Philippine Journal of Crop Science (PJCS) 2023, 48 April (1):54-62

FULL PAPER

Assessment of Conventional and Highly Mechanized Rice Production Systems Using Life Cycle Assessment (LCA) Approach

Elmer G. Bautista*, and Manuel Jose C. Regalado

Rice Engineering and Mechanization Division, Philippine Rice Research (PhilRice), Maligaya, Science City of Muñoz, 3119 Nueva Ecija, Philippines.
*Corresponding author, egbautista@exchange.philrice.gov.ph

A well-managed and judicious utilization of energy from fossil fuel, chemical fertilizers, and pesticides in intensive rice production may favor less GHG emission and not contribute to global warming as well. To avoid high emissions in rice production, there is a need to thoroughly look into factors that contribute to increased emissions and recommend ways of reducing them. This study used LCA (Life Cycle Assessment) to compare farm inputs in conventional or common farmer's practice and highly mechanized rice production systems through actual field experimentation. Generally, inbred and hybrid varieties had similar energy efficiencies, as well as GHG emissions for both dry and wet seasons. Energy inputs (10,714 MJ/ha) of transplanted rice production for both conventional and highly mechanized farming were higher compared to direct-seeded rice. It also had higher cost of production owing to more human labor-days employed, and had higher GHG emissions. Rice production during the dry season had higher energy efficiency, owing to lower energy input, production cost, and GHG emissions. Direct-seeded rice using machine is advantageous in terms of cost, number of human labor-days, energy input, GHG emissions, and time of machine operations. Conventional rice production cost was 39.9 % higher compared to highly mechanized, resulting from the number of human labor employed and time of machine operations. Energy output-input ratio and GHG emission were higher in highly mechanized production compared to conventional. Additionally, mechanized production in the dry season had higher yield, and higher energy efficiency compared to conventional.

Keywords: conventional production, energy input-output, GHG emission, highly mechanized production, LCA, rice

INTRODUCTION

Rice production in the Philippines is predominantly done using a combination of human, animal, and machine or engine power sources (Lantin 2016). In semi-mechanized areas, local power tillers, irrigation pumps, mechanical threshers, and rice mills are used (Bautista 2003; Amongo and Larona 2015). The country has one of the lowest levels of mechanization in Asia at 1.23 horsepower per hectare (hp/ha) for all crops, and 2.31 hp/ha for rice and corn (DA 2013). Major reasons are: low buying power of farmers (Bautista 2003), farm labor or the rural landless workforce is still abundant in many areas (Bordey et al. 2016), and small landholding per farmer. Rice is grown in 3.83 million farms, which cover a physical land area of 3.9 million hectares (PSA 2015), hence, the national average individual farm size is less than a hectare. Since the passage of the Agriculture and Fisheries Modernization Act of 1997, the government has been striving to modernize agriculture to lower cost of production and become globally competitive (Bautista et al 2022). The promotion of agricultural technologies as key elements to raise the efficiency of farm operations and inputs, to lower production costs, and to reduce post-harvest losses is being prioritized.

Utilization of modern farm inputs, such as high-yielding varieties, inorganic fertilizers, pesticides, and farm machines has substantially increased rice productivity, reduced the cultivation cycle, and maximized yield potentials. Particularly, hybrid and high-quality inbred seeds were introduced, irrigation facilities were developed, and loans and subsidies were provided to encourage farmers to produce more yields. These can help address poverty alleviation and food security, enhance agricultural competitiveness, and foster sustainable development to increase farmers' income (Rodulfo et al. 2008; Cao et al. 2014).

Climate change is a threat to agriculture as a consequence of greenhouse gas (GHG) accumulation in the atmosphere (Johnson et al. 2007). Agriculture contributes 10–12% of the total global anthropogenic GHG emissions (Smith et al. 2007) and 32 percent of the global anthropogenic non-CO_2 GHG emissions (USEPA 2006). Rice fields have been identified as essential source of 40% anthropogenic methane and biogenic emissions (Corton et al. 2000). The climate of the Philippines is tropical and maritime characterized by relatively high temperatures ranging from 25.5-33.9°C, high humidity, and plenty of rainfall varying from 965 mm to 4,358 mm annually. Fortunately, the rainy-season months coincide with the rice cropping season that uses rainfall for irrigation. Central Luzon has two pronounced seasons: dry from November to April and wet from May to October, which permits farmers to grow rice within the period. The Philippines is one of the most affected regions by climate change as it has been experiencing severe natural calamities, such as floods, typhoons, and drought or dry spells. These phenomena are more devastating in the tropics than in other climatic zones (UNFCCC 1999).

