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Comparative energy bill of inbred and hybrid rice genotypes grown under conventional and organic production system in Bay, Laguna, Philippines

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Abstract The major energy hotspots for the conventional production system were agrochemical inputs particularly nitrogen fertilizer at12336 MJ ha^{-1} (62%) and pesticides (1592 MJ ha^{-1}, 8%). The major energy hotspot in organic system was applied organic fertilizer at 1440 MJ ha^{-1} (25%), and labor at 1134 MJ ha^{-1} (20%) due to the labor intensiveness of preparing and applying the organic fertilizer. Transplanting one seedling per hill reduced the amount of seed energy used per hectare up to 91% (80kg seeds were used in the conventional while only 4kg/ha at 1 seedling per hill and 30cm x 30cm spacing under organic). The use of synthetic fertilizer in conventional, especially nitrogen, and chemical pesticides led to greater total energy bill. In turn, energy return over energy input (EROEI) was only 4 under conventional and 15 for organic methods . The energy productivity (EP) under organic was higher at 0.88 kg grain MJ^{-1}, while it was only 0.26 kg grain MJ^{-1} under conventional method. Organic system had 3.4 times higher EP than conventional due to the lower TEI (5715 MJ ha^{-1}) in organic and higher TEI (19821 MJ ha^{-1}) in conventional method. Likewise, the net energy in organic (77634 MJ/ha) was higher by 12% (68403 MJ/ha) than in conventional systems making organic more energy efficient. Organic system not only reduced the energy bill by 71% of total energy input but also gave comparable grain yield to the conventional system. It required 1.164 MJ to produce 1.0 kg unmilled rice under organic, while it was 3.83 MJ kg^{-1} under conventional or 3.3 times more energy than organic method.

Keywords: Energy input, Energy output, Energy productivity, Net energy gain, Energy hotspots

Introduction

Rice is mainly grown through conventional production systems, using high-yielding varieties huge amount of synthetic fertilizers and pesticides manufacture using high fossil fuel energy inputs. Pesticide and nitrate contaminations of surface water and groundwater, increased pest resistance,

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and loss of biodiversity are also evident results (National Research Council, 1989, Pimentel *et al*., 1995; Releya, 2005). Problems arising from conventional practices have led to the development and promotion of organic production systems that consider the environment and public health as main concerns (Melero *et al*., 2005). An organic production system is less fossil fuel-dependent and is agrochemical-free. It is an environment-friendly system of farming that attempts to make the best use of local natural resources for sustainable agricultural production. The Food and Agriculture Organization (FAO) regards organic agriculture as an effective strategy for mitigating climate change and building robust soils that are better adapted to extreme weather conditions associated with climate change (Pretty, 1999; IFOAM 2009). Farmers should now shift their production systems from agrochemical-intensive to minimal or even zero use of agrochemicals (chemical fertilizers and pesticides), and for them to adopt farm practices that rebuild the soil leading to balanced agro-ecosystems, or minimal agro-ecological stresses (Rigby and Caceres, 2001, Willer and Yussefi, 2001, Badgely *et al*., 2006, Magdoff and Weil, 2004).

There are doubts that organic systems can feed the world population because lower yields are obtained with organic methods as compared to that of the conventional systems. All of the currently released rice genotypes (inbred and hybrid) in the Philippines have been mainly developed using the conventional system of applying high external inputs (high energy inputs) and synthetic fertilizers, resulting in higher yields. Increases in yields depend on using appropriate Genotypes (G), Environment (E), and Management (M) – (G*E)*M (Burgueño, 2012, Mendoza, 2015). Planting arrangement (M) refersto the management of the plant population per unit area. The optimum spacing is also essential for proper rice growth and increased grain yields in an organic production system. While many studies reported that an organic system in rice showed better performance than a conventional system in terms of sustainability, only a few studies have compared the energy use of organic and conventional rice production in the Philippines (Mendoza, 2005; Soriano, 1982; Mendoza, 2005; Quility *et al.*, 2014).

