Food Research 4 (Suppl. 6) : 96 - 106
Journal homepage: http://www.myfoodresearch.com

FOOD RESEARCH

FULL PAPER

Energy audit of rice production in West Sumatra province, Indonesia

[1]Putri, R.E. [2]Lubis, M.I.A., [1]Andasuryani, [1]Hasan, A., [1]Santosa and [1]Arlius, F.

[1]*Department of Agricultural Engineering. Andalas University, Padang, Indonesia*
[2]*Department of Plantation Cultivation. Institute of Agricultural Sciences – Plantation Agribusiness (STIP-AP), Medan, Indonesia*

Article history:
Received: 13 April 2020
Received in revised form: 17 September 2020
Accepted: 26 September 2020
Available Online: 27 December 2020

Keywords:
Audit Energy,
Energy Input-Output,
Energy Analysis,
Rice Cultivations

DOI:
https://doi.org/10.26656/fr.2017.4(S6).019

Abstract

Audit energy is an appropriate method to determine the energy consumption expended in each agricultural cultivation activity, thereby reducing the wasteful use of energy. Energy consumption in rice cultivations consists of humans, fuel, machinery, seed, fertilizer and pesticides. The objective of the study was to analyze the total energy consumptions in the form of an energy audit activity on lowland rice cultivation in West Sumatera Indonesia. It is important to do, because of much energy input excessed, but less on productivity. So, by using analysis energy expenditure, productivity can be optimized with fixed input energy the costs could be minimized. Energy inputs were measured during all operating activities in rice cultivation (seeding, tillage, planting, fertilizing, spraying, weeding and harvesting). Energy input analysis based on energy sources used was divided into six parameters, namely: engine energy, fuel, humans, seeds, chemicals (pesticides) and fertilizer energy. The result showed the average of the total energy inputs in this study was 16,816,612 MJ/ha distributed to human, fuel, machinery, seeds, fertilizers and pesticides energy respectively 216.39; 890.75; 60.02; 983.29; 14,207.54; and 458.60 MJ/ha. Production costs incurred in rice cultivation activities in this study were IDR 13,107,562/ ha. Finally, the rice yield prediction model based on the input energy are $Y_1 = 4786.56 - 28.29X_1 + 36.23X_2 - 24.73X_3 - 8.43X_4 + 0.06X_5 - 0.80X_6$ and $Y_2 = 3605.11 + 5.44X_2$. The data of total energy were needed as a recommendation for the government to balance energy input and output on rice cultivations.

1. Introduction

Rice is a cereal crop grown and consumed on every continent of the world because of its adaptive capabilities which enable it to grow in areas with different soil types and climatic conditions. Central Statistics Agency (CSA) of West Sumatera (2018) reported that yield areas (507,545 to be 491,875.70 hectares), production (2,550,609 to be 503.45 tons) and productivity (50.25 to be 50.09 tons/hectares) for paddy decreased in 2015 to 2016. Based on this case, important to do an effort to solving decreased rice production. An effort to increase rice production by implementing sustainable agriculture is a solution that must be implemented so that food imports do not increase as well as a means of achieving self-sufficiency, sovereignty and food security. The real effort that can be implemented is to overcome the problem of land conversion by adding, maintaining and establishing sustainable agricultural land. Sustainable agricultural land itself is divided into areas (agriculture and agricultural allotment), the stretch of land (irrigated, reclaimed and non-irrigated) and land for sustainable agricultural reserves (Suswono, 2012). Efforts to achieve sustainable agriculture are implemented by implementing management of increased production that can reduce production costs, labor efficiency and other input factors and protect the environment (Piringer and Steinberg, 2006). Input factors are energy sources that have a sale value (cost) that is used both during the production, drying, packaging, storage and transportation processes (Zangeneh *et al*., 2010).

Purwantana (2011) said that the effort to increase energy efficiency in rice production is by carrying out calculations or studies of energy needs. This effort includes scheduling activities, estimating the time of each activity, the number of labor, the number of agricultural tools and machinery, as well as all facilities used (seeds, fertilizers, medicines, etc.). Energy analysis can be done by recording all activities, starting from fuel

*Corresponding author.
Email: *rennyekaputri@ae.unand.ac.id*

eISSN: 2550-2166

consumption and time spent on each activity.

Energy audits have been applied to previous studies on several agricultural commodities, including potatoes in Hamadan-Iran Province (Zangeneh *et al*., 2010), cucumbers in Iran (Mohammadi and Omid, 2010), tomatoes in Turkey (Ozkan *et al.,* 2011), rice in Malaysia (Bockari-Gevao *et al*., 2005; Muazu *et al*., 2015), rice in low land paddy cultivation (Lubis *et al*., 2019), rice planting using rice transplanter (Putri, Fadhilah, Cherie *et al*., 2020) and combine harvester (Putri, Cahyani, Fahmy *et al*., 2020). Research on the efficiency of energy use and economic analysis of several agricultural crops has been carried out (Muazu *et al.,* 2015). Economic analysis is expected to be able to calculate the costs incurred during rice cultivation activities. So that in the future it can be known technical rice cultivation with the production of energy inputs (power sources incurred costs) and optimum costs. Rahmat (2015) explained that energy audits are evaluation activities of energy utilization and analysis of savings opportunities on energy use as well as recommendations to improve the efficiency of energy use itself.

The objective of the study is to analyze total energy consumptions in the form of an energy audit activity on lowland rice cultivation in West Sumatera Indonesia and to explore the prediction model of yield on rice cultivation based on the energy input. Energy inputs are measured during all operating activities in rice cultivation (seeding, tillage, planting, fertilizing, spraying, weeding and harvesting).

2. Materials and methods

This research was conducted in 15 paddy fields from farmers and different implementation times. This research was carried out on paddy fields in Nagari Sungai Abang, Lubuk Alung Subdistrict located at coordinates 0.6788 – 0.6768 latitude and 100.2770 – 100.2796 longitude. The process flow, equipment and energy input for rice cultivation can be seen in Figure 1.

