ORIGINAL ARTICLE

Analysis of energy consumption in lowland rice-based cropping system of Malaysia

Sahr Marvin Bockari-Gevao[1], Wan Ishak bin Wan Ismail[2], Azmi Yahya[3] and Chan Chee Wan[4]

Abstract

Bockari-Gevao, S.M.[1], Wan Ishak, W.I.[2], Azmi, Y.[3] and Chan, C.W.[4]

Analysis of energy consumption in lowland rice-based cropping system of Malaysia

Songklanakarin J. Sci. Technol., 2005, 27(4) : 819-826

Sufficient energy is needed in the right form and at the right time for adequate crop production. One way to optimize energy consumption in agriculture is to determine the efficiency of methods and techniques used. With the current increase in world population, energy consumption needs effective planning. That is, the input elements need to be identified in order to prescribe the most efficient methods for controlling them. This study was undertaken in order to determine the direct and indirect energy consumption of field operations in a lowland rice production system of Malaysia. Field time, fuel and other energy requirements were measured for the tillage, planting, fertilizing, spraying and harvesting operations performed. Energy analysis carried out revealed the highest average operational energy consumption was for tillage (1747.33 MJ ha^{-1}) which accounted for about 48.6% of the total operational energy consumption (3595.87 MJ ha^{-1}), followed

---

[1]Ph.D.Student in Bio-production Machinery, [2]Ph.D.(Agricultural Engineering), Prof., [3]Ph.D.(Agricultural Engineering), Assoc. Prof., Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, D.E. Malaysia. [4]Ph.D.(Agricultural Engineering), Senior Research Officer, Mechanization and Automation Division, Malaysian Agricultural Research and Development Institute (MARDI), GPO. Box 12301, 55774, Kuala Lumpur, Malaysia.

Corresponding e-mail: smbgevao@yahoo.co.uk

Received, 8 September 2004 Accepted, 13 December 2004

by harvesting (1171.44 MJ ha^{-1}, 32.6%) and planting (562.91 MJ ha^{-1}, 15.7%). Fertilizing and pesticide spraying did not make any significant contributions to the operational energy consumption. Based on energy sources, fuel was the main consumer of direct energy with 2717.82 MJha^{-1} (22.2%), and fertilizer recording the highest indirect energy consumption of 7721.03 MJha^{-1} (63.2%). Human labour, pesticides, seeds and indirect energy for machinery use had marginal importance, contributing only 0.2%, 0.6%, 6.8% and 6.9%, respectively to the total energy consumption (12225.97 MJha^{-1}). Average grain yield was 6470.8 kg ha^{-1}, representing energy output of 108321.75 MJha^{-1}, that is, 96095.78 MJ net energy gain or 8.86 MJ output per MJ input. Energy input per kilogram grain yield was 1.89 MJkg^{-1}. The results of the study indicate energy gain in the lowland rice production system of Malaysia.

Key word : direct and indirect energy, operational energy consumption, lowland rice production, Malaysia

Agricultural productivity cannot hope to increase unless adequate inputs such as power, improved seeds, fertilizers and irrigation water are available in a timely manner and applied judiciously. With the current increase in world population, energy consumption needs effective planning. That is, the input elements need to be identified in order to prescribe the most efficient methods for controlling them. Crop yields and food supplies to consumers are directly linked to energy, which means sufficient energy is needed in the right form at the right time for adequate crop production. One way to optimize energy consumption in agriculture is to determine the efficiency of methods and techniques used (Kitani, 1999; Safa and Tabatabaeefar, 2002). Crop-yield is directly proportional to the energy input (Srivastava, 1982). Fuel and fertilizers (N and P) account for the largest share (>75%) of all energy expenditures in a mixed cropping system (Hetz, 1992; Ahmad, 1994; Safa and Tabatabaeefar, 2002). Fluck and Baird (1980) hypothesized that the highest partial energy productivity is achieved at the point of minimum mechanization energy inputs and increasing mechanization energy increase crop yield at a decreasing rate.

