija, Philippines with coordinates 15º 40’ 17”N 120º 53’ 27”E approximately 33 km from the wind-pump system in Gerona, Tarlac. This was the nearest weather station from the windmill installation during the conduct of the study.

Water output of the wind-pump system based on normalized 10-year wind speed data was predicted using the relationship between the monitored daily wind speed and daily discharge of the wind-pump system. Total potential water supply included water pumped from the wind-pump system and rainfall as well. The 10-year data from PhilRice weather monitoring station was analyzed.

5.2.3. Evaluation of energy input and output in the wind-pump system

Energy input for manufacturing the wind-pump system was evaluated. Energy output created by the operation of the wind-pump was also estimated by estimating the total water output pumped by the wind-pump system in 20 years. The total water output was calculated using the daily average output found in previous study multiplied to 365 day-year and energy coefficient of irrigation water 0.62 MJ m^{-3} (Pimentel 1992, Ozkan et al 2008, Esengun 2006).

Data for manufacturing such as duration of operations and electricity consumption were monitored during actual cutting, bending, welding, drilling, and machining of wind pump specific parts. Shop operations were individually measured using a stopwatch in three replications each. Dimensions of materials were measured from raw materials before shop works had been done. Length of welding of each part was measured from the wind-pump system previously constructed in the study site.

Several shop equipment for manufacturing were used during fabrication of wind-pump system. An arc welding with 22kW, 500A was ordinarily used to weld parts of the wind-pump system. Actual welding of materials was done to gather information for specific material and correspondingly measuring the length and time of welding. Shear cutter machine with 5.7 kW power rating was used to cut sheet metal for the wind-pump blades. Cutting of sheet metal was done by two technicians who were simultaneously holding and controlling the shear cutter. The 4.2 KW lathe machine was used for machining main shaft of rotor. The total time consumed by one technician to fabricate specific part was manually measured.

The energy input for human labor, electricity and steel material was computed using the energy coefficient of 0.8 MJ h^{-1} (Pimentel D. 1992, Umar 2003), 47.8 MJ L^{-1} (Umar 2003, Safa and Tabatabaeefar 2002), and 20 MJ kg^{-1}, (Hammond G. and Craig J., 2008), respectively.

System boundary

Figure 21 shows the system boundary of this study. The system boundary included the raw materials, fabrication, and utilization of the wind-pump system. The energy of scrap materials after 20 years was not included in the study due to unavailable energy factor for scrap metal in the Philippines.

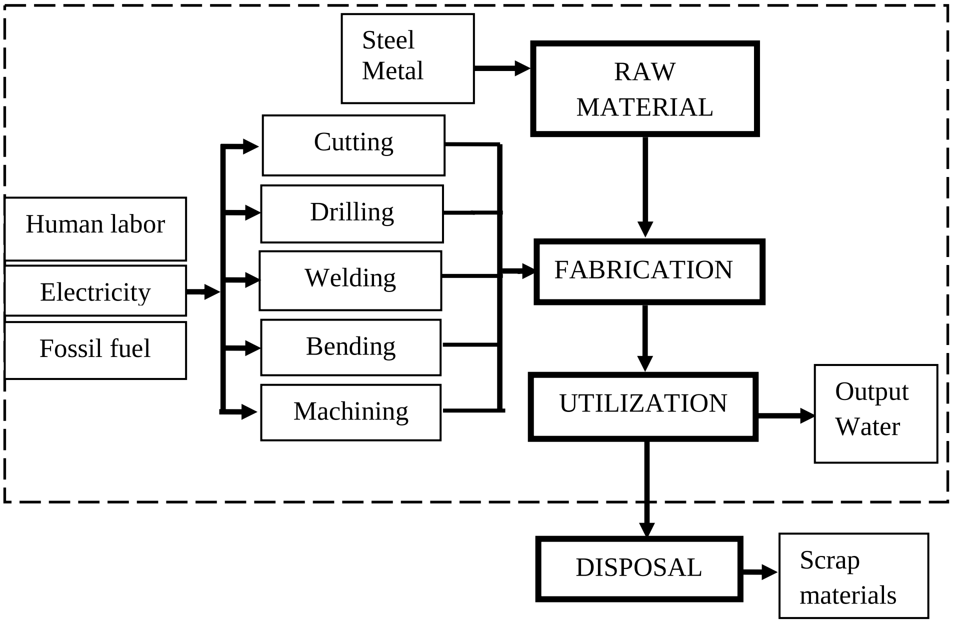


Figure 21. System boundary for evaluation of manufacturing the wind pump system,

5.3. RESULTS AND DISCUSSIONS

5.3.1. Performance of the wind-pump system

Figure 22 shows wind speed and water discharge with the wind-pump system. Wind speed from April to July 2012 was monitored at the study site in daily and hourly measurement with varying value from 0.1 m s^{-1} to 2.7 m s^{-1}. The computed average daily wind speed was 1.6 m s^{-1}. The daily discharge of the wind-pump system varied from 0.7 m^3d^{-1} to 22.1 m^3d^{-1} with average discharge of 9.2 m^3d^{-1}. Highest wind speed of 2.7 m s^{-1} resulted to highest discharge which was observed somewhere in April, while the lowest was in May with wind speed of 0.5 ms^{-1}. The functional relationship between the wind speed and the discharge of the wind-pump system was found as follows:

$$\mathbf{Q_s = 6.64*V - 3.44} \qquad (R^2 = 0.91)$$

where: Q_s = discharge of suction pump, $m^3\ d^{-1}$

V = wind speed, m s^{-1}

This indicates that, with annual average daily wind speed of 1.78 ms^{-1}in Nueva Ecija, the discharge of the pump will be 8.4 m^3d^{-1}.