This study was conducted to determine the energy bill of two rice genotypes (inbred and hybrid) grown under organic methods transplanted in three different spacing and compared to the conventional systems . Specifically, the study aimed to account the direct and indirect energy usage of inbred and hybrid rice genotypes and identify the energy hotspots to calculate the energy use per kilogram or ton of rice (MJ/kg), break-even energy (kg/ha), energy returns over energy inputs (EROEI), energy productivity (kg/MJ), net energy (MJ/ha) in the two genotypes grown under organic methods and conventional systems.

Materials and methods

Study area , experimental design, and treatments

The study was conducted at BarangayPuypuy, Bay, Laguna Province, Philippines from November 2016 to March 2017. The experiment was laid out in the Strip-Plot Design with 15 treatments and three replications. The three spacings (20 cm×20cm, double rows and 30cm×30cm) occupied the main plot where five different varieties (Pabinhi-1, Bigante, GSR-8, M-20 and Rc-222) were in the subplots**.** Plant populations were 250,000 plants ha^{-1}in 20cm×20cm, 333,333 plants ha^{-1} in (20 cm×10cm)×40cm and 111,111 plant ha^{-1} in 30 cm×30 cm.

For nutrient management and crop establishment, the following practices were adopted from Nature Farming but modified to use locally available resources as adopted by Mendoza (2016) as described below:

(1) Bokashi compost was prepared with the mixture of cattle manure and carbonized rice husk (1:2); about 10% rice bran (100 kg) was mixed.

(2) The compost is adopted from Mendoza (2016). The mixture was treated with iundigenous microorganisms (IMO) at 1 L per ton. Bokashi compost was applied at 2 tons ha-1 before final harrowing. The components of nutrient elements in the compost were 8.31% OM, 0.7% N, 4.22% P and 2.32% K.

(3) Using a 200 L-capacity plastic drum, liquid fertilizer was prepared with 20 kg of fresh manure + 2 kg molasses + 2 kg rice bran. The drum was filled with water up to the brim. The mixture was stirred clockwise and counter-clockwise for 10 minutes; this was done every day for 7 days each time before application. About 2 drums (400 L) liquid fertilizer was prepared per application. The liquid fertilizer (1600 L per half ha or 3200 L ha^{-1}) was distributed evenly in the experimental plots. Application was repeated at 2 weeks, 4 weeks and 6 weeks after transplanting.

(4) Seeds were soaked for 24 hours, then incubated for another 24 hours before sowing. The seedbed area was plowed once and constructed when the mud had settled. Five seedbeds were prepared, one for each variety. For each seedbed, about 50 kg of Bokashi compost was applied for basal and 100 L of cattle liquid fertilizer was applied 10 days after sowing. Seeds were sown at a rate of 1.5 kg per seedbed. To protect the seeds from bird attacks, carbonized rice hull was used to cover the seedbeds.

(5) Twenty days after sowing, rice seedlings were transplanted in three planting arrangements at one seedling per hill. Replanting was done 7 days after transplanting from remaining seedlings. Golden apple snails were handpicked. Weeding was done 3 times using a rotary weeder, while the remaining weeds were hand-pulled. Irrigation was applied to keep the soil moist.

Data gathered

The energy data included seeds (inbred and hybrid), fertilizer, labor, machinery, transportation, crop establishment and maintenance as well as rice grain. Energy requirement was divided into two categories; direct energy and indirect energy inputs. Direct energy included diesel fuel oil to run the machines and indirect energy inputs included seeds, fertilizers, pesticides, planting materials, labor energy and embedded energy used in the following: (1) additional cost of producing hybrid seed, (2) the manufacturing of machines, fertilizer and chemical inputs, (3) packaging of fertilizer and (4) transporting, distributing and applying of chemical fertilizer and farm equipment.