Traditionally, products were designed and developed without considering their adverse impacts on the environment. Factors considered in product design included function, quality, cost, ergonomics, and safety. No consideration was given specifically to the environmental aspects of a product throughout its entire life cycle. Consequently, rice production needs to improve in terms of yields due to fast increasing population. Without addressing impacts from the entire life cycle of a rice production, one cannot resolve the environmental problems accruing from the its production. Therefore, it is a very challenging task to increase rice production to feed the burgeoning population using modern and advanced technologies, knowing that more GHGs emitted contribute further to climate change (Ngonidzashe 2018). Production intensification with lower GHG emission level is the greatest challenge in rice agriculture. In terms of cultivation environments and agricultural practices, rice production in the Philippines is different from those in temperate countries such as Japan, China, Korea, and others. The tremendous utilization of energy from fossil fuel, chemical fertilizers, pesticides, machinery, and electricity (González et al. (2020).) to support intensive production has resulted in remarkably increased GHG emissions thus causing global warming, which became the most serious problem of humankind today.

Basic sources of power for rice production are human labor, animal, and machine which are dependent on farm size, cultural practices, soil conditions, and topography. It was found that activities using hand tractor, which is commonly used in the country for land preparation and transport, emit less potent greenhouse gas, i.e. carbon dioxide (CO_2), to the environment compared with using the carabao or water buffalo (Bautista and Saito 2015). A water buffalo emits methane (CH_4), which has more than twentyfold global warming potential than CO_2, at 56 kilograms per day by enteric fermentation and 3 kg/d from its manure (IPCC 2006).

Many factors challenge the capability of farmers and researchers to produce more rice (Bautista et al 2022) and at the same time reduce GHG emissions. It therefore becomes necessary to investigate the factors that contribute to high GHG emission involved in rice production. Understanding the sources of emissions can lead us to a better formulation of mitigating measures and will be the basis of managing them. We postulate that to intensify rice production, it should be highly mechanized not only to improve efficiency and shorten production and postproduction periods but also to reduce GHG emissions. This study was conducted to evaluate farm productivity and competitiveness of rice production systems through field experiments. The Life Cycle Assessment approach was used to assess the environmental impact of all stages of rice production from land preparation to harvesting including input materials and machines used during production (Bautista and Saito 2015). Specifically, the study assessed the energy input-output ratio and GHG emission in conventional and highly mechanized rice production systems using hybrid and inbred varieties, reduced and conventional tillage, and direct-seeded and transplanted methods of crop establishment.

MATERIALS AND METHODS

Site description

Actual field experiment was conducted within a four-hectare rice farm of the Rice Engineering and Mechanization Division located at the eastern part of PhilRice's Central Experiment Station, Science City of Munoz, Nueva Ecija (Figure 1) with GPS coordinates of Latitude 15.675491 and longitude 120.864332. The farm has a level topography and its soil is Maligaya clay (Vertic Tropaquept).

Figure 1. Location map of the field experiment inside PhilRice-CES

Experimental design

The experiment consisted of 24 equally sized plots (1,200 m^2 each) laid out using RCBD in split-split-split plot design with production system (conventional and highly mechanized tillage) as main plot treatments, and cropping season (dry and wet), variety (inbred and hybrid), and crop establishment (transplanted and direct-seeded) as sub-plot treatments with three replications. It was conducted for four consecutive rice croppings (2016 dry season to 2017 wet season). Highly mechanized production system meant that all field operations were done mechanically using customarily available machines, such as one pass of floating tiller after four-wheel tractor rotovation, mechanical transplanting or manual drum seeder, and combine harvesting. On the other hand,

Table1. Treatment of the field experiment

Plot number	Used variety	Establishment method	
Plot 1	Inbred	Transplanted	Conventional
Plot 2	Hybrid	Transplanted	
Plot 3	Hybrid	Direct seeded	
Plot 4	Inbred	Direct seeded	
Plot 5	Inbred	Transplanted	Highly mechanized
Plot 6	Hybrid	Transplanted	
Plot 7	Hybrid	Direct seeded	
Plot 8	Inbred	Direct seeded	

conventional cultivation system employed the existing common land preparation method using hand tractor for two harrowings and final leveling, manual transplanting including pulling of seedlings or manual broadcast seeding, and manual harvesting and mechanical threshing (Table 1).

Energy-use in rice production

Energy inputs were expressed in mega joules (MJ) of field operations from land preparation to harvesting such as human labor, machinery, irrigation, diesel fuel, chemical fertilizers, and pesticides (Table 2). The prevailing prices of farm inputs in 2016-17 were considered in the study (Table 2). Actual time of field operation was measured excluding travel time before and after each operation. The energy output was evaluated based on average of paddy yields using crop cut and actual harvest of plots. Output/input ratio is the efficiency of rice production in terms of energies. The energy input-output audit was done based on the following farm inputs during rice production:

1. Human labor – human labor activities employed during irrigation, seedling and land preparation, transplanting, fertilizer application and crop care, harvesting, and other production-related activities were precisely scored.

2. Irrigation methods - water applied using shallow tube well during the rice cropping system was measured. All plots were irrigated with similar amounts of water throughout the growing season.

3. Fuel - total amount of fuel used during actual irrigation, land preparation, planting, harvesting and threshing, and other activities was determined.

4. Machinery - machines involved in the experiment were monitored, which included actual time of machine operation used in every rice production activity.