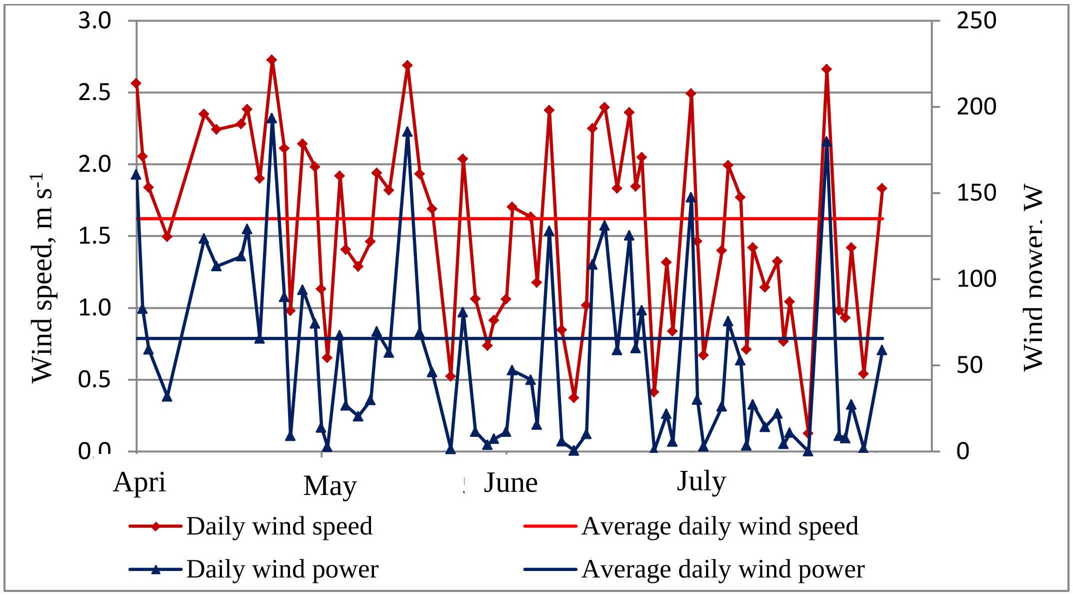


Figure 22. Relationship between wind speed and power (courtesy of Nghi 2010) collected at Tarlac, Central Luzon, Philippines.

5.3.2. Potential of the wind-pump: Estimation with 10-year weather data

Figure 23 shows the 10-year (2004-2013) average daily rainfall from the weather station at PhilRice, Nueva Ecija. The highest average daily rainfall was observed in the month of August with average 13.9 mmd^{-1} and lowest was in the month of January with average 0.2 mmd^{-1} only. The rainfall in 2005 and 2006 had the highest amount of daily average rainfall to almost 22 mm d^{-1} which were also observed in August and July, respectively. Rainfall usually started in the month on May until October then became very low to almost zero rainfall in December until March.

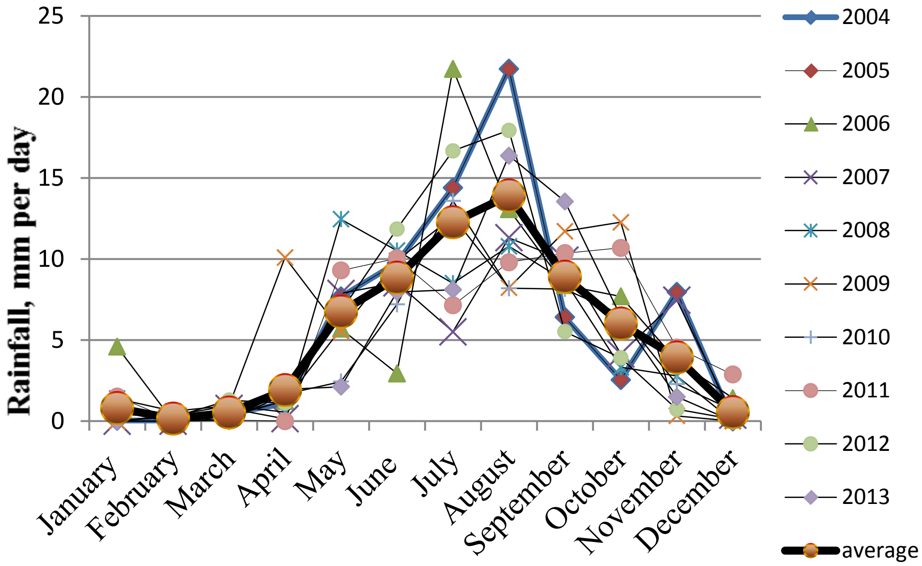


Figure 23. The 10-year rainfall data at PhilRice, Nueva Ecija, Philippines.

Figure 24 shows the 10-year (2004-2013) annual average wind speed data at PhilRice weather station. Strongest average wind speeds were monitored during December with 3.3 ms^{-1} and January with 2.9 ms^{-1}. This became weaker during the months of April until September of every year to only about 1 ms^{-1}. The year 2007 and 2008 had apparently strong winds in this period. The average prevailing wind speed favorable to wind-pump system was observed in the months from November to February, hence, remaining months' average fell below for starting up wind speed. It was also noticeable that wind during the low rainfall months was favorable to wind-pumping operation.

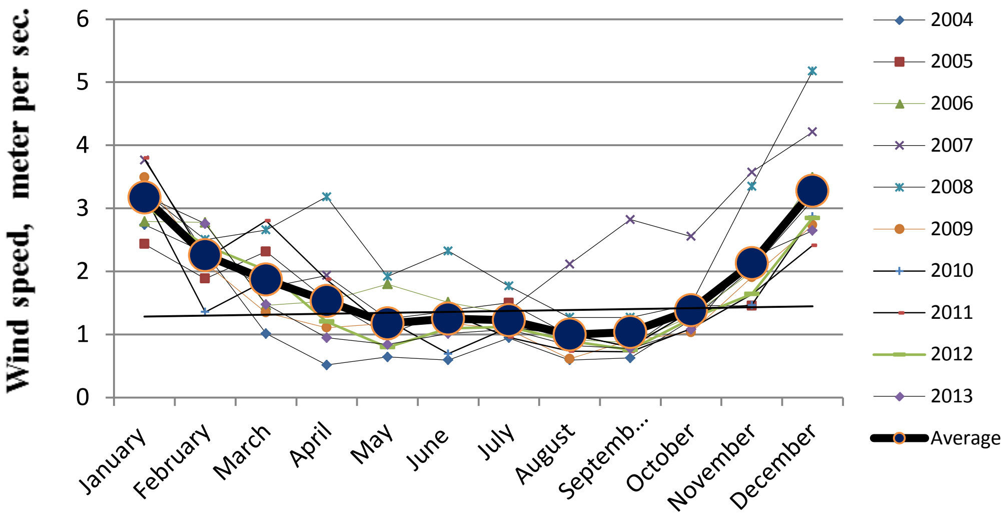


Figure 24. The 10-year wind speed data at PhilRice, Nueva Ecija, Philippines

Figure 25 shows the monthly change in rainfall, water pump output, and estimated water availability in comparison with water requirement for 1/4 ha of rice field. Water availability is the sum of rainfall and water output by the wind pump system, which was estimated based upon the weather data and the empirical equation in the section.