Table 1. The energy coefficient of various inputs used in rice production

Item	Unit	Energy Coefficient (MJ/Unit)	Source
Diesel fuel	L	47.8	Canakci and Akinci, 2006, Pimentel, 1980, Cervinka, 1980
Machinery	kg	86.77	Bowers, 1992
Rice (Seed)	kg	16.75	Gliessman, 2015, Mendoza, 2005
N	kg	102.8	Mendoza, 2016; Rodolfo, 2008; Pfeiffer, 2003.
P_2O_5	kg	24.8	Mendoza, 2014; Lal, 2004; Mudahar and
K_2O	kg	15.3	Higneet, 1987.
Compost	kg	0.3	Hatirli, 2006.
Herbicides	kg	264	Barber, 2004; Lillywhite, 2007.
Insecticide	kg	214	Barber, 2004; Lillywhite, 2007.
Labor	hr	1.96	Kazemi *et al*., 2015; Sarauskis *et al*., 2014; Nassiri and Singh, 2009

The units of different inputs and outputs were converted into energy units for the energy analysis using energy coefficients based on the handbook of Pimentel (1980), and from other relevant literatures as cited by Mendoza (2005), Mendoza (2010), Mendoza (2014), Kazemi *et al*. (2015), and Mendoza (2016) as summarized in Table 1. For comparison (control), energy data from conventional production system beside the field experiment was gathered (inbred namely RC-216 grown by 20 cm×20 cm only). Data on energy use were collected by interviewing the farmer. Data were recorded , digitally inputted and then processed using the Microsoft Excel 2010 application. Data for grain yield in kg at 14% moisture content (MC) were taken from the sampling plot ($9m^2$) of each plot, excluding the two border rows and end-hills of each row. After threshing, cleaning, and drying, the grain weight, straw weight and MC were recorded and the yield for each plot was converted to kg ha-1 adjusted to 14% MC (PNRRC, 2004).

Energy calculation formula

The following equations were used to calculate the total direct and indirect energy bills in rice production based on one hectare. The energy equivalences of unit inputs are given in megajoule (MJ). The energy value for a given item is obtained by simply multiplying the unit or amount used and the corresponding energy equivalent of a given input; e.g., seeds have 16.75 MJ kg^{-1}. Thus, the energy use (MJ) of 60 kg seeds = 60 kg x 16.75 MJ kg^{-1} = 1005 MJ, following Mendoza (2005). The total energy inputs of rice production were calculated by adding up the energy equivalences of all inputs in megajoule (MJ). It is expressed in the equation below:

$$\sum TEi = \sum DEi + \sum IDEi$$

Where: ∑TEi=Total energy inputs (MJ ha^{-1}); DDEi = Direct Energy Inputs (MJha^{-1}); ∑IDEi = Indirect Energy Inputs

Energy use indicators

The energy use indicators and the formula used in the calculation are shown below:

$$\text{Energy Output (MJ ha}^{-1}\text{)} = \text{Grain Yield (kg ha}^{-1}\text{)} \times 16.75 \text{ MJ kg}^{-1}$$

$$\text{Energy use per kg of rice} = \text{TEI (MJ ha}^{-1}\text{)} \div \text{Grain yield (kg ha}^{-1}\text{)}$$

In addition, the break-even energy equivalent (BEE) of un-milled rice, and the energy equivalent of un-milled rice to offset the total energy use per ha, were also calculated using the formula:

$$BEE = \sum TEi / E1kg$$

Where: BEE=Break even energy of un-milled rice; ∑TEi=Total energy input; E1 kgmr=energy (MJ/kg) in 1 kg un-milled rice.

$$\text{EROEI} = \text{Energy outputs (MJ ha}^{-1}\text{)} \div \text{Total energy inputs (MJ ha}^{-1}\text{)}$$

$$\text{EP (kg MJ}^{1}\text{)} = \text{Grain yield (kg ha}^{-1}\text{)} \div \text{Total energy inputs (MJ ha}^{-1}\text{)}$$

$$\text{NE (MJ ha}^{-1}\text{)} = \text{Energy outputs (MJ ha}^{-1}\text{)} - \text{TEI (MJ ha}^{-1}\text{)}$$

Where: EROEI=energy returns over energy input, EP= energy productivity, NE= net energy.