To adequately evaluate crop production energy requirements and be able to choose alternative crop production systems, energy data need to be collected for machinery and soils of major crop production systems. For instance, in Malaysia, the only available tillage energy data is currently limited to upland soils under cash crops such as rubber and oil palm. Field studies need to be conducted in paddy soils to enable the compilation of a more thorough tillage energy database. Field operating energy data is also needed for fertilizer, lime and pesticide applicators and for transplanters and harvesters. Energy requirements of various crop production systems can then be determined and compared. This study was therefore undertaken in order to establish an initial data bank of field operating energy involved in a lowland rice production system of Malaysia. The specific objectives were:

1. To determine the operational energy consumption of field operations involved in the lowland rice production system.
2. To compare the total energy involved in the rice production in terms of direct and indirect energy sources.
3. To determine the overall energy efficiency of the lowland rice production system.

Materials and Methods

The present research work was undertaken at the Sungai Burong Compartment of the Tanjong Karang Rice Irrigation Scheme in the Northwest Selangor Integrated Agricultural Development Project. Data was collected in the off-season (January to June) and main season (August to December) in 2003. An 80"-rotavator was used to carry out first rotary tillage pass (referred to as first rotavation) and a 110"-rotavator was used for the second and third rotary tillage passes (referred to as second rotavation and third rotavation, respectively). This sequence of rotary tillage implementation is the standard practice for seedbed preparation among the lowland rice farmers in Malaysia. The 80"-rotavator with less power requirement, compared to the 110"-rotavator, is used to break up the virgin soil. During the second and third rotavations, farmers are usually concerned with both timely completion of the seedbed preparation and the minimization of tillage trips so as to reduce re-compaction of the moist loose soil already created during first rotavation. More so, tractors operating in wet paddy fields have limited traction due either to wheel slip or drivewheel penetration. The use of the 110"-rotavator with greater bite length, defined as the amount of forward travel per cut, would help increase the negative draft and negative specific energy requirement for traction. A FIAT 640 diesel tractor, having a maximum power of 46.31 kW at PTO shaft and operating with a PTO speed of 540 rpm was used as the power source for the tillage operations. A 6-row Kubota rice transplanter SPA65 was used to transplant the 16-day old seedlings of rice variety MR 219. Field time, fuel, and other energy requirements were measured for all field operations performed on twelve experimental plots. The number and duration of operations, the seed, fertilizer and pesticide rates, and the amount of human labour involved in each operation were investigated through field measurements. For each operation by a self-propelled machine used, fuel consumption was measured by filling the machine's fuel tank twice, before and after each operation (Alcock, 1986; Nielsen and Luoma, 2000). A knapsack-powered blower (sprayer) was used to apply fertilizer and pesticides. All the experimental plots were fertilized at the same levels in order to reduce the significance of differential fertility on crop yield. The amount of each fertilizer and pesticide (herbicide, insecticide and fungicide) used for weed, insect and disease control were recorded for the determination of the fertilizer and chemical energy inputs in the production process. Supplemental irrigation water was pumped into the field before commencement of the third rotavation.

Computation of Parameters

Energy analysis was performed based on field operations (tillage, planting, fertilizing, spraying and harvesting) as well as on the direct (fuel and human labour) and indirect (machinery, fertilizer, pesticide, and seed) energy sources involved in the production process. The irrigation energy expenditure was not included in the energy analysis since the supplemental irrigation water application during the land preparation stage was only situational; it is not a common practice among the lowland rice farmers in the study area. Under normal circumstances, there is no water pumping involved in the rice production process. The rice farmers rely totally on "free" irrigation supply by gravity flow from the central water distribution system under the management of the Department of Irrigation and Drainage of Malaysia.

The direct energy use per hectare for each field operation was computed by the following equation (Moerschner and Gerowitt, 2000):

$$ED = h \times AFU \times PEU \times RU \quad [1]$$

where:

ED = Specific direct energy use (fuel) for a field operation, MJ $ha^{-1.}$
h = Specific working hours per run, h ha^{-1}
AFU = Average fuel use per working hour, L h^{-1}
PEU = Specific energy value per litre of fuel, MJ L^{-1}
RU = Runs, number of applications in the considered field operation.

The energy contribution of machinery for each field operation was determined by the following equation:

$$EID = \frac{TW \times CED}{UL} \times h \times RU \quad [2]$$

EID = Specific indirect energy for machinery use for a field operation, MJ ha^{-1}
TW = Total weight of the specific machine, kg.
CED = Cumulative energy demand for machinery, MJ kg^{-1}

UL = Wear-out life of machinery, h
h = Specific working hours per run, h ha^{-1}
RU = Runs, number of applications in the considered field operation.