Rice cropping season in the Philippines commonly starts on every December and June, and are harvested every March and October for dry season and wet season crop season, respectively. Water requirement of rice crop are at the least 11 mmd^{-1} (Yoshida 1981). In dry season, therefore, supplying irrigation water for rice crop from wind-pumping alone will make it insufficient for one ha. However, the wind-pump may contribute to a supplemental role for irrigation. Assuming that 1 ha of rice field needs an average 11 mmd^{-1} for a growing period, 120 days, in a dry season, it is equivalent to 13,200 m^{3} ha^{-1}. If the water is irrigated by the sum of rain fall and pumped up water by engine, it may require 389 Lha^{-1}season^{-1} of diesel oil for water pump because the common diesel water pump has an ability to discharge 32.4 m^{3}h^{-1} with one liter of diesel oil. During dry season, a total of 1,717 m^{3} of water can be discharged by the wind-pump system, so the diesel oil needed for pumping up 1,717 m^{3} could be reduced. This corresponds to 53 L diesel oil per ha. In terms of greenhouse gas (GHG) emissions due to combustion of diesel oil, 140 kg CO$_2$eq could be reduced per ha.

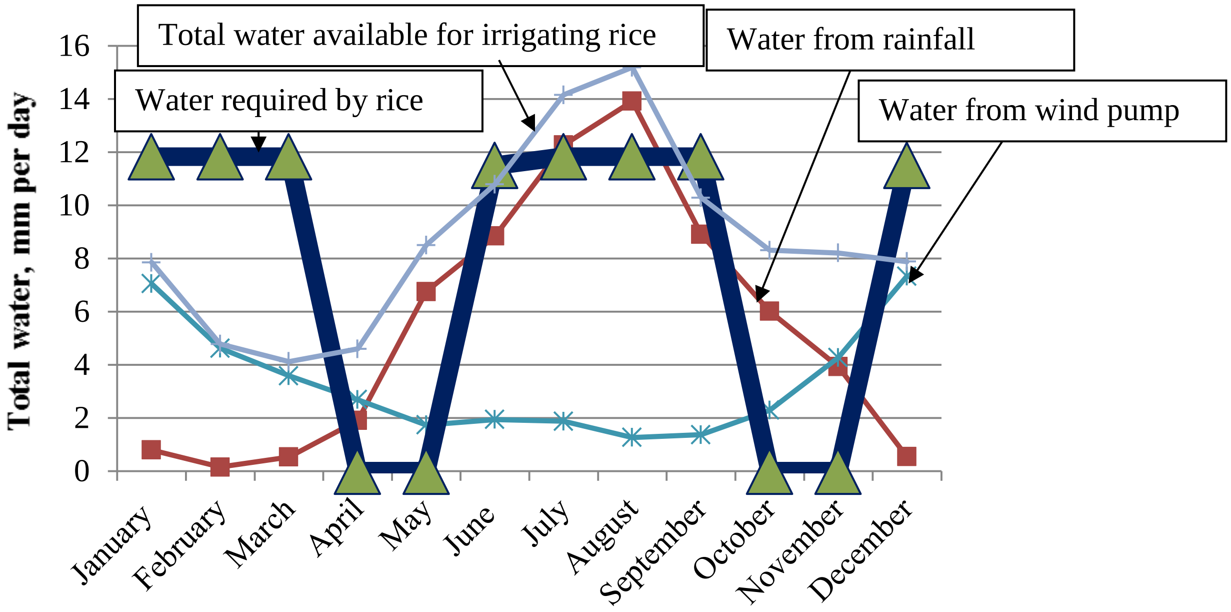


Figure 25. Monthly change of rain fall, wind pump output, and their sum in comparison with water requirement in 1/4 ha rice field

Thus, the wind pump system in this study has only a limited potential for irrigation to rice field under the weather conditions in Central Luzon. It may be needed to explore more suitable use of the present system such as drip irrigation to vegetables.

5.3.3. Evaluation of energy input and output and GHG emission of the wind-pump system

Table 12 shows energy input-output estimates for 20 years of wind pumping operations. The energy input of the wind-pump system was 25 GJ with raw materials being the biggest energy contributor at 23 GJ followed by welding at 1.8 GJ. Other fabrication activities contributed a very small amount of input to the system. Energy output was found at 38 GJ composed of pumped irrigation water by wind-pump system within a 20-year period. This showed that using the wind-pump system could give more benefit compared to the cost of fabricating the unit. The energy input-output ratio was 1.5 which indicated that the system is economically acceptable. It showed that wind-pump system could be used for smaller areas of rice crop. It could also be suggested to use wind-pump system for irrigation of high-value crops and other crops requiring lesser water and does not require total flooding.

The raw materials of wind-pump system were the major source of input energy. The weight of fabricated parts was the basis of energy input computation. The whole wind-pump system had a total weight of 1,158 kg consisting of base plate 75 kg, lower frame 428 kg, upper frame 254 kg, rotor 119 kg, and others. It indicates that improving the design of the present wind-pump system will further improve the input-output ratio.

Table 12. Energy input-output of windmill system.

Energy input			
	Raw materials		23,160
	Fabrication	Drilling	4
		Cutting	17
		Bending	17
		Machining	23
		Welding	1,826
	Total		25,046
Energy output			
	Irrigation water (20 years)		37,487
Input-output ratio			1.5

The GHG emission of irrigating rice crop by using engine-pump system minus the rainfall available during the dry season was 1 Mg CO_2 eq ha^{-1}. It was computed from the diesel fuel consumed by the engine-pump system to pump the water required to irrigate rice crops. When the wind-pump system was used together with the engine-pump system to pump water, the GHG emission was about 1 Mg CO_2eq ha^{-1}. This means that using wind-pump system during irrigation of rice crop could mitigate around 0.1 Mg CO_2 eq. ha^{-1}.