Data analysis

Analusis of variance (ANOVA) was done by the statistical tool for Agricultural Research version 2.0.1 (IRRI-STAR). The treatment means were compared by using LSD Test (Gomez and Gomez, 1984). Abbreviations used as LDOE–Liter diesel oil equivalent, EROEI–Energy return over energy input, DEI-Direct energy input, IDEI-Indirect energy input, TEI-Total energy input.

Results

Energy analysis

The total energy inputs under organic were accounted for at 5849 MJ ha^{-1} in 20×20 cm, 5999 MJ ha^{-1} in double rows and 5300 MJ ha^{-1} in 30×30 cm spacing as shown in Table 2. The values were 5148 MJ ha^{-1} and 6567 MJ ha^{-1} for inbred and hybrid genotypes, respectively. Of the total energy inputs (TEI), direct energy inputs (DEI) were not different at 2152 MJ ha^{-1} due to the same field operations used, including machinery and diesel fuel in running the tractor for land preparation and thresher for threshing grown under different spacing and different genotypes. Indirect energy inputs (IDEI) included embedded machinery energy, seed energy, fertilizer energy and labor energy for land preparation, seedbed preparation, crop establishment and harvesting The amount of organic fertilizer such as compost manure and liquid fertilizer applied in the organic system had an energy value of 1440 MJ kg^{-1} under both spacing and genotypes. There were no energy values for pesticides and herbicides for controlling pests and diseases because no synthetic chemicals were used under organic. Irrigation energy was the same amount at 59 MJ kg^{-1} under the organic system. Land preparation including labor with machine consumed 1509 MJ ha^{-1} that where in 1147 MJ is for diesel fuel, 237 MJ for embedded machinery energy, and 125 MJ for labor. Weeding was done with a rotary weeder three times in double rows and 30×30 cm while it was done only once in 20×20 cm. The highest labor energy (408 MJ ha^{-1}) for weeding was in 20×20cm because it was difficult to enter the inter-rows using rotary weeder. Harvesting were done by hand. The highest harvest energy was noted in 20×20 cm (157 MJ ha^{-1}) followed by double rows and 30×30 cm in which the same energy value was consumed at 125 MJ ha^{-1} including threshing energy.

The different planting patterns at 20×20 cm, double rows and 30×30 cm spacing grown under organic production were shown in Figures 1, 2 and 3.

Table 2. Total energy bill (MJ ha^{-1}) in two rice genotypes with three spacing grown under organic production system

ITEM	20×20 cm					Mean	(20×10)×40 cm					Mean	30×30 cm					Mean
	V1	V2	V3	V4	V5		V1	V2	V3	V4	V5		V1	V2	V3	V4	V5	
Direct Energy Input																		
Ploughing	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287
Harrowing + Levelling	860	860	860	860	860	860	860	860	860	860	860	860	860	860	860	860	860	860
Transportation	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287
Threshing	717	717	717	717	717	717	717	717	717	717	717	717	717	717	717	717	717	717
TOTAL	2151	2151	2151	2151	2151	2151	2151	2151	2151	2151	2151	2151	2151	2151	2151	2151	2151	2151
Indirect Energy Input																		
Machinery	279	279	279	279	279	279	279	279	279	279	279	279	279	279	279	279	279	279
Seed	168	1744	134	1526	151	744	218	2398	184	2180	201	1036	84	872	67	654	84	352
Organic Fertilizer	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440
Labor	1235	1235	1235	1235	1235	1235	1094	1094	1094	1094	1094	1094	1078	1078	1078	1078	1078	1078
Land Preparation	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125
Preparing and applying compost	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62
Seed bed preparation	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110
Transplanting	157	157	157	157	157	157	188	188	188	188	188	188	125	125	125	125	125	125
Irrigation	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59
Replanting and weeding	94	94	94	94	94	94	78	78	78	78	78	78	125	125	125	125	125	125
Preparing and applying liquid fertilizer	156	156	156	156	156	156	156	156	156	156	156	156	156	156	156	156	156	156
Weeding	314	314	314	314	314	314	188	188	188	188	188	188	188	188	188	188	188	188
Harvesting	157	157	157	157	157	157	125	125	125	125	125	125	125	125	125	125	125	125
TOTAL	3121	4697	3087	4479	3104	3698	3030	5210	2996	4992	3013	3848	2880	3669	2864	3451	2880	3149
Total Energy Input	5272	6848	5238	6630	5255	5849	5181	7361	5147	7143	5164	5999	5031	5820	5015	5602	5031	5300

Note: V1= Pbinhi, V2= Bigante, V3= GSR-8, V4= M-20 and V5= RC-222.