5. Pesticides - applications of insecticide, fungicide, molluscicide, and herbicide were separately monitored. IPM practices were adopted so pesticides were the last resort.

6. Fertilizers - individual nutrients NPK from different fertilizer sources were monitored. Rates (120-60-60 DS and 90-40-40 WS) were based on PhilRice recommendations. All plots were manually fertilized using the same rates for all seasons.

Table 2. Energy coefficients of farm inputs.

Farm inputs	Energy coefficient	References
Human labor	0.8 MJ h^{-1}	Pimentel et al.; Umar, Samootsakorn
Machinery	109 MJ kg^{-1}	Pimentel 1992, Kalk and Hulsbergen 1996 and Umar
Fuel	47.78 MJ^{-1}	Umar, Safa and Tabatabaeefar 2002
Nitrogen	80 MJ kg^{-1} N	Pimentel 1979; Tippayawong and Chamsing Pimentel 1979; Esengun et al.
Phophorus	14 MJ kg^{-1} P	2006, Kalthsmitt 1997; Reinharht 1997; Samootsakorn 1982
Potassium	9 MJ kg^{-1} K	Pimentel 1979, Esengun 2006 and Samootsakorn 1982, Pimentel, Rutger and Grant 1980,
Seeds	16.75 MJ kg^{-1}	Intravichai 1998; Saunders and Betschart 1979
Paddy yield	12.36 MJ kg^{-1}	Pimentel et al.
Irrigation	0.615 MJ m3^{-1} water	Pimentel et al.; Ozkan et al.; Esengun 2006
Insecticide	101.2 MJ kg^{-1} insecticide	Pimentel 1979; Esengun et al. 2006

Table 3. Prevailing costs of farm inputs used in the study (2016).

Operation	Prices
Human labor	Php 300 day^{-1}
Handtractor operations	Php 500 ha^{-1}
Fertilizers	Php 13 kg N^{-1}
	Php 22 kg P^{-1}
	Php 22 kg K^{-1}
Herbicide/pesticide	Php 500 ha^{-1}
Fuel	Php 25 L^{-1}

7. Rice seeds –the study used hybrid seeds due to higher yield potential.

8. Rice yield energy output – data were gathered using the yield components and actual harvesting method.

GHG emissions of rice production

GHG emissions were computed from all farm inputs applied during rice production. Contributors to GHG emissions are farm machinery, NPK fertilization, pesticides and herbicides, and fuel for machines

(Table 4). Human GHG emission was not included. The following formula was used:

$$GHG_{rc} = \sum((EF_i \times mach) + (EF_{npk} \times fert\ N, P, K) + (EF_{ps} \times pesticide/herbicide) + (EF_f \times fuel))$$

Where:

GHG_{rc} = the total GHG emission during rice production, kg CO_2 eq.

EF_i = GHG emission factors of agricultural machinery input

$Ef_{n,p,k}$ = GHG emission factors of fertilizer N, P,

Ef_{ps} = GHG emission factors of pesticide and herbicide

Ef_f = GHG emission factors of fuel for machines

GHG emission of Fertilizers

$$GHG_{fertNPK} = \sum((EF_a \times AF) + (EF_p \times AF))$$

Where:

$GHG_{fertNPK}$ = the GHG emission of fertilizer applied, kg CO_2 eq.

EF_a and EF_p = Emission factors of N_2O due to N fertilizer application and production of NPK fertilizers, respectively. (Table 4)

AF = Amount of fertilizer applied during rice production, kg ha^{-1}

GHG emission of Pesticides

$$GHG_{Pesticide/herbicide} = EF_{ac} \times A_{ac}$$

Where:

$GHG_{Pesticide/herbicide}$ = the GHG emission of pesticides, kg CO_2 eq.

EF_{ac} = Emission factors of pesticides, g CH_4 kg^{-1}(Table 4)

A_{ac} = Amount of pesticides used in rice production, kg ha^{-1}

GHG emission of Fuel

$$GHG_{fuel} = EF_d \times A_d \times NCV$$

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}(Table 4)

A_d = Amount of diesel used by machinery, L ha^{-1}

NVC = Net calorific Value, TJ t^{-1}

In 2016, the price of diesel oil was P34.46 /liter

GHG emission of machines

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

Where:

GHG_{mach} = the GHG emission of machine, kg CO_2 eq.

EF_{mc} = Emission factors of farm machinery, kg CO_2 kg^{-1} (Table 4)

W_{mc} = Weight of machine, kg

T_u = Total time of operation, h ha^{-1}

LS = life span of machine, h

Table 4. GHG emission factors of farm inputs.