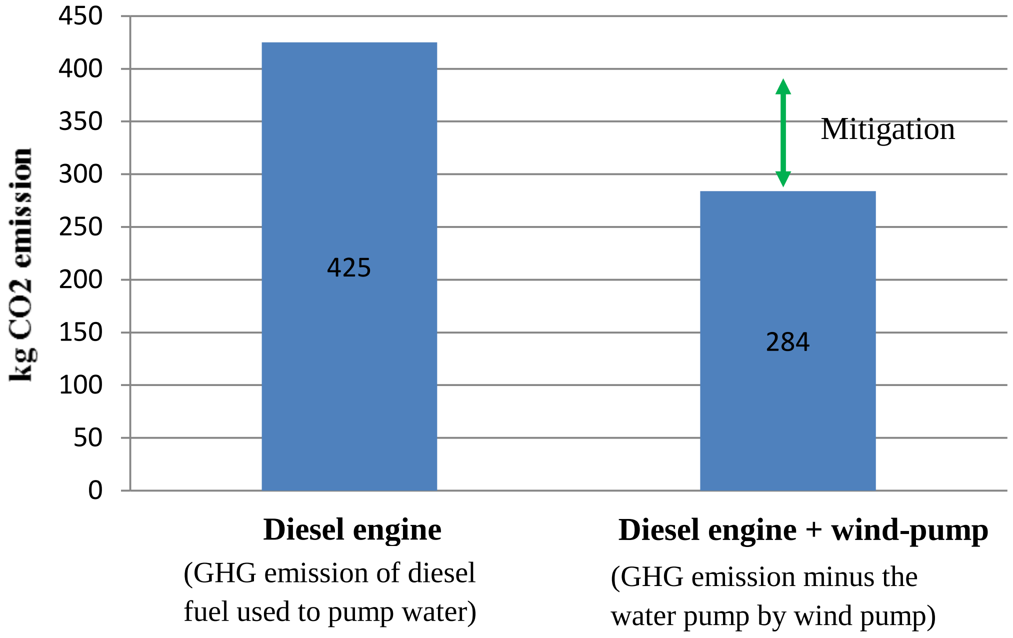


Figure 26. GHG emissions during water pumping for irrigation using full diesel engine and diesel engine + wind-pump system.

5.4. CONCLUSION

Performance and potential of the locally designed wind-pump system was evaluated in central Luzon by using the 10-year weather data. Energy input-output analysis for manufacturing the wind-pump system was proven to be feasible in 20 years of life. However, the wind-pump system in this study has only a limited potential for irrigation of rice fields under the weather conditions in central Luzon. It may be needed to explore more suitable use of the present system, such as drip irrigation of vegetables.

The GHG mitigated during its operation in the dry season pumping also had significant amount. The wind-pump system mitigated the GHG emission during water pumping by replacing the fossil fuel with naturally available source of energy.

Chapter VI

Mitigation Technologies

Evaluation of an Up-Draft Rice Husk Gasifier System for Powering Village Rice Mills in the Philippines

6.1. INTRODUCTION

The increasing cost and declining supply of fossil fuels have spurred scientists to search for alternative energy sources. A few years ago, rice husk (RH) gasification systems have attracted attention as an alternative energy source in Southeast and East Asian countries, where rice is a staple crop. China and Thailand have led the development of several big gasifier designs for electric generation with output from 1-9.8MW (Zhou et al 2012, Thipwimon 2004).

Rice husk gasification is the process whereby RH is converted to “producer gas,” a combustible mixture of carbon monoxide (CO), hydrogen (H_2), and a small amount of methane (CH_4), through partial burning in an environment in which the supply of air is limited. Producer gas can be used as fuel for heating as well as for operating internal combustion engines that power electric generators (Zhou 2012; Chungsangunsit 2004). The use of this technology offers several advantages: gasification systems operating at rice milling factories can mitigate the problem of improper RH disposal, which negatively impacts both the environment and human health, while converting a considerable fraction of this biomass to useful energy, in the form of producer gas that can power rice mills, reducing fossil fuel utilization and consequent resource depletion, while lowering operation costs.

The intensive rice production in the Philippines, and the proportionately massive amount of RH residue produced, make the use of gasification technology especially relevant. Annually, about 3.2 million metric tons of RH are produced by roughly 10,000rice millers dispersed nationwide (BAS 2008). This amount of biomass is equivalent to up to 1.7 GW-h of electricity, if used for power generation, but the minimal implementation of RH biomass to energy systems at present means that improper disposal is ongoing (Figure 27). Thus, development of RH gasification systems is a promising approach to reducing the deleterious effects of RH waste while improving the efficiency of rice production.

Figure 27. Traditional disposal of RH in the Philippines: a) at the back of a ricemill; b) along a roadside. (photos courtesy of JFAE)

In the Philippines, a small rice milling factory is typically located in each village that cultivates rice. The majority of these small operations use single-pass milling machines that have a processing capacity of 0.3–1.8 t h^{-1}, which adequately mill the remaining paddy supply of households in the village. A 1986 study by the University of the Philippines Los Baños showed that the majority of rice millers use Engelberg hullers powered by diesel engines (Paras 1984), but due to outdated design and less efficient performance, adoption of small rubber roll hullers that provide higher milling recovery became popular (See 1986). In 2003, a small and simple up-draft RH gasification system was installed by the New Energy and Industrial Technology Development Organization (NEDO, under the Ministry of Commerce and Industry of Japan) at the Philippine Rice Research Institute (PhilRice), a government research institute. Located roughly 150 km north of Manila, PhilRice works on rice-related studies, including machine development. The system was used in a collaborative project that explored the use of low calorific RH as a fuel for electricity generation and production of carbonized rice husk (CRH) as a useful byproduct of the gasification process (Hoki 2006).

Up-draft gasifier testing shows that it is more thermally efficient than downdraft gasifier designs, because ascending gases pyrolyse and dry incoming biomass, transferring heat so that the exiting gases are relatively cool (90°C) (Hoki 2006). Historically, the principle of up-draft gasification was widely used for coal gasification, starting in 1850 (Anon 2012). In an up-draft gasifier system, the airflow direction is the same as that of the gasses in the fire zone. Although the operation of the PhilRice's gasifier was smooth with RH input at the top of the reactor and CRH removed from the bottom, this mode of gasification produces large quantities of tar and smoke; so, the resulting producer gas must be thoroughly cleaned, especially if it is intended for use as fuel for internal combustion engines.

Although the up-draft RH gasifier installed at the PhilRice location is fully operational, it has not been used to power a rice mill, despite the potential for RH gasification systems to supply electric power for small-scale rice milling operations. The objectives of the present work are (1) to examine the technical performance of the PhilRice's up-draft RH gasification system as a possible alternative source of energy for operation of single-pass rice milling factories; (2) to discuss the potential of introducing up-draft RH gasification systems to village rice milling factories; and (3) to evaluate its mitigating effect during rice milling operation.

6.2. MATERIALS AND METHODS

6.2.1. Up-draft gasification system

The up-draft gasification system installed at PhilRice includes a gasifier reactor, a scrubber, two condensers, a filter, a gas storage unit, and an internal combustion engine coupled to an electric generator (Figure 28). Seven electric motors perform various functions when the system is operating, requiring 3 kW of power that is supplied by the grid. Rice husk material is loaded by a bucket elevator that lifts it to a screw conveyor that feeds the RH into the reactor. The reactor space in which RH gasification occurs is 1.0m in diameter and 1.8 m high (1.4 m^3 total reactor volume).As a safety measure, two pressure relief outlets made from a pipe through a drum of water are provided, one at the bottom and the other at the top lid. A regulated blower supplies air to the reactor, delivering a maximum of 340 L min^{-1}.