2.1 Energy analysis

2.1.1 Engine Energy

The agricultural machinery used in rice cultivation in this research included hand tractors and threshers. Every machine that works certainly releases energy. Energy calculation for each machine is done by completing some data obtained in the field and can be calculated using the following equation (Muazu *et al*., 2015):

$$ME = \frac{C_{f.m} \, x \, w}{F_c \, x \, N} \quad (1)$$

For Fc, it can be solved by using the following equation (Santosa, 2008):

$$F_c = \frac{A}{t} \quad (2)$$

Where ME = engine energy (MJ/ha), $C_{f.m}$ = energy conversion factor for machinery used (MJ/kg), show in Table 1, w = weight of machinery (kg), about 355,8 kg for hand-tractor and 48 kg for thresher, N = economic life of machinery (hr), assumed 12,000 hrs for hand-tractor and 4,000 hrs for thresher, F_c = effective field capacity (ha/hr), A = size of the farm (ha) and t = effective working time (hr)

During the rice cultivation activity takes place, the machine working time in the field is an effective time. Effective time is the difference between the total time total to the time lost (when turning, due to slipping, due to rest, due to the adjustment of tools, etc.). Furthermore, effective working time can be formulated as follows:

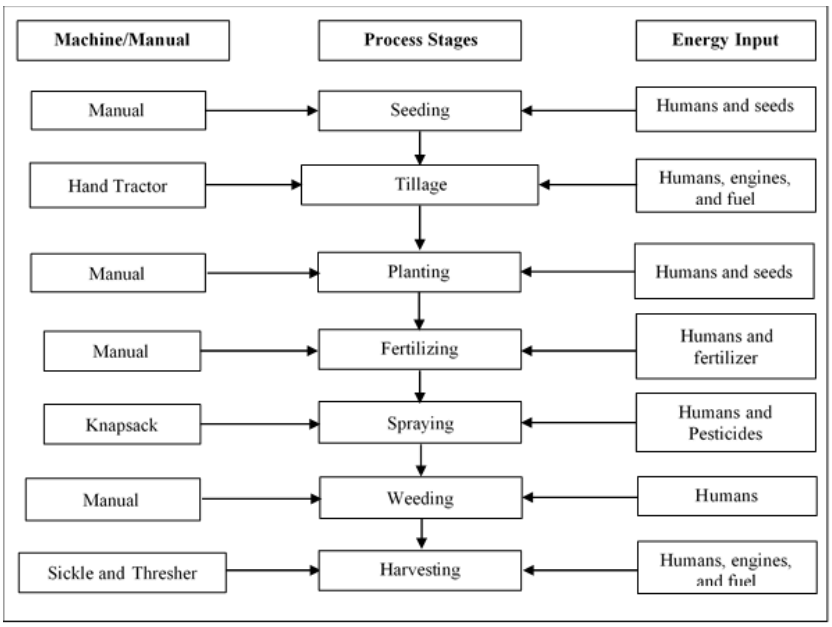

Figure 1. Flow chart of process, equipment and energy input of rice cultivation

$$t = t_s - t_h \quad (3)$$

Where t_s = total total time (hr) and t_h = time lost (hr)

2.1.2 Fuel energy

Fuel energy can be calculated using the following calculations (Muazu *et al*., 2015):

$$FE = \frac{F_{con} \times C_{f.f}}{A} \quad (4)$$

Where FE = fuel energy (MJ/ha), F_{con} = fuel consumed (L), $C_{f.f}$ = fuel energy conversion factor (MJ/L), shown in Table 1 and A = size of the farm (ha).

Table 1. Energy equivalent (MJ/Unit)

Type of Energy	Value	Unit	References
Machinery	93.61	kg	Muazu (2015)
Fuel (Diesel)	47.8	Liter	Cherati *et al.* (2011)
Paddy Seed	16.74	Kg	Muazu (2015)
Pesticides:			
Herbicides	238	kg	Cherati *et al.* (2011)
Fungicides	216	kg	Cherati *et al.* (2011)
Insecticides	101.2	kg	Zangeneh *et al.* (2010)
Fertilizer:			
Nitrogen (N)	60.6	kg	Cherati *et al.* (2011)
Phosphorus (P)	11.93	kg	Cherati *et al.* (2011)
Potassium (K)	11.15	kg	Zangeneh *et al.* (2010)
Sulfur (S)	9.23	kg	FAO (2001)
Zincum (Zn)	5.3	kg	FAO (2001)

2.1.3 Human energy

Measurement of the amount of energy expended by energy farmers is measured directly (real-time) using Garmin Forerunner 35 and heart rate monitor (HRM) (Figure 2).

Figure 2. Garmin Forerunner 35 (left) and Heart Rate Monitor (right)

2.1.4 Seed energy

Paddy seed which used in this research is "Anak Daro" variety. It used because it's cultivated usually by the farmers at West Sumatera and most of the people at the Province only consumed the rice with characteristic "Badarai/Scattered". In general, rice seed energy can be calculated using the following equation (Muazu *et al*., 2015):

$$SE = \frac{S_w \times C_{f.s}}{A} \quad (6)$$

Where SE = seed energy (MJ/ha), S_w = weight of seeds used (kg), $C_{f.s}$ = seed energy conversion factor (MJ/kg), shown in Table 1 and A = size of the farm (ha)

2.1.5 Pesticides energy

The pesticides that used in this research is liquid pesticides by Syngenta's product, with types are insecticides and fungicides. Pesticides energy used can be calculated using the following equation (Muazu *et al*., 2015):

$$PE = \frac{P_w \times C_{f.p}}{A} \quad (7)$$

Where PE = pesticides energy (MJ/ha), P_w = weight of pesticides used (kg), $C_{f.p}$ = pesticides energy conversion factor (MJ/kg), shown in Table 1 and A = size of the farm (ha)

2.1.6 Fertilizer energy

The fertilizer that used with branding name is Urea, Phonska and SP36. The amount of fertilizer energy given to plants can be calculated using the following equation (Muazu *et al*., 2015):

$$FTE = \frac{FT_w \times (\sum_{i=1}^{n} FT_i \times C_{f.ft})}{A} \quad (8)$$

Where FTE = fertilizer energy (MJ/ha), FT_w = weight of fertilizer used (kg), FT_i = percent composition of i^{th} element (decimal), $C_{f.ft}$ = fertilizer energy conversion factor (MJ/kg), shown in Table 1 and A= size of the farm (ha)

2.1.7 Total input energy

The total input energy is the total amount of energy used. The general form of the equation used to calculate the total input energy is as follows (Muazu, 2015):

$$TE_i = ME + FE + HE + SE + PE + FTE \quad (9)$$

Where TE_i = total input energy (MJ/ha) and ME, FE, HE, SE, PE and FTE are following the previous explanation above.