Sources of GHG emissions	Emission factors	Source of data
Farm machinery, (bandtractor. and axial flow thresher)[a]	12.8 kg CO_2kg^{-1}	Maraseni et al. 2004
Fertilizer production, N[b]	1.3 kgCO_2eq. kgN^{-1}	Pathak 2007, Schlesinger 1999
Fertilizer production, P[c]	0.2 kgCO_2eq. kgP^{-1}	Pathak 2007, Schlesinger 1999
Fertilizer production, K[d]	0.2 kgCO_2eq. kgK^{-1}	Pathak 2007, Schlesinger 1999
Fertilizer application, N[e]	0.003 kgN2O-N kgN^{-1}	IPCC 2006
Pesticide and herbicide)[f]	5.5 kgCO_2eq. kg^{-1}	Lal 2004, Schlesinger 1999
Fuel[l]	20.2 to TJ^{-1}	IPCC 2006

[e] [l] IPCC 2006. 2006 IPCC Guidelines for national greenhouse gas inventories. Prepared by the national greenhouse gas inventory programme. Eggleston HS, Buendia L, Miwa K, Ngara T, & Tanabe K. (ed) Published: IGES Japan

[b] [c] [d] Pathak HR Wassman. 2007. Introducing GHG mitigation as a development objective in rice-based agriculture: Generation of technical coefficients. Indian Agriculture Research Institute Agricultural Systems 94(2007) 807-825

[f] Schlesinger WH. 1999. Carbon sequestration in soils. Science 25 June 1999. Volume 284 no. 5423 p. 2095 doi: 10.1126/Science. 284.5423.2095

[m] Lal R. 2004. Carbon emission from farm operations. Columbia USA. Environment International 30(2004) 981-990

[a] Maraseni , TN. et al. 2009. Greenhouse emission from rice farming inputs: a cross-country assessment.' Journal of Agricultural Sciences (2009) 147, 117-126.

Cost of Production

This was computed using the then prevailing prices of farm inputs. All farm inputs from land preparation to harvesting such as human labor, machinery, irrigation, diesel fuel, chemical fertilizers, and pesticides were considered.

System boundary

This Life Cycle Assessment (LCA) study had system boundary which included seedbed and land preparation, transplanting, crop care, harvesting, and threshing. Figure 2 diagrams the system boundary of the study, showing flow of farm inputs and output during rice production. Given that photosynthesis is a natural input from environment, all farm inputs were substantial factors in obtaining a good yield. These farm inputs consequently contribute GHG emission to the environment including the rice plant that consumes the carbon dioxide but produces more in terms of methane. Rice paddy is the only output that resembles the summation of all farm inputs or the harvest.

RESULTS AND DISCUSSIONS

Comparison between Conventional and Highly Mechanized Rice Production

The energy inputs of conventional (9,757 MJ ha^{-1}) and highly mechanized (9,487 MJ ha^{-1}) rice production are significantly different, unlike that energy outputs at 36,062 and 32,314 MJ ha^{-1}, respectively. Energy output-input ratios are not significantly different at 3.7% and 3.2% for highly mechanized and conventional, respectively. Energy output was 3.7 times more than the energy inputs of the highly mechanized production. Rice production also had higher energy efficiency in the dry season (3.7%) than in the wet season (3.2%). Due to higher energy output and lower energy inputs in the DS.

Table 5. Comparison between conventional and mechanized rice production

	Energy input, MJ	Energy output, MJ	GHG emission, kg CO$_2$ eq	Cost of operations, x1000	Human labor day	Machine, hr
conventional	10,190	32,314	1,962	7.2	49	7.3
mechanized	9,748	36,063	1,822	6.4	46	3.6

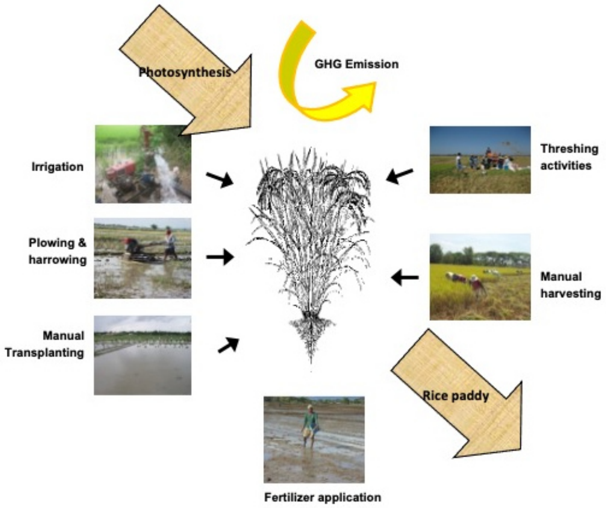

Figure 2. Factors that affect rice production, system boundary of the study

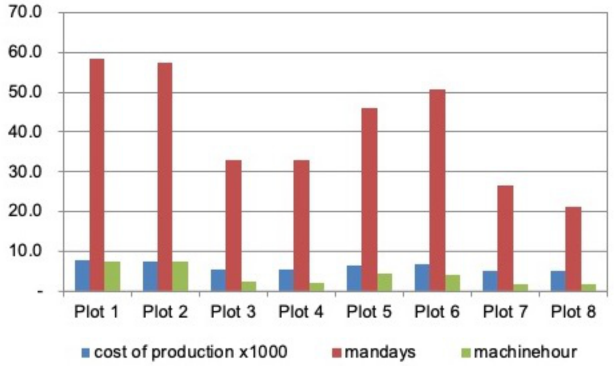

Figure 3. Cost of production, human labor, and machine hours of rice production during 2016 DS.