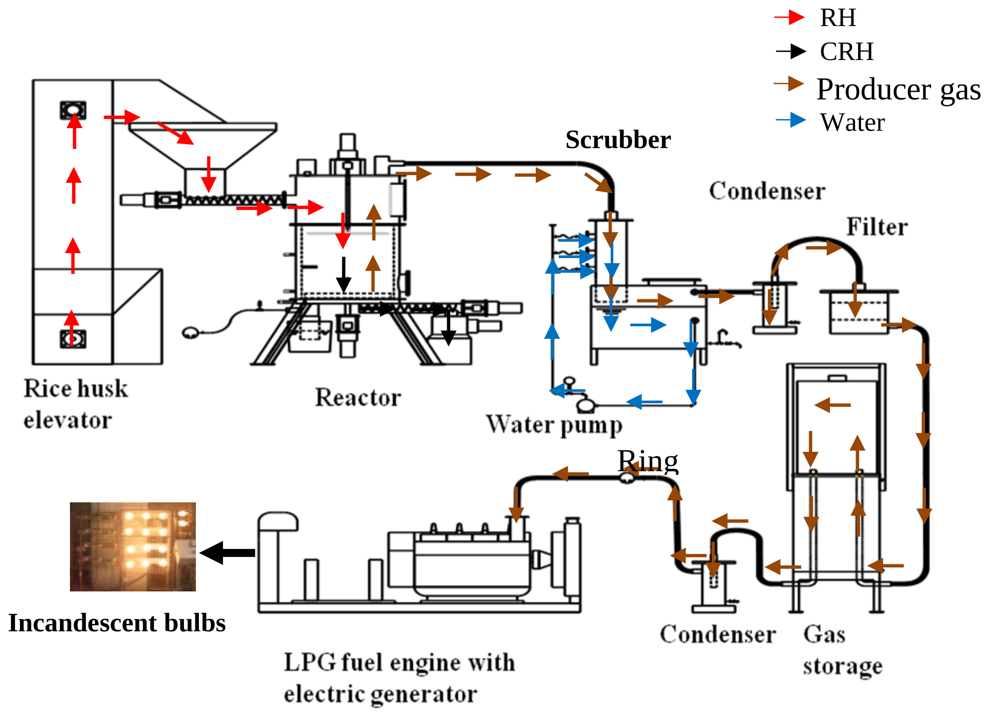


Figure 28. Schematic diagram of the PhilRice's up-draft gasification system.

During the gasification process, the producer gas output by the reactor passes through a recirculating water scrubber system, powered by an Ebara Corporation, Japan M7 model pump (requiring 1 kW at 60 Hz), which sprays the incoming gas with water to lower its temperature and remove particulates and tar. The cooled producer gas then passes through a condenser and filter system that further reduces the tar content and removes moisture, after which it flows to a gas storage unit, a secondary condenser downstream from the storage unit, and thence to the internal combustion engine. The flow of producer gas is maintained by a ring blower located between the second condenser and the internal combustion engine that powers the electric generator. The ring blower is a 1 hp E.G. & G. Rotron, operating at 3450 rpm (200–230 v, 60 Hz).

The installed internal combustion engine is an 8-valve, 4-cylinder OHV, 2Y model with an aerodynamic volume displacement of 1.8 L from ISSI Corporation, Japan, and a power rating of 63 kW at 5000 rpm and 51 kW at 4600 rpm. The electric generator which is directly coupled to the engine shaft is a three-phase NEG-600 model (60 kVA rating) that outputs 173 A at 200 v via a 1500 rpm brushless AC generator (Nippon Sharyo Seizo Kaisha Ltd., Nagoya, Japan).The internal combustion engine is first started using LPG and operated for a few minutes before it is switched to producer gas operation.

The RH used in this study's operational tests was collected from the rice milling factory at PhilRice and had 12% moisture content. The reactor was initially started by directly loading three12-kg bags of RH, adding 0.5L of kerosene, and igniting the material with flaming pieces of paper. Additional RH was loaded when sufficient combustion was observed inside the reactor. The startup time interval was measured as the time from when the input RH was ignited until electricity was generated using producer gas. The ignition process was continued until a good fire was achieved inside the reactor then the reactor window was closed. The flammability of the producer gas was manually tested by using a lighter at a small bleeder pipe upstream of the engine intake manifold. The engine was then slowly switched from LPG to producer gas using a ball valve when the gas was readily combustible.

Temperatures in the reactor were measured with three 6.4-mm diameter SK-type thermocouples placed at top, middle, and bottom of reactor; the thermocouples were capable of measuring temperatures up to 950°C. Water temperatures at pressure relief of reactor, scrubber, and condenser, were measured by dial-type thermometers and surface temperatures of the reactor, scrubber, bulb, engine, and gas holder were measured using an optical pyrometer.

The electric energy output of the RH gasification system was measured by means of a power clamp meter and with a variable number of 1 kW incandescent bulbs acting as the load. The number of lit bulbs was used to determine the power output of the system. During these operations, the performance of the system was monitored, and the energy input and output were estimated based on data gathered based on energy coefficient from literature.

6.2.2. Evaluation of Central Luzon rice milling factories

The number of rice milling factories operating in the Philippines was obtained from a national survey conducted by PhilRice in cooperation with other government agencies (Philippine National survey of postharvest facilities, 2008).The rice mills were categorized as single-pass or multi-pass. Single-pass rice mills have a de-husker and polisher combined in a single machine (See 1986), whereas the de-husker, polisher, sorter, and other components are present as separate machines in multi-pass mills. Milling factories with capacities greater than five t h^{-1} were classified as commercial factories. Data were analyzed according to factory size and distribution among provinces.

In 2012, the author visited 5 representative small rice mills in Nueva Ecija province, Central Luzon, and operators were interviewed. Information such as rice mill capacity, power source capacity, rice husk disposal practices, and other related information were recorded.