2.1.8 Total output energy

The total energy produced from rice cultivation can be seen from the rice production produced. The total output energy is only fill based on mass of rice production in a hectare. The output energy shall increase by the mass rice production (linear correlation). The equation used to calculate the total output energy produced is as follows (Muazu, 2015):

$$TE_o = Y_p \times C_f \quad (10)$$

Where TE_o = total output energy produced (MJ/ha), Y_p = harvested rice production (kg/ha) and C_f = conversion factor used (MJ/kg).

3. Results and discussion

3.1 Energy analysis

3.1.1 Engine energy

The engine energy is distributed inland processing and harvesting activities. The total average energy of the machine was 60.02 MJ/ha, based on the operation was 56.35 MJ/ha in tillage activities and 3.67 MJ/ha in harvesting activities. The distribution of the level of use of the machine in this study was 0.66 kg/ha. This is different from research in Malaysia, where mechanical energy is distributed in every operational activity, namely tillage, seeding, fertilizing, spraying, harvesting and weeding with a total energy of 477,780 MJ/ha (Muazu, 2015). In contrast to the use of engines in China 14.62 kg/ha (Dazhong dan Pimentel, 1984), India 4.33 kg/ha (Chauhan *et al*., 2006), USA 38 kg/ha (Pimentel, 2009), Philipina 4.03 kg/ha (Mendoza, 2015) and Malaysia 5.74 kg/ha (Muazu, 2015). Respectively 22, 6, 57, 6 and 9 times, compared with the level of machine used in this study. This is due to differences in the types of agricultural equipment and machinery used and in each cultivation activity between this study and previous research.

The value of machine energy spent on land management and harvesting activities is influenced by working time and land area. The mechanical energy in soil processing activities has a greater value than machine energy at harvest. This is influenced by working time, conversion factors and the mass of agricultural equipment and machinery used, where energy is directly proportional to the three parameters. Apart from these three factors in the tillage, there are two times the use of agricultural machinery (tractors). This is due to the condition of the soil being harder and drier and more weeds, so it requires longer time, as Muazu (2015) explained that the energy expended during tillage is influenced by soil type, moisture content and protective vegetation.

3.1.2 Fuel energy

The analysis of fuel energy used by farmers in this study was recorded in two activities, similar to the analysis of engine energy. The average of total fuel energy input released in this study was 890.76 MJ/ha. This shows that the energy input in this study was 79.43% lower than the research in Northern Thailand (Chaichana *et al*., 2008), 67.22% (Bockari-gevao *et al*., 2005) and 68.51% (Muazu *et al*., 2015) lower than rice research in Malaysia, 66.94% (Chauhan *et al*., 2006) and 59.85% (Mendoza, 2015) lower than research in India and the Philippines. Some things that can cause differences in the value of this energy input are the type of soil, the area of land cultivated and the machine used. As explained by Muazu (2015), the texture and condition of the cultivated land are one of the determinants of the time spent, where the greater the work time spent, the amount of fuel used will increase. In addition, another factor is the area of land, where the greater the area of land cultivated will result in a decrease in the value of fuel energy (according to equation 4). Each engine has different specifications so that the consumption of spent fuel will also be different. Apart from the type/ specification of the engine, the other determining factors for fuel consumption are engine life and maintenance.

The highest value of fuel energy is found in soil processing activities. This is due to the distribution of fuel energy in tillage there are two activities, namely first and second tillage. Tillage activities on land 10 emit the largest fuel energy, which is 753.04 MJ/ha and the lowest is found in land 8 of 419.52 MJ/ha. A big or small amount of energy spent on land treatment activities is influenced by the volume of fuel used and the area of land worked on. The volume of fuel used is identic to the soil water content and compactness/soil density (Muazu, 2015) which will affect the length of work, where the longer the tillage time, the greater the fuel spent.

The fuel energy recorded in the land processing activities was 64.02% (570.22 MJ/ha) of the total fuel energy, as well as being the largest energy in the distribution of fuel energy. Furthermore, the distribution of fuel energy is found in the harvesting activities of 35.98% or equivalent to 320.53 MJ/ha (Figure 3). Cherati, Bahrami and Asakereh (2011) and Khan *et al*., (2010) explained the same thing in rice research in Iran and Australia, which obtained the largest distribution of fuel energy in tillage and subsequently in harvesting activities. In a row is 45.89% (3,378.60 MJ/ha) and 31.85% (867.68 MJ/ha), 23.08% (1,698.90 MJ/ha) and 28.97% (789.22 MJ/ha). Other than that, Safa, Samarasinghe, dan Mohssen (2010) also noted in wheat research in New Zealand that the largest fuel energy was spent in two operational activities namely tillage and harvesting, respectively 46.15% (1,419 MJ/ha) and 27.69% (851.40 MJ/ha).

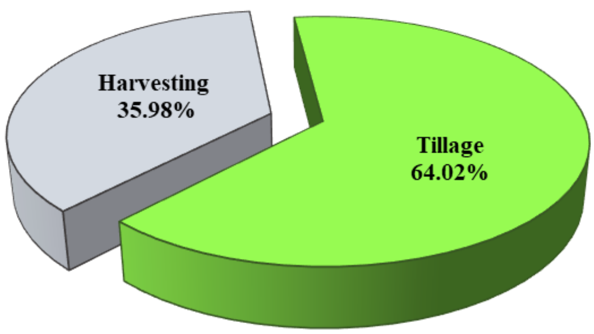

Figure 3. Fuel energy analysis

3.1.3 Human energy

Analysis of human energy during rice cultivation activities in this study was distributed in seven operations, which amounted to 216.39 MJ/ha. The value of human energy released in this study was 5.19 times out of 41.70 MJ/ha (Muazu, 2015) and 11.96 times out of 18.08 MJ/ha (Khan *et al.*, 2010). This is due to the fact that in this study some activities were still carried out manually, except for the tillage activities that had been carried out mechanically and the harvesting activities applied a semi-mechanical system. As in agricultural activities in Malaysia which still tends to some operating systems (such as seeding, spraying and fertilizing) done manually, resulting in an increase in human energy consumption (Muazu, 2015).