Figure 1. The 20 cm ×20 cm spacing grown under organic production system

Figure 2. The double rows [(20cm×10cm)×40 cm] spacing grown under organic production system

Figure 3. The 30 cm×30 cm spacing grown under conventional production

Between two different genotypes, the hybrid genotypes (Bigante and M-20) had higher seed energy values at 1562 MJ ha^{-1} compared to the inbred genotypes (Pbinhi, GSR-8 and RC-222) at 143 MJ ha^{-1} (Table 2). The comparative total energy bill (MJ ha^{-1}) and energy hotspot (%) grown under organic and conventional systems were seen in Table 3. On the average, of the total energy bill (5715 MJ ha^{-1}) under organic, direct energy inputs contributed 38% (2151 MJ ha^{-1}) in diesel fuel energy and indirect energy inputs shared 62% . The major energy hotspots were organic fertilizer (25%), labor (20%) and seed (12%) at 1440 MJ ha^{-1}, 1134 MJ ha^{-1} and 711 MJ ha^{-1} respectively. Under the conventional system, the total energy bill was 19821 MJ ha-1. The direct energy inputs provided 11% (2151 MJ ha^{-1}), while 89% (17670 MJ ha^{-1}) came mainly from indirect energy inputs including energy embedded in machinery, seed, chemical fertilizer, pesticide, herbicide and labor. Fertilizer (N, P and K) energy under conventional had 13458 MJ ha^{-1},which was 9.5 times higher energy than organic (1440 MJ ha^{-1}) was the main energy hotspot. Seed energy (711 MJ ha^{-1}) was not a major energy hotspot under organic due to planting one seedling per hill in both inbred and hybrid genotypes. In the conventional systems, the farmer used 80 kg of seeds per ha which is equivalent to about 1340 MJ ha^{-1} for seed energy. About 5-6 seedlings per hill ere transplanted in 20cm×20 cm spacing. Transplanting one seedling per hill reduced the amount of seeds from 80 kg ha-1 to 4 to 10 kg ha^{-1} and the seed energy from 1340 MJ ha^{-1} to 168 MJ ha^{-1}. Energy used for weeding was accounted at 280 MJ ha^{-1} under organic and 134 MJ ha^{-1} under conventional. Weeding was done thrice by using rotary weeder in organic while weeding was done twice by manual and then by herbicides under conventional. Conventional added the application of herbicide energy (1234 MJ ha^{-1}) to total energy bill.

Energy use indicators

The energy use indicators (energy output, energy use per kg of rice, break-even energy, EROEI, energy productivity and net energy) of three inbred and two hybrid rice genotypes grown under organic production are shown in Table 3. Bigante hybrid had the highest energy output at 93995 MJ ha^{-1} followed by RC-222 inbred at 86,944 MJ ha^{-1} due to the higher grain yield under organic. Energy output of RC-216 fertilized at 120:28:28 kg NPK in conventional system was 88,713 MJ ha^{-1} and it was statistically insignificant at 6% higher than energy output in organic system . The energy use per kg of un-milled rice were significantly different among the varieties. M-20 hybrid had the highest energy use at 1.35 MJ kg^{-1} while the inbred RC-222 had the lowest at 1.00 MJ kg^{-1}. Energy use per kg of un-milled rice grown under conventional (3.83 MJ kg^{-1}) was 3.3 times higher than under organic (1.164 MJ kg^{-1}). Break-even energy were not significantly different among spacings and varieties.