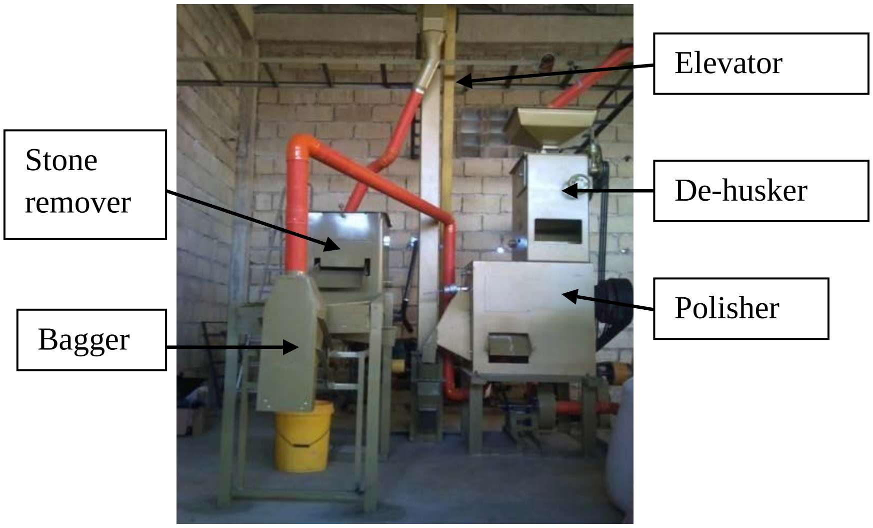


Figure 29. The single-pass village rice mill in Nueva Ecija province, Central Luzon. (Photo courtesy of JFAE)

6.3. RESULTS

6.3.1. Up-draft rice husk gasification

With an average RH input of thirteen 12-kg bags, the voltage range of the generated electric output was 173–240 V. At consumption rate of 78 kg h^{-1} the energy output was 13 kW. The average CRH production was 28 kg for every operation and conversion rate was 18% of RH. The average temperature inside the reactor was 780ºC, well within the allowable temperature range for RH gasification. Although the composition of the resulting producer gas was not measured, a previous study (Hoki 2006) using the same up-draft RH gasification system operated with the same feedstock and the same conditions showed that it is composed of 15–20% CO, 5–7% H_2, and 1–3% CH_4, and has a caloric value of 4,000 MJ m^{-3}.

One cubic meter of water was used during each session of RH gasifier operation. This includes water for the scrubber that cools the hot producer gas exiting the reactor and removes impurities, and water for the condensers and filters. The producer gas was ultimately cooled to a safe temperature for input to the internal combustion engine. The average water temperature in the scrubber was 39ºC; the initial water temperature of 28ºC increased to 42ºC at the end of the operation. We observed that with 600 L of water used at the scrubber cooling system, 7L of tar (1.2%) were collected during the spray-cooling process. The generator rotated at a calculated average of 1,242 rpm. With faster rotation of the generator, the resulting output voltage is higher. Increasing the electric load, by increasing the number of incandescent bulbs in the circuit, slowed the rotation, and lowered the voltage.

Operation of the up-draft RH gasification system requires the input of energy in several forms, and yields energy in the form of generated electricity and waste products (Table 13). Energy input was provided in the form of RH (1,084 MJ h^{-1}), electricity to power motors (36 MJ h^{-1}), water (0.1 MJ h^{-1}), kerosene (3 MJ h^{-1}), lubricant (5 MJ h^{-1}), and LPG (12 MJ h^{-1}). Total energy output of 313 MJ h^{-1} was obtained as generated electricity (167 MJ h^{-1}), CRH (114 MJ h^{-1}), and tar (32 MJ h^{-1}). The gasification efficiency for the generation of electricity was 14.6%, a value within the range of those obtained in previous research (Hoki 2006).

Table 13. Energy input/output during RH gasification.

	Material	**Amount of Input**	**Energy (unit)**	**Energy (MJ h^{-1})**
Gasifier	RH	78 kg h^{-1}	12.8 MJ kg^{-1}(Yokoyama 2000)	998
	Electricity for gasifier	3 kW	11.9 MJ kWh^{-1}((Esengun 2006)	36
	Water for gasifier	1 m^3 in 8 h	0.6 MJ m^{-3} (Esengun 2006; Pimentel 1979; Ozkan 2003)	0.1
Engine-generator set	Kerosene	0.5 L in 8 h	46.3 MJ L^{-1}(ASTM 2013)	3
	Water for engine	1 gal h^{-1}	0.6 MJ m^{-3} (Esengun 2006)	0
	Lubricants/Oil	0.1 kg wk^{-1}	35.9 MJ kg^{-1} (ASTM 2013)	5
	LPG	2 kg d^{-1}	46.1 MJ kg^{-1} (ASTM 2013)	12
			Total input	**1,053**
		Output		
Gasifier	CRH	13 kg h^{-1}	8.5 MJ kg^{-1}(Iqbal 2007)	114
	Tar	7 L (1.2% of	36 MJ kg^{-1} (NPL UK 2012)	32
Engine-generator set	Electricity	13 kW	11.9 MJ kWh^{-1} (Esengun 2006)	167
			Total output	**313**

Our results indicate that the power output of the PhilRice up-draft RH gasification system is inadequate to operate small-scale (~1 t h^{-1}) rice milling factories that typically require 30 kW. Provision of this amount of power will require a RH gasification system that incorporates an improved design, is operated under improved conditions, or both.

6.3.2. Current status of rice milling factories in Central Luzon

In rice-producing areas in the Philippines, local dealers and farmers store their rice un-milled and bring it to a local factory for milling as needed. Data indicated that among 25,906 rice milling factories in the Philippines, more than 95% (24,980) are equipped with a small rice mill. In Central Luzon, which accounts for 18% of the country's total rice production (BAS 2008), roughly 12% of factories were equipped with multi-pass rice mills, i.e., 255 factories out of 2,165 (Figure 30). In Nueva Ecija province, which in 2008 accounted for 46% of the region's production, 515 small-scale rice mills had an annual milling output of 387 thousand metric tons. Most RH produced by the village factories servicing local farmers and rice dealers is dumped and burnt elsewhere, circumstances that are typical among the highest rice-producing provinces in the Philippines.