The indirect energy per unit area for other production inputs such as fertilizer, pesticides and seed was expressed as:

$$EID = RATE \times MATENF \quad [3]$$

where:
EID = indirect energy input, MJ ha^{-1}
RATE = application rate of input, kg ha^{-1}
MATENF = energy factor of material used, MJ kg^{-1}

The rate of labour use in the rice production process was determined for each operation. The labour energy input (MJ ha^{-1}) at every stage in the production process was estimated by the following equation:

$$LABEN = \frac{LABOUR \times TIME}{AREA} \times LABENF \quad [4]$$

where:
LABEN = labour energy, MJ ha^{-1}
LABOUR = number of working labourers
TIME = operating time, h
AREA = operating area, ha
LABENF = labour energy factor, MJ h^{-1}

The energy input intensity (*e*) was determined from the summation of Equations [1]-[4] and, in short, given by the following expression:

$$e = \frac{E}{A} \quad [5]$$

where:
e = energy input intensity, MJ ha^{-1}
E = total energy consumption, MJ
A = the effective production area, ha.

The energy output intensity (e_0) was derived by multiplying the production intensity (s) by the energy coefficient of seed (B_s):

$$e_0 = B_s \times s \quad [6]$$

where:
e_0 = energy output intensity, MJ ha^{-1}
B_s = energy coefficient of seed, MJ kg^{-1}
s = production intensity, kg ha^{-1}

The overall energy ratio (OER) was then determined as the ratio of the energy output intensity to the energy input intensity. It is assumed that, if the OER is greater than 1, then the production system is gaining energy, otherwise it is loosing energy.

$$OER = \frac{e_0}{e} \quad [7]$$

where:
OER = overall energy ratio, dimensionless
e_0 = energy output intensity, MJ ha^{-1}
e = energy input intensity, MJ ha^{-1}

In this study, an average cumulative energy demand value of 109 MJ kg^{-1} was used to represent the embodied energy in a piece of equipment (Pimentel, 1992, cited by Intaravichai, 1998). Intaravichai (1998) further explained that the average energy value of 109 MJ kg^{-1} of weight of machinery includes 62.8 MJ kg^{-1} for steel production (Doering, 1980); 8.4 MJ kg^{-1} for the fabrication of parts and assembly; and 37.7 MJ kg^{-1} for repairs and maintenance (Fluck, 1985). All practices requiring fossil fuel were evaluated with diesel and petrol as the energy sources. The energy associated with fuel use was 47.8 MJ L^{-1} and 46.3 MJL^{-1} for diesel and petrol fuels, respectively (Safa and Tabatabaeefar, 2002), which includes estimates for engine oil, grease, manufacture and transportation to the farm (Bridges and Smith, 1979). The human energy required to perform any operation or practice is based on the number of labourers required to perform the operation and the field capacity of the machine. For this study, the labour input in terms of energy (LABENF) was evaluated at 1.96 MJh^{-1} (Safa and Tabatabaeefar, 2002). One person was involved in operating each self-propelled machine or manually operated engine powered equipment used, and that person was assumed to work as many hours as the machine. The energy equivalents (MATENF) for nitrogen, phosphorus and potassium were assumed to be 61.53, 12.56 and 6.70 $MJkg^{-1}$, respectively (Pimentel and Pimentel, 1979), which are the energy requirements for producing and transporting commercial fertilizers. The average energy inputs for the production of the active ingredients of herbicides, insecticides and fungicides were assumed to be 255, 185 and 97 $MJkg^{-1}$, respectively (Anon, 2004). An average energy coefficient (Bs) of 16.74 MJ kg^{-1} for rice seeds was used (Rutger and Grant, 1980; Intaravichai, 1998).

Results and Discussion

Operational Energy Consumption Based on Field Operations

The operational energy consumption in the lowland rice production system was computed for the following field operations: tillage, planting, fertilizing, spraying and harvesting. Operational energy refers to the energy used for mechanization, i.e. direct energy (fuel and human labour) and the indirect energy for machinery use. The irrigation energy expenditure was not included in the energy analysis because the pumping of water during the land preparation stage was only situational; it is not a common practice among the lowland rice farmers in the study area.