Grown under organic, Bigante and M-20 hybrids used 409 kg ha^{-1} and 396 kg ha^{-1}, respectively, to break even in terms of the energy use while under conventional system, RC-216 used 1213 kg ha^{-1} (72% higher). The energy returns over energy inputs (EROEI) also called energy efficiency. The different varieties were significantly different in EROEI. RC-222 had the highest EROEI at 17 followed by the Pabinhi and GSR-8 at 15. Bigante and M-20 hybrid had lower EROEI values at 14 and 13, respectively. Hybrid seeds used high energy inputs to produce. EROEI was only 4 under conventional while it was 15 under than organic (15). The energy productivity (EP) were significantly different among varieties. RC-222 had the highest EP at 1.01 kg grain MJ^{-1} followed by the Pabinhi and GSR-8 inbred. The average EP under organic was 0.88 kg grain MJ^{-1} while it was 0.26 kg MJ^{-1} under conventional. Organic system had three times higher EP than conventional method. In terms of Net Energy (MJ ha^{-1}) ,the highest net energies were obtained in Bigante (87314 MJ/ha) and RC-222 (81793 MJ/ha) due to the higher energy outputs. Compared to conventional, the net energy in organic (77634 MJ/ha) was higher by 12% (68403 MJ/ha).

Table 3. Energy use indicators for the inbred and hybrid rice genotypes grown under organic production system

Energy Use Indicators	**Variety**					**MEAN**
	Pbinhi	**Bigante**	**GSR-8**	**M-20**	**RC-222**	
Energy Output (MJ/ha)	76831 c	93995 a	76322 c	82658 bc	86944 ab	**83350**
Energy Use per kg of Un-milled Rice (MJ/kg)	1.13 b	1.20 b	1.14 b	1.35 a	1.00 c	**1.164**
Break-even Energy (kg/ha)	308	399	306	386	307	**341**
Energy Return Over Energy Input (EROEI)	15 b	14 bc	15 b	13 c	17 a	**15**
Energy Productivity (kg/MJ)	0.89 b	0.85 bc	0.89 b	0.77 c	1.01 a	**0.88**
Net Energy (MJ/ha)	71669	87319	71189	76199	81793	**77634**

Discussion

Energy analysis: comparing the energy hotspots of organic and conventional systems