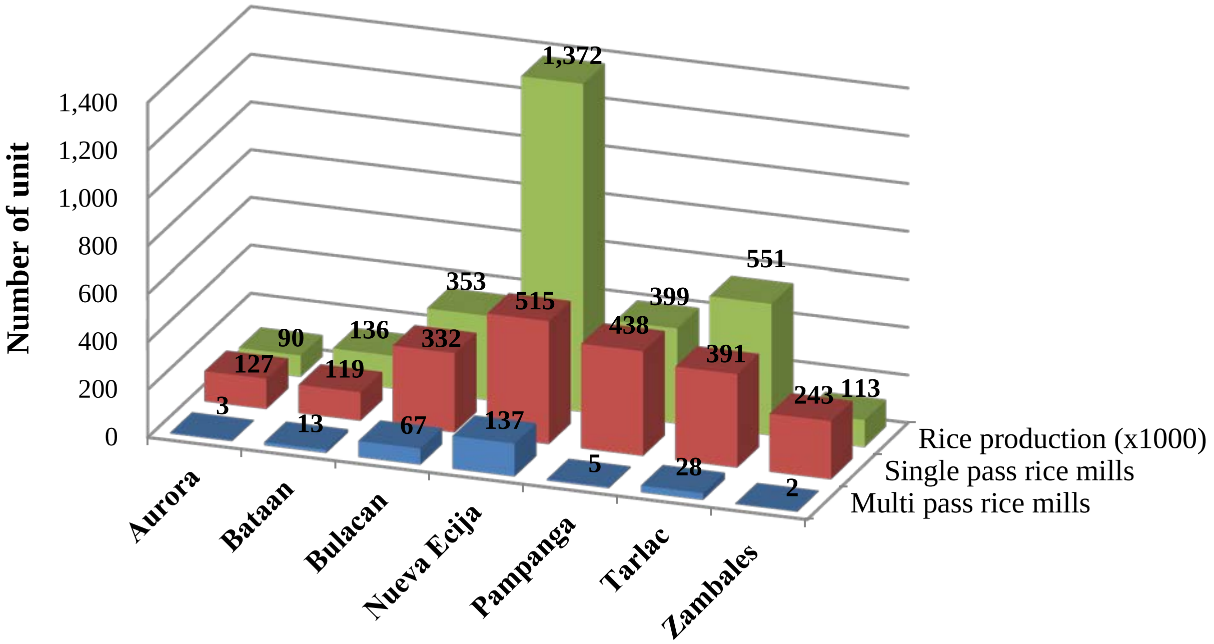


Figure 30. Rice production volume and number of rice mill in Central Luzon, 2008.

Most rice milling factories with single-pass mills (including the PhilRice facility) use automotive engines or electric motors to provide approximately 30 kW of power needed for operation. A typical factory's main components and their power requirements include the following: huller and whitening machine (15 kW), loading system (5 kW), and de-stoning machine (4 kW). Such rice milling factories have an average capacity of 5–7.5 t d^{-1}, processed during 5–10 hours of operation.

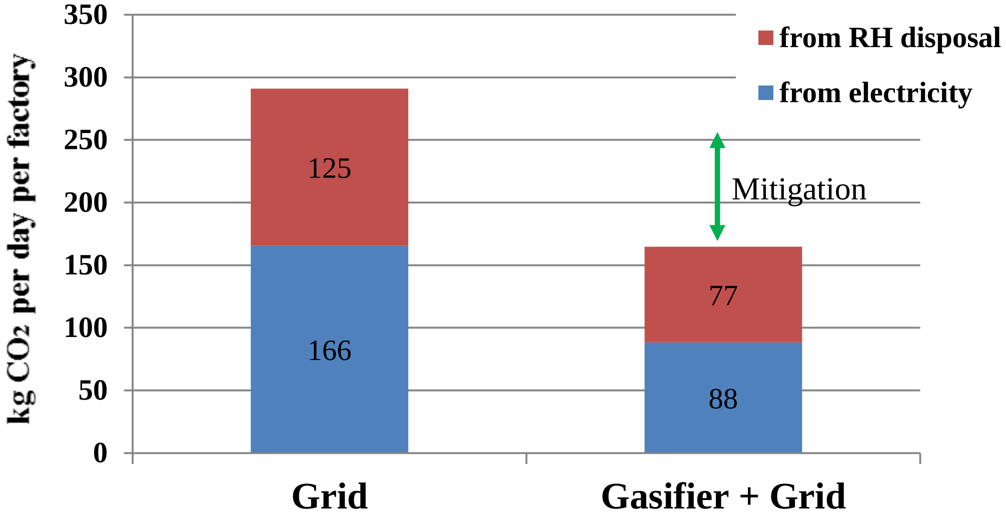
During the interviews carried out locally, it was revealed that millers operate at the request of customers mostly residing in the same village, and charge an average of 0.05 USD kg^{-1} of milled rice. The average milling recovery rate was 62% but actual values depend on the quality of the un-milled rice. Part of the RH produced as a milling byproduct is given away for local household use, and some are sold (at 0.025 USD kg^{-1}) to duck husbandry operators for use as bedding (litter).

6.4. DISCUSSIONS

Most rice milling factories in rural areas of the Philippines are small, employ a single rubber roll huller and whitening machine, have a milling capacity of roughly 1 t h^{-1}, and require about 30 kW of electric power for operation, including lighting. The results of evaluation showed that the present design was not capable enough to power a small rice mill in the Philippines.

Utilization of RH gasification systems might reduce RH disposal costs because it does not need transportation to remove it from the rice mill area and lessen the negative impact upon the environment and human health caused by open-air burning of RH.

Up-draft RH gasification systems for power generation in Nueva Ecija province rice milling factories can utilize an otherwise problematic byproduct of rice cultivation, i.e., the roughly 1,237 tons of RH annually produced. At the national level, the Philippines could make use of roughly 1.2 Mt of the RH produced annually as a valuable fuel source for gasification systems. Furthermore, approximately 18% of the RH input to gasifier reactors is discharged as CRH, a carbonaceous material of considerable utility. This bio-char is recognized as a particularly attractive material for soil amendment. The application of CRH to arable soils not only improves crop growth, it also provides superior carbon sequestration than has its use as a secondary fuel.



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	1,600
Gasifier + grid, kgd^{-1}	625	976

Figure 31. GHG emissions of an 8 t h^{-1} rice milling factory with full power from grid versus Gasifier + grid.

The mitigation effect of the RH gasifier system was related to the electricity required to power its everyday operation and from RH by-product which was disposed and burnt in open field. The rice mill factory emitted around 166 kg CO_2 eq d^{-1} due to its electricity requirement and 125 kg CO_2 eq due to RH by-product from everyday operation. However, when the RH gasifier system supplied electricity to rice mill, it emitted 88 kg CO_2eq d^{-1} and 77 kg CO_2eq d^{-1} for its electricity and RH disposal, respectively. Therefore, using the RH gasifier system could mitigate a total of 126 kg CO_2eq d^{-1}.

6.5 CONCLUSION

The up-draft RH gasification systems can be used to generate all or a portion of the electric power required for the operation of small-scale rice milling factories in central Luzon, Philippines. However, fully meeting the power needs of such factories will depend on improved system designs that provide higher RH processing capacity and more electric power than the PhilRice system tested in this study. Such systems consume a rice milling by-product produced in huge volumes; other disposal options are problematic. It was proven that the RH gasifier, although not enough to supply electricity for small rice mill, could mitigate GHG emissions during its operation. This was due to reduced electricity dependent to the electric grid and use of the RH produced by rice mill instead of burning it in open field.

The CRH biochar produced by gasification is attractive as a nutritious soil additive. Given further development and broader adoption, such systems may boost the efficiency of local rice production while decreasing harmful environmental consequences of RH disposal.