The greatest consumption of human energy is found in planting activities and the smallest is in fertilizing activities. The high or low value of the distribution of human energy is influenced by the length of work time (Table 2) and or intensity. As in spraying activities showed a greater distribution of human energy caused by the intensification of spraying in this study as much as five times, while in fertilizing activities only three times with an average processing time of 13.22 hr/ha (0.71 times smaller than spraying time).

Table 2. Human energy analysis

Activities	Energy Average (MJ/ha)	Time Average (hr/ha)
Seeding	37,805	1,373
Tillage	40,402	26,688
Planting	42,446	28,673
Fertilizing	18,579	13,225
Spraying	21,729	18,761
Weeding	27,268	24,704
Harvesting	28,160	62,223
Total	216,388	175,647

The percentage distribution of human energy can be seen in detail in Figure 4. Umar dan Noorginayuwati (2004) explained that the greatest human energy is in planting activities without including postharvest activities and maintenance pumps, which is 1.33 times greater than this research and planting activities 1.32 times from this research. Another case with research in Malaysia (Muazu *et al.*, 2015), which reported that human energy is greatest in spraying activities, which is 40.48% of the total energy used and fertilizing activity 0.59 times less than this study. The low value of human energy in the study is because the agricultural system applied has used a mechanical system in each of its activities, so it can be stated based on the research that the application of mechanical agriculture is able to reduce the use of human energy.

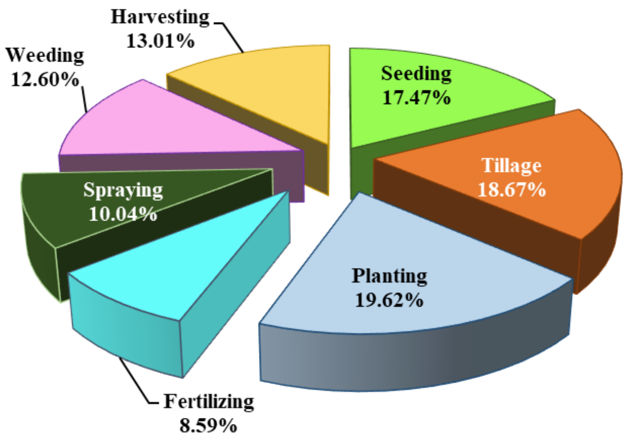

Figure 4. Percentage of human energy distribution

3.1.4 Seed energy

Seed energy distributed during this research was in planting activities. The average energy used is 983.30 MJ/ha, with an average use of seedling mass per hectare is 58.74 kg. Research in Northern Thailand, where the seed energy in succession in transplanting and broadcasting (sowing) systems was only 0.25 times (250.19 MJ/ha) and 1.00 times (984.63 MJ/ha) of this study. Another case with research by Muazu *et al.* (2015) who explained that the average seed energy used was 2,493 MJ/ha (148.93 kg/ha). That is, the average seed energy expenditure in this study was 2.53 times lower compared to research in Malaysia.

3.1.5 Fertilizer energy

Fertilizer energy released in this study as a whole comes from inorganic fertilizers. The average fertilizer energy released in this study was 14,207.55 kg/ha When compared with some previous studies, the fertilizer energy used in this study was 1.43 times out of 9,931 MJ/ha (Muazu *et al.*, 2015), 1.37 times out of 10,355,634 MJ/ha (Khan *et al.*, 2010), 2.38 times out of 5,956 MJ/ha (Chaichana *et al.*, 2008) and 1.31 times (Dazhong and Pimentel, 1984). The average use of inorganic fertilizers by farmers in this study was 917.55 kg/ha, with an average nitrogen, phosphorus, potassium, sulfur and zinc content used, respectively, 171.34; 165.05; 50.50; 49.71; and 0.10 kg/ha.

Figure 5 illustrates the percentage of fertilizer use based on the elements contained in it. The level of nitrogen usage has the highest percentage of 39.29% (171.33 kg/ha) and this value indicates a figure greater than 130 kg/ha and 116.90 kg/ha which is the average of the level of nitrogen in the Muazu *et al.* (2015) and Dobermann *et al.* (2002) study, but about 4.81% lower than the level of nitrogen in Central-China 180 kg/ha (Yuan and Peng, 2017) and 10.29% of the level of nitrogen in China 191 kg/ha (Dazhong and Pimentel, 1984).

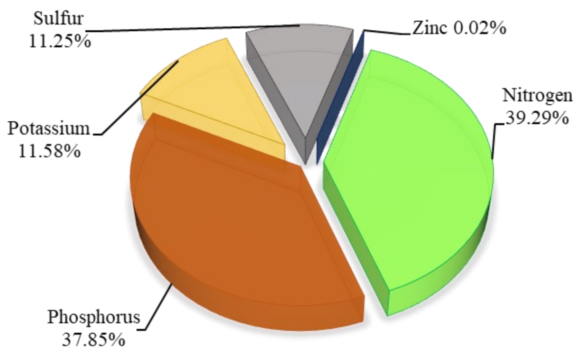

Figure 5. Percentage of level of use of mineral fertilizer elements

The level of use of phosphorus, potassium, sulfur and zinc in this study were 37.85% (165.05 kg/ha), 11.58% (50.50 kg/ha), 11.25% (49.07 kg/ha) and 0.02% (0.10 kg/ha). When compared with the level of fertilizer use in Central-China in 2015 which was 180 kg/ha nitrogen, 91.60 kg/ha phosphorus, 120.50 kg/ha potassium and 5 kg/ha zinc (Yuan and Peng, 2017), phosphorus by farmers in this study was 1.80 times larger, but smaller in nitrogen, potassium and zinc each by 0.55; 0.41; and 0.02 times.