Table 6. The energy input/output and GHG of rice production 2016

Treatment	Energy input, MJ	Energy output, MJ	GHG emission, kg CO$_2$ eq. ha^{-1}
Plot 1	10,513	51,477	2,052
Plot 2	10,486	46,399	2,051
Plot 3	9,034		1,682
Plot 4	8,994	46,275	1,671
Plot 5	10,070	41,352	1,905
Plot 6	10,045	44,004	1,901
Plot 7	8,930		1,664
Plot 8	8,902	47,144	1,657

The cost of conventional rice production (Php 40,08 ha^{-1}) is significantly higher than the highly mechanized (Php 27,084 ha^{-1}) due to more human labor and machine operation time during field operations. Cost of WS production (Php 36,707 ha^{-1}) is significantly higher than DS cost of Php 31,872 ha^{-1} due also to human labor employed (Figure 3). Among seasons of the experiment, highly mechanized DS had the lowest cost of production at Php 26,542 ha^{-1}, compared with conventional farming WS (Php 30,643 ha^{-1}), conventional WS (Php 42,771 ha^{-1}). Contributing to the high costs was abundant human labor during transplanting and harvesting operations. Conventional (49.2 human labor) rice production employed 7.2% more human labor than highly mechanized (36.1 human labor). Conventional was also found to have used significantly more machine-time significantly (7.3 hr ha^{-1}) compared to highly mechanized (3.6 hr ha^{-1}). This may be due to the longer time of threshing using the commonly used axial-flow thresher and land preparation using hand tractor, while the mechanized system used the quicker and highly efficient combine harvester. The GHG emissions are significantly different with 1,983 kg CO$_2$e and 1,815 kg CO$_2$e for conventional and highly mechanized farming, respectively (Figure 3).

Comparing Hybrid and Inbred rice production

In Figure 5, the average energy inputs of hybrid and inbred rice production were not significantly different at 9,937 MJ ha^{-1} and 10,001 MJ ha^{-1}, respectively. Energy efficiency of hybrid at 3.1% was not significantly different from that of inbred (3.2%). The average energy output of hybrid (29,339 MJ ha^{-1}) was lower than inbred (39,037 MJ ha^{-1}) but not significantly different. The effect of direct-seeded hybrid efficiency (2.5%) was the one factor that contributed to the decrease. Inbred (4.3%) seeds being more affordable were favorable to direct seeding as well as transplanting regardless of season. The average human labor employed were 47 and 48 person-days for hybrid and inbred. Direct-seeded hybrid and inbred had the lowest human labor of 31 and 30 person-days compared to other combinations, respectively. Noticeable decrease in person-days was due to less labor in crop establishment but a slight increase resulted from the labor required to remove weeds in the direct-seeded field.

On the average, the GHG emissions of hybrid and inbred rice production were similar at 1,893kg CO$_2$e and 1,890kg CO$_2$e. However, direct-seeded hybrid (1,711CO$_2$e) and inbred (1,704 CO$_2$e) had the lowest GHG emissions when compared to other system combinations. This might be attributed to low utilization of machines that were using fuels for field operations. Conventional transplanted system recorded highest GHG emissions at 2,069 and 2,083kg CO$_2$e for hybrid and inbred, in that order (Kariyaiah B 2020).

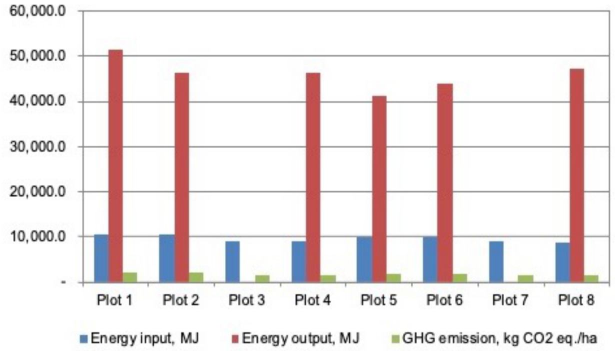

Figure 4. Energy input, output and GHG emission of rice production during DS 2016.

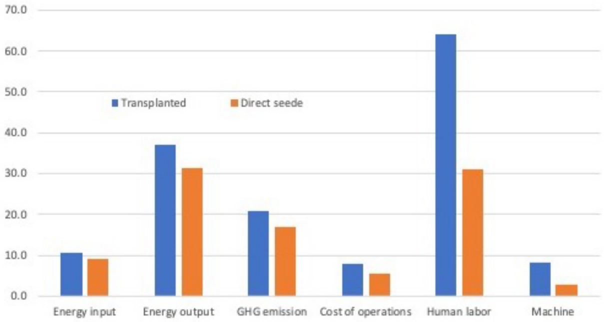

Figure 6. Comparison between transplanted and direct seeded rice.