Chapter VII

General Discussion and Conclusion

Rice is a staple food in Philippines, and its production is the most important agricultural activity. To be able to meet the100% self-sufficiency of rice in the country, productivity of rice has to be improved with intensive management. This may be achieved by introduction of new technologies such as high yielding varieties, use of more fertilizers and adoption of farm mechanization. This may increase energy inputs and GHG emission derived from rice production in the Philippines. For more sustainable rice production in the Philippines, it is necessary to grasp the GHG emission of rice cultivation and to develop mitigation technologies. In this study, therefore, the GHG emission and energy component of rice production in the Philippines were comprehensively quantified from lifecycle viewpoint. Secondly, some mitigation technologies were evaluated to possibly reduce GHG emission.

The amount of energy input and output in the Philippines were successfully analysed (Chapter 2). Irrigated rice with mechanized system had higher energy input compared to manual because of higher farm inputs application and fossil fuel used. The utilization of inputs such as fertilizer, high-yielding rice variety, pesticides, and farm machinery substantially increased the energy input that resulted in reduced cultivation cycle and increased yield potential which is happening in developed countries, like Japan and the U.S. However, it also increased the production energy input that resulted to a lower output-input ratio. Higher output-input ratio of rice production in the Philippines was brought by lower utilization of farm inputs.

The average output-input ratios were arranged in ascending order for manual, direct seeding semi-mechanized, transplanted semi-mechanized, and mechanized. The utilization of inorganic fertilizer specifically that of nitrogen, fuel for machinery, and seeds contributed to 80% of energy inputs in rice production. The study in Chapter 2 shows that rice production in the Philippines is still largely dependent upon human labor and that the output-input ratio was higher than those of developed countries.

To face with global warming, it is a pressing issue to mitigate GHG emission from human activities. In Philippine rice production, it is important to evaluate the current status of GHG emission, because we have only limited information on GHG emission through a life cycle of rice production. In Chapter 3, GHG emission from rice production was evaluated based upon life cycle inventory analysis. .

Although rice yield was higher, irrigated rice was proven to emit higher GHG emission compared to rain-fed rice ecosystem as a result of continuous flooding of irrigation water in the lowland areas. The largest proportion of the emission was derived from soil through soil microbiological processes and fertilizer utilization, such as CH_4 and N_2O emissions from soil. It was noticeable that rain-fed areas with limited supply of water during the growing period emitted lesser GHG emission compared to irrigated fields. Results of this study showed that GHG emission of rice cultivation in the Philippines was lower than that of Japan and other temperate countries, perhaps due to lower fertilizer application rate and lower utilization of farm inputs, and lower mechanization. Higher utilization of farm inputs resulted to higher GHG emissions brought about by emission of fossil fuel. So, to attain an increase in rice production, additional irrigation systems have to be developed and increasing utilization of farm inputs such as fertilizer, machine, and fuel is needed. However, the inevitable increase of GHG emission will be a great challenge to rice stakeholders.

By using the Life Cycle Inventory Analysis, mitigation process such as adaptation of mid-season drainage or the alternate wetting and drying was identified. Intermittent flooding of rice fields reduced net emission which was observed similar to that in the rain-fed areas. Utilization of carabao as draft animal in rice production may be replaced by the locally manufactured handtractor. It was found that activities using handtractor emitted lesser GHG to the environment compared with carabao but such recommendation may result to social impact due to conservation of traditional farming practices in the countryside in the Philippines. Furthermore, rice straw burning in the field emits lesser GHG compared to straw amendment into soil due to methane produce during anaerobic decomposition. However, the air pollution and health hazards created may be a risk to humans and the environment.

In Chapters 4, 5, and 6, possible technologies for mitigating GHG emissions in rice production system were investigated. In view point as an agricultural engineer, who is improving agricultural machines, mechanize rice farming could save time, increase efficiency of farm inputs, increase yield and help farmers. It is not well known how these farm machineries can contribute to the mitigation of GHG emissions. This study evaluated several farm machines as mitigation technologies.

Land preparation is one of the processes which emit significant amount of GHG. Improvement of agricultural machinery may be a promising way for this objective. The study in Chapter 4 showed that the ride-on tillage implement, a simple modification to hand tractor attachment to ease operation, can accomplish all major land preparation operations in rice production, such as: levee-side plowing, plowing, harrowing, and leveling. The incorporation of the newly developed ride-on attachment to the customarily used handtractor will enhance its capacity and gave more comfort to operator. Replacing the carabao with the conventional handtractor could substantially reduce GHG emission. Furthermore, enhancing the conventional handtractor by ride-on attachment could be of more advantage in term of GHG emission. A considerable amount of GHG emission will be mitigated when carabao will be replaced with handtractor.

The energy output-input analysis showed the pumping up of irrigation water using an engine occupies a large part of energy input. The abundance of renewable energy in the Philippines such as wind power may be useful for pumping of irrigation water for rice. In Chapter 5, the locally designed wind-pump system was evaluated according to its performance and theoretical water output using the 10-year weather data. It was proven that it would be an alternative technology for irrigating rice crop with lesser fossil fuel in the rain-fed areas in the Philippines. Due to abundant wind in the area, it could be used as supplemental irrigation in combination with rainfall in Tarlac province, Philippines.

Utilization of biomass is also another option for mitigating GHG emission. Rice husk which is largely disposed elsewhere can be used to generate electricity through a gasification system. Disposal of rice husk in the Philippines was not regulated so rice millers just dispose rice husk beside roads, rivers, and vacant lots which pose risk to human health and environment. In Chapter 6, therefore, the performance of the up-draft gasifier to power a rice mill and to ameliorate RH disposal was evaluated. The generated power from the gasifier fell short in operating a 1 t h^{-1}rice mill; however, reassessment of the operation indicates that this type of gasification system may be technically feasible if properly modified. Given further development and broader adoption, such systems may boost the efficiency of local rice production while decreasing harmful environmental consequences of RH disposal. The gasifier system reduced the GHG emission of electricity and burning of rice husk. It is a good alternative technology for rice mill to ameliorate RH disposal.

In conclusion, the comprehensive assessment of energy input-output and GHG emission of rice production in the Philippines based on life cycle thinking lead us to a possible recommendation of improving rice production that promotes protection of environment and mankind. Thorough evaluation of each rice production process gave some insights on how to reduce GHG emission and possibly suggest options to improve it. Self- sufficiency of rice in the Philippines could be attained following the recommended improvements in the production process. If the increase in energy input in rice production is proportional to the increase in rice yield, the energy ratio of rice may not significantly differ from the present amount in this study. The GHG emission should then be increased with higher utilization of farm inputs.

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