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# Energy audit for sustainable wetland paddy cultivation in Malaysia

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ABSTRACT

An on-the-farm evaluation of energy inputs and output in 40 farms was conducted to determine the distributions of six main energy sources (i.e. human, fuel, machinery, seeds, fertilizer and pesticides) used in wetland paddy cultivation in Malaysia. The average paddy yield was found to be 7625 kg/ha with total energy input of 16,440 MJ/ha, energy output/input ratio of 7.76 and energy intensity of 2.16 MJ/kg. Compared to energy intensities for the production of rice in China, India and Thailand of 3.91, 3.50 and 4.44 MJ/kg respectively, paddy farmers in Malaysia used the least energy per unit of paddy produced. Almost 84% of the total energy input used in the cultivation was from fossil-based non-renewable resources, of which fertilizer, fuel, pesticides and machinery accounted for 60, 17, 4 and 3% respectively. The share contributions from seed, human labor and organic fertilizer which constituted the renewable resources were 15, 0.25 and 0.22% respectively. The benefit-cost ratio and total cost of production were 1.37 and RM6, 657/ha respectively. The fitted regression model revealed a direct relationship of yield with fuel, machinery, fertilizer, pesticides and seed energy expenditures and an inverse relationship of yield with the human energy expenditure.



## 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. It is one of the most important and widely cultivated food crops, next only to wheat in terms of volume of production [1] and nearly half of the world population relies exclusively on rice as food [2]. In Malaysia, rice is a security crop, being a staple food for the majority of the populace and a source of employment/income to rural farmers. In Malaysia, about 150,000 farmers depend exclusively on rice cultivation for their overall sustenance [3]. The average productivity level for rice in the country is low, pegged at 3817 kg/ha compared to the world average of 4527 kg/ha. In 2013, the total paddy production in Malaysia was 2.63 million tons cultivated from 688,207 ha of farmland [4]. With per capita rice consumption of 110 kg/year and a projected population of 30.188 million people, the country's current rice self-sufficiency level was estimated to be 79% and is targeted to attain a complete self-sufficiency level by 2020. Increased paddy production could be achieved by either increasing the area under paddy cultivation or increasing farmland productivity through efficient utilization of inputs, or both. Increasing paddy production through area expansion is not feasible in the country because of the limited arable land suitable for paddy cultivation. Therefore, the only option to exploit is increasing farmland productivity, in which energy study could play a central role. Energy analysis is useful because it helps to identify wasteful uses of energy and also represents an approach for determining the percentage contribution of each segment of the energy mix (direct versus indirect; renewable versus non-renewable and commercial versus non-commercial) utilized in the crop production system. In this way, it helps to shed some light on more sustainable crop production options profitable to farmers, consumers and the environment. Energy use efficiency, net energy gain, energy productivity, energy intensity, the percent distribution of the farm inputs and the benefit-cost analysis are some of the ways to measure the sustainability of the crop production system.

Although many researches on energy use and cost analysis in crop production have been widely reported in the literature [5–11], the methodology adopted in most of these studies relied on data collected through questionnaires, for which the accuracy of the information obtained depended mainly on the farmers' ability to record the exact amount of all the farm inputs which they used in the entire production process. In addition, the methods of application of the farm inputs and the durations covered in performing each of the operations also need to be quantified. In most

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developing countries, where the average farmer is resource-poor, small-scale and hardly literate, farm record-keeping is a significant challenge and seldom observed. Assessing the sustainability of the system both from environmental and economic points of view requires precise knowledge of all the inputs used in the production, of which crop production is not an exception. In this regard, the present study was aimed to carry out a thorough on-farm evaluation of all inputs used in the wetland paddy cultivation system, develop yield predictive model and perform cost analysis, with a view to identifying the extent of the contribution of each of the energy sources used and of operations practiced by farmers that militate against the sustainability of the system. Thus, both the farmers and agricultural policy-makers in the country can know what is at stake and, therefore, recognize the need for closer cooperation in order to surmount the problems and, in doing so, promote the productivity and sustainability of wetland paddy cultivation in Malaysia. Table 1 gives typically reported paddy yields, energy inputs and energy intensities in the production of rice in some selected countries. The total energy inputs range from 9257 MJ/ha in India to 31,703 MJ/ha in China. Similarly, the yield was highest in China (8098 kg/ha) and lowest in India (2699 kg/ha). Among the individual farm inputs used in the cultivation, the energy embodied in fertilizer had the highest contribution in all four countries. Energy use intensity was lowest in Bangladesh (3.23 MJ/kg) and highest in Thailand (4.44 MJ/kg). It is important to note that the study boundaries for the energy use in the four countries were different; therefore, it is not surprising that the energy use intensity is likewise different in all the four countries.