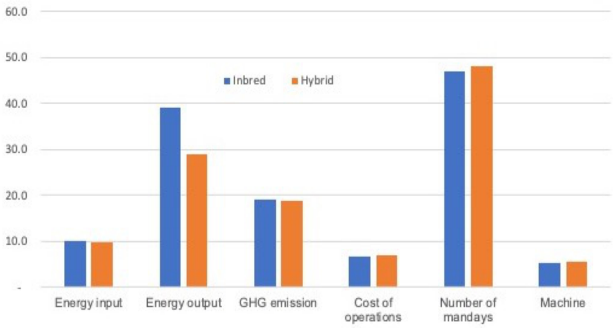

Figure 5. Comparison between hybrid and inbred rice production

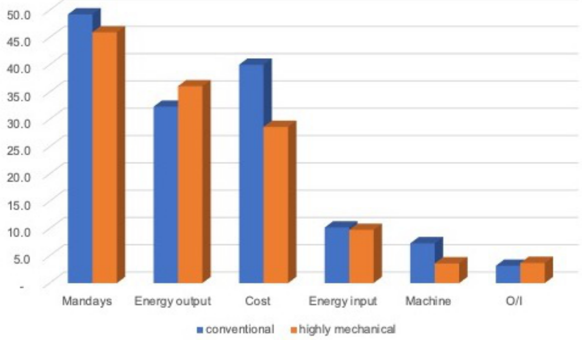

Figure 7. Comparison between conventional and highly mechanized rice production.

Table 7. Comparison between hybrid and inbred rice production

	Energy input, MJ	Energy output, MJ	GHG emission, CO_2eq	Cost of operation, Php	Human labor, day	Machine, day
Inbreed	10	39	19	6.8	47.1	5.4
Hybrid	9.9	29	18.9	6.9	48.1	5.5

Table 8. Comparison between transplanted and direct seeded rice production

	Energy input, MJ	Energy output, MJ	GHG emission, CO_2eq	Cost of operations, Php	Human labor, day	Machine, day
Transplanted	10.7	37.1	20.8	8	64.2	8.12
Direct seeded	9.2	31.3	17.1	5.7	30.9	2.8

Compared Transplanted and Direct-Seeded

In Figure 6, the average energy input of transplanted rice was significantly higher at 10,714 MJ ha^{-1} compared to 9,224 MJ ha^{-1} of direct-seeding method. Higher energy input further resulted in higher energy output (37,125 MJ ha^{-1}) compared to direct-seeded (31,252 MJ ha^{-1}). The energy efficiencies of direct seeding and transplanted rice were almost alike at 3.4 and 3.5%, respectively. Mechanically transplanted rice had higher energy efficiency (3.7%) than manually transplanted rice (3.3%). It was due to the lower energy input incurred by highly mechanized production (10,275 MJ ha^{-1}) compared to conventional planting (11,152 MJ ha^{-1}). Transplanted rice required significantly more person-days at 64 pd ha^{-1}, only 31 pd ha^{-1} for direct seeding. Transplanted also needed 9 machine-hours, only 3 machine-hours for direct seeding. The DS energy input (10,625 MJ ha^{-1}) was higher than that of WS (10,123 MJ ha^{-1}), which resulted in higher energy output (36,497 MJ ha^{-1}).

The average cost of production in transplanted rice was significantly higher at Php 45,090 ha^{-1} compared to direct seeding at Php 23,489 ha^{-1}. It was 92% more than that of direct-seeded due to the higher human labor requirements for seedling preparation and crop establishment. Transplanted incurred 8.1-machine hours, only 2.4 machine-hours for direct seeding. Using the mechanical transplanter required more human labor and machine time compared to direct-seeded using drumseeder.

The overall GHG emissions of transplanted and direct seeded rice were significantly different at 2,076 and 1,707 kg CO_2e./ha, respectively, due to more time of operation of machines. Highly mechanized direct-seeded rice had low GHG emissions of 1,699 kg CO_2e, which is lower than the national average GHG emission of rice production at 2,718 kg CO_2e (Bautista et al. 2015).

CONCLUSION

The LCA study discovered that hybrid rice production cost at Php 34,673 ha^{-1} is not significantly different from that of inbred at Php 33,906 ha^{-1}. The same can be said for GHG emissions, energy inputs, and machine hours. Inbred used more energy inputs which resulted in higher energy output than a hybrid because inbred seeds were more affordable.

The transplanted method had higher energy inputs that resulted in higher energy output compared to the direct-seeded. The GHG emission of transplanted rice was higher than direct-seeded because of longer machine utilization and use of fuel. Transplanted rice production cost averaged higher than direct-seeded because of the higher number of human labor and machine hours consumed throughout the production period.

Rice production cost during the wet season was higher at Php 36,707 ha^{-1} than in dry seasons Php 31,872 ha^{-1} due to the higher cost of human labor employed. DS human labor was 53, only 42 for the WS. The energy efficiency of transplanted rice was higher than direct seeding.