Good fertilizer management is an activity that takes into economic, social and environmental factors in order to achieve a sustainable agriculture system. The concept of good fertilizer management and has been widely adopted by the fertilizer industry in the world is by applying the 4R system (Right source, Right dose, Right time and Right place) (IPNI, 2017). Strengthening the Kitchen, Goulding and Shanahan (2008), that in agricultural practices farmers need to improve the efficiency of fertilizer use by not redundant fertilizer and apply the right time interval for fertilizer application, then Aguilar and Borjas (2005) stated that it is not justified giving water to the rice fields when fertilizer time is taking place and over the next few days to avoid soil salinity problems that will have an impact on production.

3.1.6 Chemicals energy (pesticides)

The chemicals (pesticides) used in this study consisted of two types, namely insecticides and fungicides. The average pesticide energy expenditure is 458.60 MJ/ha. The size of the energy of pesticides depends on the amount of pesticide (kg/ha) used. The more amount of pesticides used will increase the amount of energy expended.

The average pesticide use in this study was 2.27 kg/ha (Table 3). This shows that in this study the use of pesticides 49.13; 59.19; and 67.86% lower than 4.46; 5.56; and 7.06 kg/ha for each use of pesticides in rice cultivation in Yangliangyou6-China in 2015, Malaysia and Northern Thailand (Yuan dan Peng (2017), Muazu *et al*. (2015) and Chaichana *et al*. (2008)).

Table 3. Analysis of average level of pesticide use

Input	Average	
	Use (kg/ha)	Energy (MJ/ha)
Insecticides	0,339	80,268
Fungicides	1,930	378,334
Total	2,269	458,602

However, the use of pesticides in this study was higher compared to the use of pesticides in South Kalimantan Province 1.11 kg/ha (Umar and Noorginayuwati, 2004), Phatthalung-Thailand Province 1.26 kg/ha (Chaicana *et al*., 2014). Based on research that has been carried out on lowland rice cultivation in the Mekong Delta-Vietnam, that the use of pesticides that are good for the health of farmers and optimal in achieving yield production (6.70 tons/ha) is 0.74 kg/ha (Dung and Dung, 1999). Thus, the application of pesticides in the future needs to be considered so as not to harm the health of farmers and minimize wasteful energy on energy sources, in this case pesticide energy. The percentage of pesticide use can be seen in Figure 6.

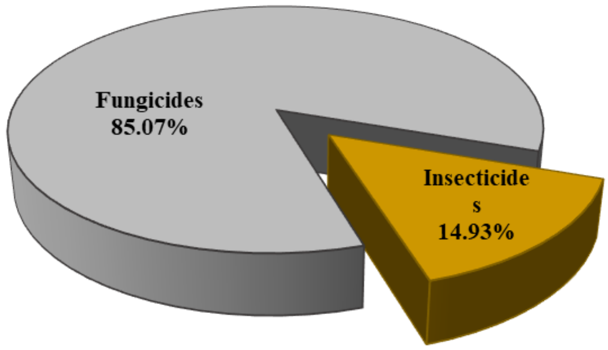

Table 3. Analysis of average level of pesticide use

3.1.7 Average energy input based on energy source

Based on the six energy sources used during rice cultivation activities that have been carried out, a total average energy value of 16,816.61 MJ/ha was obtained, 25% lower than 22,425 MJ/ha (Chaichana *et al*., 2008). However, 2.24% greater than 16,440 MJ/ha (Muazu *et al*., 2015). Fertilizer energy is the biggest energy source used in this study, which is 84.49% (Figure 7) of 100% of the total energy expended. Chaichana *et al*. (2008) and Muazu (2015) explained in a study conducted in the Northern part of Thailand and Malaysia that fertilizer energy was the holder of the biggest role of energy sources, namely 39.25% and 60.41%; So, farmers in this study used a much larger fertilizer, which is 24.08 – 45.24%.

Marzuki *et al*. (2013) explained that the use of fertilizer in large amounts (excess) can cause a decrease in plant growth and inefficient plants in absorbing nutrients actually so that it will result in a decrease in rice production. Therefore, it is necessary to apply the right fertilizer by following the 4R rules, so that there is no redundant fertilizer (IPNI, 2017) which has an impact on the waste of energy and production costs (Uhlin, 1998).

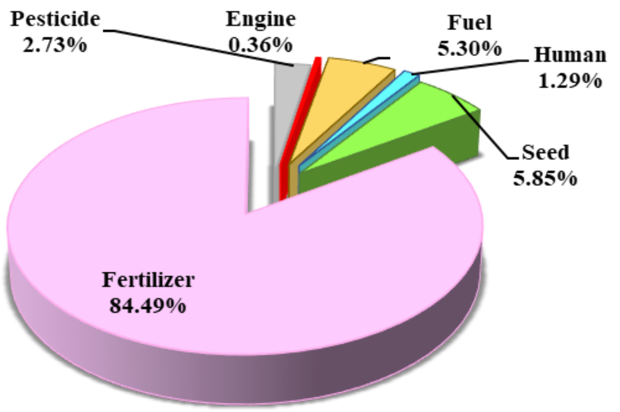

Figure 7. Percentage of energy according to energy input sources

The seed energy, fuel, pesticides and engine used in this study were lower than 15.16%; 17.21%; 4.06%; and 2.91% of each use of energy sources applied in Malaysia. However, human energy input in this study is 1.04% higher than 0.25% of human energy use in research conducted in Malaysia (Muazu, 2015). This is different from the research conducted in the District of South Kalimantan, where there was no fertilizer, engine and fuel energy (traditional cultivation systems), so it can be concluded that in this study the energy of fertilizer, engine and fuel was greater. However, the percentage of seed, pesticide and human energy expenditure in this study was smaller compared to 10.40%; 55.58%; and 34.02% of each percentage of the energy distribution of rice cultivation that occurred (Umar and Noorginayuwati 2004).

3.2 Average energy input based on operating activities

Based on research that has been carried out on average, the total value of energy input based on operations is 16,816,612 MJ/ha. The biggest energy expended is in fertilizing activities is 84.60%, then planting (6.10%), tillage (3.97%), spraying (2.86%), harvesting (2.10%), seeding (0.22%) and finally weeding is 0.16% (Figure 8 and Table 4).