As can be observed from Table 1, the average operational energy consumption was highest for tillage (1747.33 MJ ha^{-1}) which accounted for about 48.6% of the total operational energy consumption (3595.87 MJ ha^{-1}), followed by harvesting (1171.44 MJ ha^{-1}, 32.6%) and planting (562.91 MJ ha^{-1}, 15.7%). Fertilizing and pesticide spraying did not make any significant contributions to the operational energy consumption. T-test analysis in Table 2 showed that there were no significant differences among the tillage energy, fertilizing energy and harvesting energy in the off-season and main season. However, there were significant differences ($p<0.05$) between the off-season and main season with respect to planting energy and spraying energy. The higher operational energy for spraying operation observed in the main season, compared to the off-season, was due to the fact that, in the main season there was severe weed and insect infestation in the experimental field which necessitated more application of pesticide.

Total Energy Consumption Based On Energy Sources

The average total energy inputs in the off- and main cropping seasons add to 12225.97 MJ ha^{-1}. Based on energy sources, fuel was the main

Table 1. Operational Energy Consumption Distributed by Field Operations

Field Operation	Operational Energy Consumption (MJ ha^{-1})		
	Off-Season	Main Season	Average
Tillage	1756.73^a	1737.92^a	1747.33^a
Planting	485.26^c	640.56^c	562.91^c
Fertilizing	28.61^d	29.32^e	28.96^d
Spraying	25.80^d	144.66^d	85.23^d
Harvesting	1171.31^b	1171.57^b	1171.44^b
Overall Mean	693.54	744.81	719.18
R^2	0.97	1.00	0.99
CV %	19.4	0.0	18.4

Note: In a column, any means followed by the same letter are not statistically different at the 5% level of significance.

Table 2. T-test Comparison of Operational Energy Consumption of Field Operations in the Off-Season and Main Season

Season	Operational Energy Consumption (MJ ha^{-1})				
	Tillage	Planting	Fertilizing	Spraying	Harvesting
Off-Season	1756.74[a]	485.26[a]	28.61[a]	25.80[b]	1171.31[a]
Main Season	1737.92[a]	640.56[b]	29.32[a]	144.66[a]	1171.57[a]

Note: In a column, any means followed by the same letter are not statistically different at the 5% level of significance.

Table 3. Total Energy Consumption Distributed by Energy Sources.

Energy Source	Total Energy Consumption (MJ ha^{-1})		
	Off-Season	Main Season	Average
Direct Energy:			
Fuel	2589.30[b]	2846.35[b]	2717.82[b]
Human	24.38[d]	33.43[d]	28.91[d]
Indirect Energy:			
Machinery	854.04[c]	843.85[c]	848.95[c]
Seed	837.00[c]	837.00[c]	837.00[c]
Fertilizer	7721.03[a]	7721.03[a]	7721.03[a]
Pesticide	15.43[d]	129.11[d]	72.27[d]
Overall Mean	2006.86	2068.46	2037.66
R^2	1.00	1.00	1.00
CV %	5.2	8.6	4.1

Note: In a column, any means followed by the same letter are not statistically different at the 5% level of significance.

contributor of direct energy with 2717.82 MJha^{-1} (22.2%), and fertilizer recording the highest indirect energy consumption of 7721.03 MJha^{-1} (63.2%), as shown in Table 3. Human labour, pesticides, seeds and indirect energy for machinery use had marginal importance, contributing only 0.2%, 0.6%, 6.8% and 6.9%, respectively to the total energy consumption.

Overall Energy Ratio and Net Energy Gain

The overall energy ratio (OER) was determined as the ratio of output energy to input energy. It is assumed that, if the OER is greater than 1, then the production system is gaining energy, otherwise it is loosing energy. Average grain yield was 6470.8 kg ha$^{-1,}$ representing energy output of 108321.75 MJha^{-1}, that is, 96095.78 MJ net energy gain or 8.86 MJ output per MJ input. Energy input per kilogram grain yield was 1.89 MJkg^{-1}.

The energy output/input ratio of 8.86 (not including irrigation energy input) observed in the present study indicates that the lowland rice farmers in Malaysia earn at least 8 times of what they put into the production process. Duke (1983) reported that the energy output/input ratios for US rice production range from 1.03 to 1.76, compared to 3.6 or higher for developing countries.