The total energy input was 5715 MJ ha^{-1} under organic and 19821 MJ ha^{-1} under conventional. Organic reduced by 71% the total energy input over conventional. Organic fertilizer (25%), labor (20%) and seed (12%) at 1440 MJ ha^{-1}, 1134 MJ ha^{-1} and 711 MJ ha^{-1} ,respectively, were the major energy hotspots in organic systems .Under the conventional system, seeds (1340 MJ ha^{-1} for seed energy) and chemical fertilizer, especially nitrogen (N) fertilizer, was the major energy hotspot which contributed 62% (12336 MJ ha^{-1}).This is because Haber-Bosch N fertilizer needed huge energy to manufacture, at 1.8 L diesel oil per kg (Pfeiffer, 2003 and Mclaughlin, *et al*. 2000), and transportation used 0.35 L diesel oil (Mendoza, 2014). Reducing N fertilizer rate in a rice production system also reduces the total energy bill. Synthetic fertilizer (N, P and K) energy under conventional had 13458 MJ ha^{-1},which is 9.5 times higher energy than organic (1440 MJ ha^{-1}). The use of organic fertilizer reduced the energy bill of nutrient application, but it was labor-intensive mainly in preparing and applying organic fertilizer and carrying material particularly for N-rich source (animal manure) is difficult. Chemical fertilizers and pesticides are easily applied without preparation compared to organic compost and liquid fertilizer where preparation consumed a lot of labor. Between two different genotypes, inbred seed energy coefficient was only 16.75 MJ kg^{-1} while it was 218 MJ kg^{-1}) for the hybrids which was about 13 times higher than inbred seeds (Virmani *et al.,* 2002). Seed energy (711 MJ ha^{-1}) was not a major energy hotspot under organic due to planting one seedling per hill using only10 kg ha^{-1} in both inbred and hybrid genotypes. But in the conventional systems, the farmer used 80 kg of inbred seeds per ha because seedlings were transplanted at a distance of 20cm x 20cm and 5-6 seedlings per hill (equivalent to about1340 MJ ha^{-1} for seed energy) which made seeds as energy hotspots. Labor energy used for weeding was 280 MJ ha^{-1} under organic and 134 MJ ha^{-1} under conventional. This is because weeding was done 3 times by using rotary weeder in organic while weeding was done 2 times by manual and then by herbicides under conventional. But the application of herbicides contributed 1234 MJ ha^{-1} to total energy bill. Herbicides are easy to use, are effective in controlling weeds and relatively cheap compared to manual or mechanical weeding (Beltran *et al.,* 2011).However, application of herbicides is leading to building up of herbicide-resistant weeds, weed species population shifts, and environmental contamination and negative impacts on human health (Johnson and Mortimer, 2005). Transportation of herbicide after production was also a major role and transport energy mainly relied on the travel distance and types of vehicles. Philippines mainly relies on imported technical or formulations to meet the domestic demand (AgroChem Philippines, 2017). According to Pimentel (1980), transportation contributed 2% in formulation, packaging and transporting. Based on Barber (2004), herbicide energy coefficient was 550 MJ/kg. The transportation distance from production to farm was estimated at 3101 km in waterway and 200 km in roadway, and thus the herbicide energy coefficient increased from 550 MJ/kg to 562 MJ/kg. The total energy inputs included direct energy (DE) (fuel oil, lubricants) and indirect energy inputs (IDEI) such as seed energy, fertilizer energy and labor energy for land preparation, seedbed preparation, crop establishment and harvesting, and embedded energy of machinery energy. The organic fertilizer such as compost manure and liquid fertilizer applied in the organic system had only an energy value of 1440 MJ kg^{-1} .Irrigation energy was the same amount at 59 MJ kg^{-1} under the organic system. Land preparation including labor with machine consumed 1509 MJ ha^{-1} that where in 1147 MJ is for diesel fuel, 237 MJ for embedded machinery energy, and 125 MJ for labor. Labor energy was an energy hotspots under organic as it included labor in organic inputs preparation, transplanting, and weeding. Sprecifically, double rows had the highest transplanting labor energy at 188 MJ ha^{-1} because the rice transplanters were not familiar yet in double row planting scheme, followed by 20×20 cm (157 MJ ha^{-1}). Mechanical transplanter is designed for double transplanting systems in rice . A double row canepoint seeder had been optimized in sugarcane production (Mendoza *et al.,* 2003) .It should be pointed out that lowest labor energy in transplanting was in 30cm×30cm (123 MJ ha^{-1}) spacing since it had the lowest plant population and the larger space made movement easier.Labor in weeding was done with the use of a rotary weeder (three times in double rows and 30×30 cm while it was done only once in 20×20 cm). The highest labor energy (408 MJ ha^{-1}) for weeding was in 20×20cm because it was difficult to enter the inter-rows using rotary weeder. The transplanted seedlings were close to each other and this made rotary weeding and hand weeding so difficult (Mendoza, 2016). Due to faster canopy closure (30 DAS) and closer distance in the 20×20 cm spacing, rotary weeding was done only once and hand weeding was the only option afterwards . The 30×30 cm had a different plant response from 20×20 cm, as canopy closure took comparatively longer due to larger inter-rows space in the former. It made rotary weeding faster and easier and the labor energy (314 MJ ha^{-1}) for weeding was 23% lower than in 20×20 cm. Double rows had the highest plant population, which meant the highest transplanting energy, but it had good sunlight penetration between the double rows. The larger space between the double rows could allowed muscovy ducks to graze, thus favoring rice and duck integration, which is a promising farmer venture for extra income (Mendoza, 2016). Rotary weeding was the fastest and easiest because the number of plant rows were only 166 rows in double rows compared with 333rows in 30×30 cm and 500 rows in 20×20 cm . Consequently, labor energy for weeding was lowest (267 MJ ha^{-1}) in double rows by 35% reduction relative to 20×20 cm.