The energy in fertilizing activities as the biggest energy in this study, according to several previous studies. Muazu *et al*. (2015) explained the same thing that energy in fertilizing activities in rice cultivation in Malaysia was the largest, about 61.33% (10,082 MJ/ha). Furthermore, the same thing was reported by Chaicana *et al*. (2014), Khan *et al*. (2010), Chaichana *et al*. (2008) and Chauhan *et al*. (2006) that the energy in fertilizing activities as the largest energy in rice cultivation activities, respectively 13.22% (2414.69 MJ/ha) in Phatthalung Province-Thailand, 38.32% (9,247.39 MJ/ha) in Australia, in North Thailand about 26.61% (5,967.06 MJ/ha) and 33% (3,114.14 MJ/ha) in India.

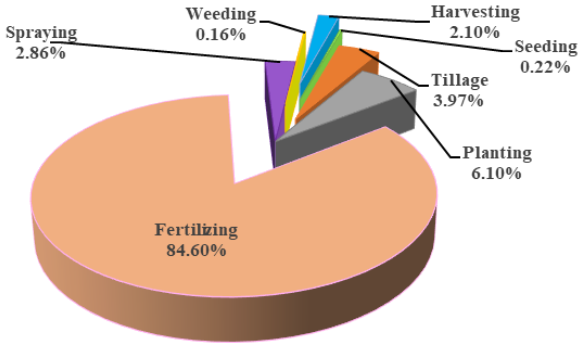

Figure 8. Percentage of energy in each operating activity

The average value of energy consumption in fertilizing activities in this study showed a percentage of 84.60% or equivalent to 14,207.547 MJ/ha. This indicates that the figure obtained is greater than the expenditure of fertilizing energy on rice cultivation in the Province of Phatthalung-Thailand, Malaysia, Australia, Northern Thailand and India. More simply can be described that the energy in fertilizing activities in this study 5.88 times greater than research in the Province of Phatthalung-Thailand, 1.41 times from research in Malaysia, 1.54 times from research in Australia, 2.38 times that of research in northern Thailand and 4.56 times bigger than research in India. The imbalance of energy distribution that occurs in this study needs to be addressed. One alternative that can be applied in overcoming the imbalance of energy distribution that occurs is to apply precision agriculture, this is useful to minimize wasteful (wasteful) energy.

Based on research that has been carried out obtained an average production yield of 6,029.466 kg/ha (6,029 tons/ha). This shows that production results are 1.13 times greater than 5.34 tons/ha of national production, 1.18 times of 5.09 tons/ha of West Sumatra rice production (CSA of West Sumatra, 2018) and 1.32 out of 4.57 tons/ha of rice production in Lubuk Alung District (CSA of West Sumatra, 2018).

Table 4. Energy analysis

Parameter	Value
Production result (kg/ha)	6,029.47
Energy intensity (MJ/kg)	2.75
Productivity (kg/MJ)	0.36
Clean energy (MJ/ha)	83,529.63
Output energy (MJ/ha)	100,933.26

When compared with some previous studies that applied mechanical systems in Malaysia (Muazu *et al*., 2015), Australia (Khan *et al*., 2010) and the United States (Pimentel, 2009), the production results in this study were smaller respectively by 20.93%; 39.07%; and 20.83%. The value of energy intensity in this study indicates that to produce 1 kg of grain requires 2.747 MJ of energy, or it can be interpreted that with 1 MJ of energy released can produce 362 grams of grain. Potential production of unhulled rice with 1 MJ energy input in this study was greater than 255 grams (Dazhong and Pimentel, 1984), 225 grams (Chamsing *et al*., 2006), 226 grams (Purwantana, 2011), 352 grams (Eskandari and Attar, 2015), 86 grams (Aghaalikhani *et al.,* 2013) and 266 grams (Yuan and Peng, 2017). However, lower than 460 grams (Muazu *et al*., 2015). Productivity of a plant should be greater by the energy that input in sample farm and between yield production and energy have linier correlation (Ozkan *et al*., 2011).

The yield prediction model built in this study is adapted to six aspects of energy input, including engine energy, fuel, humans, seeds, fertilizers and pesticides. This is in accordance with the research of Muazu *et al.* (2015) which limits the development of yield prediction models in rice cultivation in Malaysia by using six sources of energy input. All energy inputs carried out in this study were formulated based on seven activities, like: seeding, tillage, planting, fertilizing, spraying, splashing and harvesting. This is different in terms of aspects of the activity when compared to research that has been conducted in Malaysia. The prediction model of the results released in this study as described in equation 19.

Based on Table 5, the F-count value is obtained at a significant level of 0.01 which illustrates that the F-count is large from the F-table at a 99% confidence level, so it can be interpreted that the independent variables (energy input source or X) have an effect significant to the dependent variable (yield of rice or Y) and then the coefficient of determination can be used to predict the effect of variable X simultaneously on the variable Y. The T-value of the fuel is significant at the 0.01 level which describes that this variable is good for estimating of rice yields.

Table 5. Analysis of data parameter prediction model results

Variable	Coefficient	Standard Error	T-count
Intercept *[m]*	4,786.56	4,230.64	1.13^{**}
Engine energy [X_1]	-28.29	28.68	-0.99^{ns}
Fuel energy [X_2]	36.23	11.16	3.25^{*}
Human energy [X_3]	-24.73	19.28	-1.28^{ns}
Seed energy [X_4]	-8.43	3.7	-2.28^{ns}
Fertilize energy [X_5]	0.06	0.14	0.41^{ns}
Pesticide energy [X_6)	-0.8	7.3	-0.11^{ns}
R^2	0.81		
Multiple-R	0.9		
F-count	82.26^{*}		
F-table	15.21		

The coefficient of determination (R^2) model from the input energy is 0.811. This means that 81.10% of the variables X simultaneously affect the Y variable, the remaining 18.90% is influenced by other factors outside the equation of the variable under study. According to Junaidi (2014), the value of R^2 gets better if the value approaches 1. Therefore, we can state that the input energy has a good level of suitability. Next, if we look at the Multiple-R value which shows the level of closeness (correlation) of the dependent variable and the independent variables. That is, the level of closeness of the value of production results to the independent variables is very strong that is equal to 90.10%. The prediction model of the first results produced is as follows:

$$Y_1 = 4786.56 - 28.29X_1 + 36.23X_2 - 24.73X_3 - 8.43X_4 + 0.06X_5 - 0.80X_6$$

$$Y_2 = 3605.11 + 5.44X_2$$

Where Y_1 = prediction of results with all variables (ton/ha), Y_2 = prediction results using significant variables (ton/ha), X_1 = engine energy input (MJ/ha), X_2 = fuel energy input (MJ/ha), X_3 = human energy input (MJ/ha), X_4 = seed energy input (MJ/ha), X_5 = fertilizer energy input (MJ/ha) and X_6 = pesticide energy input (MJ/ha)