Conclusions

The production energy indicators were evaluated using field data collected during the 2003 off- and main cropping seasons. The indicators included measures of total energy use per unit of effective cropping area (energy intensity) and per unit of rice seed production. For international comparison, a measure of energy conversion efficiency in terms of the overall energy ratio (energy output per unit energy input) was included. Since the goal of the study was to consider total energy inputs as an indicator of sustainability, it was necessary to include the energy requirements to manufacture and transport consumable items such as fertilizer and pesticides as indirect energy inputs. The indirect energy associated with agricultural machinery use was also considered as an important aspect of mechanization. However, the energy inputs associated with the manufacture of capital items such as vehicles for transportation and other farm improvements were not included in the present study. Since different international studies use different indicators, all the results are presented here to aid comparison. Probably, only the limited set described above is required to specify the energy performance of a lowland rice farm.

References

Ahmad, B. 1994. Energetics of Major Crops in Mixed Cropping System. AMA, 25(3): 52-54.

Alcock, R. 1986. Tractor-Implement Systems. AVI Publishing Co., Inc. Westport, Connecticut.

Anon 2004. Appendix C: Units, Equivalents and Energy Constants. Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. http://edis.ifas.ufl.edu/BODY_EH015. Accessed 1 March 2004.

Bridges, T.C. and Smith, E.M. 1979. A Method for Determining the Total Energy Input for Agricultural Practices. Trans. of the ASAE, p 781-784.

Doering, O.C. 1980. Accounting for Energy in Farm Machinery and Buildings. **In**: Handbook of Energy Utilization in Agriculture. United States, Florida, Boca Raton: CRC Press.

Duke, J.A. 1983. Handbook of Energy Crops. http://www.hort.purdue.edu/newcrop/duke_energy/Oryza_sativa.html#references. Accessed 2 September 2004.

Fluck, R.C. 1985. Energy Sequestered in Repairs and Maintenance of Agricultural Machinery. Trans. of the ASAE, 28(3): 738-744.

Fluck, R.C. and Baird, C.D. 1980. Agricultural Energetics. AVI Publishing Company Inc., West Port, Connecticut.

Hetz, Edmundo,J. 1992. Energy Utilization in Chilean Agriculture. AMA, 23(2): 25-6.

Intaravichai, P. 1998. Energy Analysis in Mechanised Rice Production System: Specifically for Central Thailand. PhD dissertation. Universiti Putra Malaysia. Malaysia.

Kitani, O. 1999. CIGR Handbook of Agricultural Engineering, Volume V - Energy and Biomass Engineering. ASAE Publication.

Moerschner, J. and Gerowitt, B. 2000. Direct and indirect energy use in arable farming - An example on winter wheat in Northern Germany. **In**: Weidema, B.P. and M.J.G Meeusen (Eds.), Agricultural Data for Life Cycle Assessments. The Hague, Agricultural Economics Research Institute (LEI). Report 2.00.01, Volume 1. February 2000. 195 p.

Neilsen, V. and Luoma, T. 2000. Energy consumption: Overview of data foundation and extract of results. **In**: Weidema, B.P. and M.J.G Meeusen (Eds.), Agricultural Data for Life Cycle Assessments. The Hague, Agricultural Economics Research Institute (LEI). Report 2.00.01, Volume 1. February 2000.195 p.

Pimentel, D. 1992. Energy Inputs in Production Agriculture. **In**: Fluck, R.C. (Ed.), Energy in Farm Production. The Netherlands: Elsevier Science Publishers B.V.

Pimentel, D. and Pimentel, M. 1979. Food, Energy and society. Resource and environmental Science Series, Edward Arnold, London.

Rutger, J.N., and Grant, W.R. 1980. Energy Use in Rice Production. **In**: Pimentel, D. (Ed.), Handbook of Energy Utilization in Agriculture. CRC Press, Inc. Boca Raton, Florida. 475p.

Safa, M. and Tabatabaeefar, A. 2002. Energy Consumption in Wheat Production in Irrigated and Dry Land Farming. **In**: Proc. Intl. Agric. Engg. Conf., Wuxi, China, Nov. 28-30, 2002 :

Srivastava, A.C. 1982. A Comparative Study of Conventional and Mechanized Farming Relative to Energy Use and Cost. AMA. Spring 1982. p 42-46.