## 2. Methodology

Data for the study were collected during the March–July 2013 cropping season at Block E5 Part Lima Timur, Sungai Besar in the Sabah Bernam district of Selangor, Malaysia located at 3°41′51.60″ to 3°41′19.01″ latitude and 101°01′21.09″ to 101°01′59.51″ longitude. The amount of rainfall recorded in the area during the period was 255.30 mm, with a mean daily temperature of 27.76 °C, mean relative humidity of 84.45% and mean solar radiation of 246.70 W/m$^2$. The study location was selected for being one of the most productive wetland paddy cultivation areas in the country. All the farm lots were planted with local varieties of rice that included MR219 and MR220 CL-2. The block has a net land area of 27.005 ha, divided into 40 farm lots where the majority of the individual lots were managed by a farmer, and the maximum number of lots managed by a farmer was two. During the study season, all the farmers in the block practiced the direct seeding method of paddy cultivation. The data collection covered six energy inputs, namely human labor, fuel, machinery, seeds, fertilizer and pesticides used in the cultivation, and one energy output – paddy yield. Inputs such as seeds, fertilizers and pesticides used by the farmers were weighed in the vicinity of the farms just before application, while fuel consumed by the prime movers was determined through direct measurements by filling the machinery tanks at the beginning and end of operations and noting the difference. Data concerning the types, makes and models of machinery used in performing each operation at each farm were also obtained and recorded at the time of performing the operations. The field time for each operation in all the lots required for the computations of human and machinery energy expenditures was recorded using a digital stopwatch. The useful life of farm machinery (Table 2) stated in the ASABE Standard [16] was used in the estimations of machinery energy expenditures.

**Table 2**
Useful life of farm machinery used by farmers in the study area.

| Machine | Useful life, h |
|---|---|
| Tractor (2WD) | 12,000 |
| Combine harvester | 3000 |
| Rotary tiller | 1500 |
| Sprayer | 1500 |
| Spreader | 1200 |

Source: ASABE Standard D497.5 [16].

The paddy yield obtained from each farm was weighed using a weighing bridge at the paddy collection center. All the farm inputs used and the recorded output (paddy yield) from each farm were then converted into equivalent energy values using appropriate conversion coefficients obtained from published data, as given in Table 3. The following equations were used in computing the energy values for the six farm inputs covered by the study:

$$ME = \frac{Cf * W}{Fc * L} \tag{1}$$

where $ME$ is machinery energy (MJ/ha), $Cf$ is the energy conversion factor for machinery used (MJ/kg), $W$ is the weight of machinery (kg), $Fc$ is the effective field capacity (ha/h) and $L$ is the useful life of the machinery (h).

$$FE = \frac{fcon * fc}{A} \tag{2}$$

where $FE$ is fuel energy (MJ/ha), $fcon$ is fuel consumed (L), $fc$ is the fuel energy conversion factor (MJ/L) and $A$ is the size of the farm (ha).

**Table 1**
Energy use, energy intensity and paddy yield in some selected countries.

| Details/country | China [12] | Thailand [13] | India [14] | Bangladesh [15] |
|---|---|---|---|---|
| Human energy (MJ/ha) | – | 24 | 2291 | 1306 |
| Draught animals (MJ/ha) | 6348 | – | – | 76 |
| Fuel energy (MJ/ha) | 3482 | 4760 | 2694 | 5781 |
| Seed energy (MJ/ha) | 2020 | 2637 | 1153 | 735 |
| Farmyard manure (MJ/ha) | – | – | 62 | – |
| Fertilizer energy (MJ/ha) | 10,806 | 9335 | 2695 | 7434 |
| Machinery energy (MJ/ha) | 1491 | 3062 | 361 | 419 |
| Pesticides energy (MJ/ha) | 1113 | 653 | – | – |
| Electricity (MJ/ha) | 1460 | – | – | – |
| Irrigation (MJ/ha) | 4895 | – | – | – |
| Transportation (MJ/ha) | 87 | – | – | – |
| Total energy (MJ/ha) | 31,703 | 20,471 | 9257 | 15,751 |
| Paddy yield (kg/ha) | 8098 | 4609 | 2699 | 4870 |
| Energy intensity (MJ/kg) | 3.91 | 4.44 | 3.43 | 3.23 |