Energy use indicators

The energy use indicators (energy output, energy use per kg of rice, break-even energy, EROEI, energy productivity and net energy) of un-milled rice were significantly different among the varieties. M-20 hybrid had the highest energy use (1.35 MJ kg^{-1}) to produce one kg of un-milled rice due to the highest total energy inputs (TEI) and lower grain yield (energy use per kg of rice=TEI/Grain Yield). RC-222 had the lowest energy use per kg of un-milled rice at 1.00 MJ kg^{-1} due to the lowest total energy inputs per hectare under organic, while it was 3.83 MJ kg^{-1} under conventional. Energy use per kg of un-milled rice grown under conventional (3.83 MJ kg^{-1}) was 3.3 times higher than under organic (1.164 MJ kg^{-1}). The energy returns over energy inputs (EROEI) is the ratio of energy output and total energy inputs; it is also called energy efficiency. EROEI is unit-less. Bigante and M-20 hybrid had lower EROEI values at 14 and 13, respectively. This is because inbred genotypes used lower seed energy inputs than hybrid genotypes. This means that EROEI was directly related with energy output and inversely related with energy input (EROEI=Energy output/Total energy input). Therefore, increasing energy output (grain yield) and reducing total energy input will give the higher EROEI or energy efficiency. EROEI was only 4 under conventional and 15 for organic . The use of higher synthetic fertilizer amounts in conventional, especially nitrogen, and chemical pesticides application, led to greater total energy bill. Furthermore, the energy productivity (EP) under organic was higher at 0.88 kg MJ^{-1} while it was only 0.26 kg MJ^{-1} under conventional. Organic system had 3.4 times higher EP than conventional due to the lower TEI (5715 MJ ha^{-1}) in organic and higher TEI (19821 MJ ha^{-1}) in conventional .Likewise, the net energy in organic (77634 MJ/ha) was higher by 12% (68403 MJ/ha) than in conventional systems making organic more energy efficient. Mendoza (2005) analyzed the energy bill of 3 farming methods including organic, low external inputs sustainable agriculture (LEISA) and conventional method. Of the three farming methods, he found that growing rice through organic farming used the least amount of energy inputs (4371 MJ ha^{-1}) and showed the highest energy efficiency compared with LEISA (7424 MJ ha^{-1}) and conventional farming (11925 MJ ha^{-1}). That study showed organic farming decreased 63% of total energy bill relative to the conventional method. In this study, organic system reduced 71% of total energy input. This indicates that larger energy inputs are needed to increases in grain yields in conventional than organic.

It is concluded that the energy cost in producing hybrid seed is enormous. Inbred genotypes reduced 91% seed energy. Of the 3 spacings, the difficulties rice transplanters and the high plant population made double rows to have the highest TEI (5999 MJ ha^{-1}) followed by 20×20cm (5849 MJ ha^{-1}) and 30×30 cm (5300 MJ ha^{-1}). Grown under organic, Bigante hybrid and RC-222 inbred had higher energy output (grain yield) and EROEI in 30×30 cm and double rows than in 20 cm x 20 cm under organic. The energy used to produce 1 ton of un-milled rice were highest in 20cm×20cm followed by double rows and 30cm×30cm while RC-222 inbred was the lowest energy used in all spacing. Organic rice reduced the total energy bill by 71% over conventional rice; thus,energy return over enrgy input (EROEI) and energy productivity (EP) were higher and break-even energy and energy use per kg of milled rice were lower when rice was grown under organic. The major energy hotspots for the conventional production system were agrochemical inputs particularly nitrogen fertilizerat12336 MJ ha^{-1} (62%) and pesticides (1592 MJ ha^{-1}, 8%), which were not used in organic. The major energy hotspot for the organic system were organic fertilizer at 1440 MJ ha^{-1} (25%) and labor at 1134 MJ ha^{-1} (20%) due to the labor intensiveness of preparing and applying the organic fertilizer.Transplanting one seedling per hill reduces the amount of seed energy used per hectare up to 91% (80kg to only 4kg/ha at 1 seedling per hill and 30cm x 30cm spacing).

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