Fuel energy has the most influence on the prediction of rice production, followed by the energy of fertilizers, pesticides, seeds, humans and the smallest is engine energy. Fertilizer is one of the factors needed and influencing rice growth needs to be considered the pattern of administration and dosage, because these factors will influence the yield (Muazu, 2015). One way is to implement a 4R system (IPNI, 2017). Steps that can be taken to implement the 4R system is to test the type of soil so that it can be seen what elements are lacking in the soil. In addition to fertilizer as a factor that has a positive influence on the prediction of yield is fuel energy.

Another thing is if we examine the energy coefficient values of pesticides, seeds, humans and engines that have negative predictive coefficient values. That is, if there is an increase in energy at the four sources, rice production will decrease according to the prediction model that is built. One way to reduce this reduction is by reducing the operator and machine's working time (Muazu, 2015) and regulating the use of seeds and pesticides as efficiently as possible.

4. Conclusion

The conclusions of this study are the average of the total energy inputs of 16,816,612 MJ/ha distributed to human energy, fuel, engine, seeds, fertilizers and pesticides respectively 216.39; 890.76; 60.02; 983.30; 14,207.55; and 458.60 MJ/ha. As a limitation in this research, every parameter made uniform as like as land's characteristics, seed variety, labor in all activities is same for each field area, hand-tractor and thresher that used with the same type for all field area and also for fuel is same (diesel) and weight of fertilizer and doses of pesticides in every broadcasting is same for every field area. Human energy that is measured in real-time and using a conversion table has a difference in the value of 7.53 MJ/ha, where human energy is calculated using a smaller conversion table (22.00 MJ/ha). The final result of the research is the determination of a prediction model of rice yield, with a mathematical model $Y_1 = 4786.56 - 28.29X_1 + 36.23X_2 - 24.73X_3 - 8.43X_4 + 0.06X_5 - 0.80X_6$ and $Y_2 = 3605.11 + 5.44X_2$. For further research, it can be conducted by using comparing both of two until three seed variety in the same land characteristics or comparing energy expenditure with any parameters equals except land characteristic (low-land and high-land cultivation).

Acknowledgment

The authors would like to thank Andalas University Grant number 95/ UN.16.17/PP.PGB/LPPM/2018 for providing financial support or this project.

References

Aghaalikhani, M., Kazemi-poshtmasari, H. and Habibzadeh, F. (2013). Energy Use Pattern in Rice Production: A Case Study from Mazandaran Province, Iran. *Energy Conversion and Management*, 69, 157–162. https://doi.org/10.1016/j.enconman.2013.01.034

Aguilar, M. and Borjas, F. (2005). Water Use in Three rice Flooding Management System Under Mediterranean Climatic Conditions. *Spanish Journal of Agricultural Research,* 3(3), 344–351. https://doi.org/10.5424/sjar/2005033-157

Bockari-gevao, S.M., Ishak, W. and Yahya, A. (2005). Analysis of Energy Consumption in Lowland Rice-Based Cropping System of Malaysia. Songklanakarin Journal of Science Technology, 27 (4), 819–826.

Chaicana, T., Pethuayluk, S., Tepnual, T. and Yaibok, T. (2014). Energy Consumption Analysis for SANGYOD Rice Production. *Energy Procedia*, 52, 126–130. https://doi.org/10.1016/j.egypro.2014.07.062

Chaichana, T., Chaitep, S., Jompakdee, W. and Dussadee, N. (2008). Energy Analysis of Wet Season Rice Production in Northern Thailand. *International Agricultural Engineering Journal*, 17(1-4), 1-7.

Chamsing, A., Salokhe, V.M. and Singh, G. (2006). Energy Consumption Analysis for Selected Crops in Different Regions of Thailand. *Agricultural Engineering International: the CIGR Ejournal*, 8, 1–18.

Chauhan, N.S., Mohapatra, P.K.J. and Pandey, K.P. (2006). Improving Energy Productivity in Paddy Production Through Benchmarking - An Application of Data Envelopment Analysis. *Energy Conversion and Management*, 47(9–10), 1063–1085.

Cherati, F.E., Bahrami, H. and Asakereh, A. (2011). Energy Survey of Mechanazied and Traditional Rice Production System in Mazandaran Province of Iran. *African Journal of Agricultural Research*, 6(11), 2565–2570. https://doi.org/10.1016/j.enconman.2005.07.004

CSA of West Sumatera. (2018). Produksi Padi (ton), dan Produktivitas Padi di Sumatera Barat. Retreived on April 17, 2018 from Sumbar BPS website: https://www.sumbar.bps.go.id.

Dazhong, W. and Pimentel, D. (1984). Energy Inputs in Agricultural Systems of China. *Agriculture, Ecosystems and Environment*, 11(1), 29–35. https://doi.org/10.1016/0167-8809(84)90046-X

Dobermann, A., Witt, C., Dawe, D., Abdulrachman, S., Gines, H.C. and Nagarajan, R. (2002). Site Specific Nutrient Management for Intensive Rice Cropping System in Asia. *Field Crops Research*, 74(1), 37–66. https://doi.org/10.1016/S0378-4290(01)00197-6

Dung, N.H. and Dung, T.T.T. (1999). Economic and Health Consequences of Pesticides Use in Paddy Production in the Mekong Delta, Vietnam. Singapore: Economy and Environment Program for Southeast Asia (EEPSEA).

Eskandari, H. and Attar, S. (2015). Energy Comparison of Two Rce Cultivation Systems. *Renewable and Sustainable Energy Reviews*, 42, 666–671. https://doi.org/10.1016/j.rser.2014.10.050

[IPNI] International Plant Nutrition Institute. (2017). 4T Hara Tanaman: Pedoman Peningkatan Manajemen Hara Tanaman. Indonesia: International Plant Nutrition Institute. [In Bahasa Indonesia].