Highly mechanized production cost was lower (Php 28,592 ha^{-1}) compared to conventional tillage (Php 39,987 ha^{-1}) which needed higher human labor and machine-hours requirements. In contrast, GHG emissions of highly mechanized were higher than conventional farming due to higher energy inputs. We, therefore, conclude that intensifying rice production by highly mechanizing it can truly improve efficiency and shorten production and postproduction periods, but will not reduce GHG emissions. Further studies on different rice production methods such as dry seeded, alternate wetting, and drying on rice production on transplanted and direct seeded, and regional studies are recommended to enhance data analysis on this matter and strengthen recommendations for the protection of our environment.

ACKNOWLEDGEMENT

The authors thank the PhilRice management for funding the field experiment, and field workers Edward Fernandez, Nelson Baldovino, Rodolfo Juliano, and Rudy Fulgencio for their assistance during data gathering.

LITERATURE CITED

Amongo RMC, Larona MVL. 2015. Agricultural mechanization policies in the Philippines. CSAM Policy Brief, UN ESCAP Center for Sustainable Agricultural Mechanization, Beijing, China, 18 p. Retrieved from: http://www.un-csam.org/publication/PB201501.pdf

[BAS] Bureau of Agricultural Statistics. 2007. Department of agriculture of the Republic of the Philippines. Retrieved from http://www.bas.gov.ph/. Date accessed10 June, 2013.

Barile VL. 2002. Reproductive efficiency in female buffaloes. In: buffalo production and research REU Technical Series 67. Food and Agriculture Organization of the United Nations. Chapter IV, p 77-108.

Bautista EG, Saito M. 2015. Greenhouse gas emission from rice production in the Philippines based on life-cycle inventory analysis. Journal of Food Agric and Environment. Vol 13(1):139-144.

Bautista EG, Minowa T. 2010. Analysis of the energy for different rice production systems in the Philippines. Philippine Agriculture Scientist. September 2010. 93(3):346-357.

Bautista EG, Regalado MJC, Juliano AS, Ramos JA, Mataia AB, Beltran JC. 2022. Improving Filipino rice farmers' competitiveness through mechanization. RBBJ pp 113-118.

Bautista EU. 2003. Mechanizing rice production and postharvest operation in the Philippines: present status, prospects and challenges. Retrieved from: http://agris.fao.org/agris-search/search.do?recordID=PH2004000787.

Boumann BA, Cao W, Huang H, Yang M. 2014. The effect of agricultural mechanization on food yield in China. Retrieved from https://elibrary.asabe.org/abstract.asp?aid=44572 Date accessed August 18, 2021)

Toung TP 2001. Field water management to save water and increase its productivity in irrigated lowland rice. Soil and water Sci. Div., IRRI, Los Baños, Laguna, Philippines. Retrieved at http://www.irri.org/ipswar/publication/articles.pdf August 25, 2010(49):11-30.

Bordey FH, Moya PF, Beltran JC, Dawe DC, editors. 2016. Competitiveness of Philippine Rice in Asia. Science City of Munoz (Philippines): Philippine Rice Research Institute and Manila (Philippines): International Rice Research Institute. Retrieved from: https://dbmp.philrice.gov.ph/palaystat/publications/view/104/competitiveness-of-philippine-rice-in-asia. 172 pp.

Corton TM, Bajita JB, Grospe FS, Pamplona RR, Asis CA, Wassmann R, Lantin RS, Buendia LV. 2000. Methane emission from irrigated and intensively managed rice fields in Central Luzon Philippines. Nutr. Cycl. Agroecosystems 58:37–53.

[DA] Department of Agriculture. 2013. PHL farm mechanization is 1.23 hp/ha. Retrieved from: https://www.official gazette.gov.ph/2013/05/21/phl-farm-mechanization-is-1-23-hpha/.

González de Molina, M. et al. 2020. Agricultural inputs and their energy costs 1900–2010.

In: The Social metabolism of Spanish Agriculture, 1900–2008. Environmental History. Vol.10. Springer, Cham. https://doi.org/10.1007/978-3-030-20900-1_3.

[IPCC] Intergovernmental 2006. 2006 IPCC Guidelines for national greenhouse gas inventories. Prepared by the national greenhouse gas inventory programme. Eggleston HS, Buendia L, Miwa K, Ngara T, & Tanabe K. (ed) Published: IGES Japan

Johnson JM, Fransluebbers AL, Weyers SL, Reicosky DC. 2007. Agriculture opportunities to mitigate greenhouse gas emissions. Environmental pollution. Volume 150(1):107-124.

Kariyaiah B, Ramesha YM, Paramesh V, Rajanna GA, Lal Jat S, Misra SD, Kumar Gaddi A, Girisha HC, Yogesh GS, Raveesha S, Roopa TK, Shashidhar KS, Kumar B, Diaa O, El-Ansary, Elansary HO. 2020. Energy budgeting, data envelopment analysis and greenhouse gas emission from rice production system: A case study from puddled transplanted rice and direct-seeded rice system of Karnataka, India. Journal: Sustainability. Vol 12: 6439.

Lantin RM. 2016. Agricultural mechanization in the Philippines, Part I: Brief history. Agricultural Mechanization in Asia, Africa & Latin America 47(2):80-86.

Lal R. 2004. Carbon emission from farm operations. Columbia USA. Environment International 30(2004) 981-990.

Lindau CW, Bollich PK, Delaune RD, Patrick WH, Law VL. 1991. Effect of urea fertilizer and environmental factors on CH_4 emissions from a Louisiana, USA rice field. Plant and Soil. Vol 136(2):195-203.

Macandong BD. 2007. Methane emissions from major rice ecosystems in Asia. IRRI. Institute of Bio. Science, UPLB, Laguna, Philippines. Paper presented during the 4th workshop on GHG inventory in Asia, Jakarta, Indonesia.

Maraseni TN, Mushtaq S, Maroulis J. 2009. Greenhouse gas emissions from rice farming inputs: a cross-country assessment. Journal of agriculture Science. 147:117-126.

Ngonidzashe Chirinda et al. 2018. Sustainable and low greenhouse gas emitting rice production in Latin America and the Caribbean: A Review on the Transition from Ideality to Reality. Sustainability journal. Vol 10:3.

Pathak H, Wassman R. 2007. Introducing GHG mitigation as a development objective in rice-based agriculture: Generation of technical coefficients. Indian Agriculture Research Institute Agricultural Systems 94(2007):807-825.

[PHilMech] Philippine Center for Postharvest Development and Mechanization website. CLSU Compound, Science City of Munoz, Nueva Ecija.

[PhilRice] Philippine Rice Research Institute Web team. Nueva Ecija, Philippines. Turning rice waste into energy. www.philrice.gov.ph. Date Accessed on 09 May 2008

[RNAM] Regional Network For Agricultural Mechanization. 1986. Test codes and procedures for ploughs. 2nd ed. Retrieved from the World Wide Web: http://edis.ifas.ufl.edu/. Date accessed March 4, 2009. pp 17-33.

[PSA] Philippine Statistics Authority. 2015. Special Report - Highlights of the 2012 Census of Agriculture (2012 CA). Retrieved from: https://psa.gov.ph/content/special-report-highlights-2012-census-agriculture-2012-ca.

Rodulfo VA, Del Rosario AC, CJM Tado (2008) Country Report: Philippines. Country report presented during the Study Meeting on Appropriate Mechanization Strategies for Improving Agricultural Productivity, September 24-30, 2008. New Delhi, India.

Rypinski A. 1997. Estimating emissions of other GHG. A presentation to the Department of Energy, Sept 17, 1997. US Dep't of Energy.

Schlesinger, WH. 1999. Carbon sequestration in soils. Science 25 June 1999. Volume 284 no. 5423 p. 2095 doi: 10.1126/Science.284.5423.2095.

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B, Sirotenko O. 2007. Agriculture. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA. (Eds.), Climate Change 2007: Mitigation. Contribution of working group III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 497–540.

Tripaldi C. 2003. Buffalo milk quality. In: Buffalo production and research REU Technical Series 67. Food and Agriculture Organization of the United Nations. Chap IX. p 178-184.

[UNFCCC] United Nations Framework Convention on Climate Change. 1999. The Philippines initial national communication on climate change. 1994 National GHG inventory. Chapter 2. pp 28.

[US EPA] United States Environmental protection agency. 2006. Anthropogenic Non-CO_2 greenhouse gas emissions: 1990-2020. Washington DC.EPA 430-R-06-003.

Vergel XP, Kimpe C, Desjardins RL. 2007. Agricultural production, greenhouse gas emission and mitigation potential. Agricultural and Forestry Meteorology. 142 pp 255-269.

Vlek P, Rodrigues KG, Sommer R. 2003. Energy use and CO_2 production in tropical agriculture and means and strategies for reduction and mitigation. Environment, Development and sustainability. 6 pp 213-233.

Wassmann R, Neue HU, Lantin RS. 1994. Temporal patterns of methane emissions from wetland rice fields treated by different modes of N application. J. Geophys. Res.: Atmospheres99 (D8): 16457-16462.

Wassmann R, Lantin RS, Neue HU, Buendia LV, Corton TM, Lu Y. 2000. Characterization of methane emissions from rice fields in Asia. II. Mitigation options and future research needs. Nutrient Cycling in Agroecosystems 58: 23-36.

Wassmann R, Hosen Y, Sumfleth S. 2009. Agriculture and climate change: an agenda for negotiation in Copenhagen for food, agriculture, and the environment reducing methane emissions from irrigated rice focus 16 Brief 3. International Food Policy Research Institute, Washington, USA.

[WHO] World Health Organization. 2008. Energy and protein requirements. A Report of a joint FAO/WHO/UNU expert consultation, WHO Technical Report Series 724, Geneva 27, Switzerland. URL: www.who.int/