Junaidi. (2014). Regresi dengan Microsoft Office Excel.Indonesia: Fakultas Ekonomi dan Bisnis

Universitas Jambi.

Khan, M.A., Khan, S. and Mushtaq, S. (2009). Energy and Economic Efficiency Analysis of Rice and Cotton Production in China. *Sarhad Journal of Agriculture,* 25(2), 291–300.

Khan, S., Khan, M.A. and Latif, N. (2010). Energy Requirements and Economic Analysis of Wheay, Rice and Barley Production in Australia. *Soil Science Society of Pakistan*, 29(1), 1–8.

Kitchen, N.R., Goulding, K.W.T. and Shanahan, J.F. (2008). Chapter 15 - Proven Practices and Innovative Technologies for On-Farm Crop Nitrogen Management In Hatfiled, J.L. and Follett, R.F. (Eds). Nitrogen in the Environment. 2nd ed., p. 483–517. USA: Academic Press. https://doi.org/10.1016/B978-0-12-374347-3.00015-9

Lubis, M.I.A., Putri, R.E., Arlius, F. and Hasan, A. (2019). Energy Consumption on Tillage Operation in Low Land Paddy Cultivation. *IOP Conference Series: Earth and Environmental Science*, 327(1), 012010. https://doi.org/10.1088/1755-1315/327/1/012010

Marzuki, Murniati and Ardian. (2013). Pengaruh Jarak Tanam dan Dosis Pupuk Terhadap Pertumbuhan dan Produksi Padi Sawah (*Oryza sativa* L.) dengan Metode SRI. *Journal Online Mahasiswa Fakultas Pertanian Universitas Riau*, 1, 1-12. [In Bahasa Indonesia].

Mendoza, T.C. (2015). An Energy-Based Analysis of Organic, Low External Input Sustainable Agriculture An Energy-Based Analysis of Organic, Low External Input Sustainable Agriculture (LEISA) and Conventional Rice Production in the Philippines. *The Philippine Agriculture Scientist*, 88(3), 257-267.

Mohammadi, A. and Omid, M. (2010). Economical analysis and relation between energy inputs and yield of greenhouse cucumber production in Iran. *Applied Energy*, 87(1), 191–196. https://doi.org/10.1016/j.apenergy.2009.07.021

Muazu, A. (2015). Modeling For Energy Optimization in Wetland Paddy Production in Malaysia. Malaysia: Universiti Putra Malaysia, PhD Thesis.

Muazu, A., Yahya, A. and Ishak, W.I.W. (2015). Energy audit for sustainable wetland paddy cultivation in Malaysia. *Energy,* 87, 182–191. https://doi.org/10.1016/j.energy.2015.04.066

Ozkan, B., Ceylan, R.F. and Kizilay, H. (2011). Comparison of Energy Inputs in Glasshouse Double Crop (Fall and Summer Crops) Tomato Production. *Renewable Energy,* 36(5), 1639–1644. https://doi.org/10.1016/j.renene.2010.11.022

Pimentel, D. (2009). Energy Inputs in Crops Production in Developing and Developed Nations. *Energies*, (2), 1–24. https://doi.org/10.3390/en20100001

Piringer, G. and Steinberg, L.J. (2006). Reevaluation of Energy Use in Wheat Production in the United States. *Industrial Ecology*, 10(1), 149–167. https://doi.org/10.1162/108819806775545420

Purwantana, B. (2011). Kajian Input Energi pada Budidaya Padi. *Agritech*, 31(1), 1–8.

Putri, R.E., Fadhilah, R., Cherie, D. and Novianda, A.W. (2020). Analysis of Energy Consumption and Performance Test on Rice Planting Using Rice Transplanter: A Case Study in West Sumatera Province. Indonesia. *Journal of Applied Agricultural Science and Technology*, 4(1), 12-25. https://doi.org/10.32530/jaast.v4i1.152

Putri, R.E., Cahyani, G.A., Fahmy, K., Arlius, F. and Hasan, A. (2020). Comparison of Performance and Total Energy Requirement for Several Harvesting Method of Indonesian Farmers. *IOP Conference Series: Earth and Environmental Science*, 515(1), 012004. https://doi.org/10.1088/1755-1315/515/1/012004

Rahmat, R. (2015). Pentingnya Energi Audit untuk Efisiensi Energi. Retreived on October 16, 2018 from Indonesia Envrionment and Energy Center website: https://environment-indonesia.com/audit-energi-adalah/. [In Bahasa Indonesia].

Safa, M., Samarasinghe, S. and Mohssen, M. (2010). Determination of Fuel Consumption and Indirect Factors Affecting It in Wheat Production in Canterbury, New Zealand. *Energy*, 35(12), 5400–5405. https://doi.org/10.1016/j.energy.2010.07.015

Santosa. (2008). Manajemen Tenaga Alat dan Mesin Pertanian. Retrieved on October 12, 2018 from website: https://www.slideshare.net/iqrimhayamada/manajemen-alat-dan-mesin-pertanian. [In Bahasa Indonesia].

Suswono. (2012). Peraturan Menteri Pertanian. Jakarta: Indonesia. [In Bahasa Indonesia].

Uhlin, H.E. (1998). Why Energy Productivity is Increasing : An I-O Analysis of Swedish Agriculture. *Agricultural System*, 56(4), 443–465. https://doi.org/10.1016/S0308-521X(97)00059-0

Umar and Noorginayuwati. (2004). Use of Energy in Farming on Lebak Land (Penggunaan Energi pada Usaha Tani pada Lahan Lebak). *Agritech*, 25(2), 96–102.

Yuan, S. and Peng, S. (2017). Input-output Energy Analysis of Rice Production in Different Crop Management Practices in Central China. *Energy*, 141, 1124–1132. https://doi.org/10.1016/j.energy.2017.10.007

FULL PAPER

Zangeneh, M., Omid, M. and Akram, A. (2010). A Comparative Study on Energy Use and Cost Analysis of Potato Production Under Different Farming Technologies in Hamadan Province of Iran. *Energy*, 35(7), 2927–2933. https://doi.org/10.1016/j.energy.2010.03.024

eISSN: 2550-2166