Energy Consumption Analysis for Selected Crops in Different Regions of Thailand

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ABSTRACT

In this study the energy consumption for five major crops viz. rice, maize, sugarcane, cassava and soybean in three regions of Thailand is analyzed. The energy consumption for different farm operations from land preparation to transportation, - to storage, and - to market places was considered. Primary data were obtained through field survey and personal interviews using questionnaires. The data were collected from 909 farms owned by 487 farmers. Secondary data and energy equivalents were obtained from available literature. Results showed that energy input in farm operations for sugarcane production was the highest (14.48-18.65 GJ/ha). For irrigated rice, rainfed rice, maize, wet-season soybean and cassava, it varied between 1.79-18.49, 10.09-13.11, 9.79-12.79, 5.21-10.03 and 4.95-9.13 GJ/ha respectively. Energy input in dry-season soybean production was the lowest with a range of 5.31-7.86 GJ/ha. About 62% and 38% of energy inputs in farm operations was from material and physical energy inputs respectively. Energy from fertilizer contributed the highest followed by energy from seed, pesticide and herbicide. Over 97.8 % of physical energy input was energy from mechanical power sources. Total energy input for sugarcane in the Central plain was the highest (24.68 GJ/ha), whilst lowest was energy input in cassava production in the Northeast (8.81 GJ/ha). Energy sequester was the main cause of variation of total energy input for different crops. Energy ratio for different crops had a range of 2.0-11.1. Both, wet-season and dry-season soybean showed the lowest energy ratio (2.0-3.7) followed by rainfed rice and irrigated rice. Sugarcane gave the highest energy ratio (9.3-10.1) followed by cassava and maize.

Keywords: Crop production, energy consumption, energy ratio, mechanization, Thailand

1. INTRODUCTION

Thailand is an agricultural country. Approximately 21 million ha or 40.9% of the total area is used for agricultural production. About 49.8% of the agricultural land is used for growing rice, 21.5% for field crops, 21.2% for fruit or horticultural crops and 7.5% for others (OAE, 2004).

Thailand is almost sufficient in food production. Agriculture is an important sector and the largest source of employment of rural population of the country. About 46.6% of the total population (62.8 million) is engaged in this sector (FAO, 2005). Although, the importance of agriculture in Thailand has declined a bit due to the expansion of other sectors (industry, tourism, construction and other service sectors) but its contribution was still about 10.1% of total GNP in 2004 (NESDB, 2005).

Crop production is the most important sub-sector of agriculture. In 2003, it contributed approximately 61.8% of gross agricultural output of Thailand, followed by livestock (15.6%), fisheries (22.4%), forestry (0.02%) and others (0.18%) (OAE, 2004). The five most important crops in terms of cultivated area and value of production in Thailand are rice, maize, sugarcane, cassava and soybean with the area of 10.75, 1.11, 1.14, 1.03 and 0.16 million ha respectively. Rice, maize and sugarcane are important domestic food commodities as well as foreign exchange earners. Thailand continues to be the world's largest exporter of milled rice. During 2000-2005, annually average 7.67 million tons of rice was exported (OAE, 2006). Cassava is predominantly an export crop, while soybean is used in food and feed industries, which is insufficient for domestic demand.

Agriculture is both a user and producer of energy. All agricultural operations require energy in one form or another: human labor, animal power, fertilizer, fuels and electricity. In 1950, energy input in crop production in Thailand was approximately 9 PJ. The biological energy inputs in the form of seeds contributed the most (61%) followed by physical energy inputs from agricultural labor (21%) and draft animal (17%). After 1970, total energy input sharply increased due to the increased use of chemical fertilizer and physical energy input. By 1998, the total energy input increased around 13 times compared to 1950 while the crop production increased around six times from 7 million tons in 1950 to 44 million tons grain equivalent in 1998 (Singh and Anuchit, 2000). To meet the growing demand of the increasing population and for exports, the productivity of land and labor need to be increased substantially which would require higher energy input and better management of food production systems. Moreover, the cost of energy resources has significantly increased. Therefore, the assessment of energy consumption for crop production is required to understand the current situation for improved use of energy resources.

2. METHODOLOGY

To assess the situation of energy consumption for different crops in various regions of Thailand, primary data for energy input resources in crop production year 2000/01 were collected by field survey and personal interview of farmers. Secondary data and energy equivalents for energy input resources and energy output were obtained from the available literatures.

2.1 Selection of Crops and Study Area

Five major crops in term of planted area and value of their production were selected viz. rice, maize, sugarcane, cassava and soybean. The first three crops are important domestic commodities and foreign exchange earner. Cassava is predominantly an export crop while soybean is used in food and feed mill industries. Soybean production is still insufficient to meet domestic demand.

Three regions of the country, namely the Central plain (C), the Northern (N) and the Northeastern (NE) regions were selected for analysis. The Southern region was not included because it predominantly grows rubber trees, oil palm and tropical fruits. To select the study area and farmers from regional level to village level, a stratified multi-stages sampling technique (Clark and Clark, 1983) was adopted. Selected provinces in the study area with different crops are given in Table 1. A total of 487 farmers from 76 sub-districts in 12 provinces were interviewed for primary data collection.

Table 1. Details of crops and their geographical location in the study area

Crop	Region		
	Central plain provinces	Northern provinces	Northeasthern
Rice - Irrigated area - Rainfed area	 Ayuthaya Lop Buri	 Phitsanulok Nakhon Sawan	 Khon Kaen Nakhon Ratchasima
Maize	Sa Keo	Tak	Nakhon Ratchasima
Cassava	Chasoengsao	Phitsanulok	Chaiyaphum
Sugar cane	Nakhon Pathom	Nakhon Sawan	Chaiyaphum
Soybean - Irrigated area - Rainfed area	 - -	 Phitsanulok Sukhothai	 Khon Kaen Khon Kaen

2.2 Field Survey, Data Collection and Data Analysis

The data collected for each crop included energy input resources for different farm operations from land preparation up to transportation or to market. Energy inputs via different power sources and material were obtained for each farm operation. These data were collected for each farm through personal interviews of farmers.

A total of 909 sample data were collected. An application program using Microsoft Access was developed for data entry into computer. Entered data were transferred and Microsoft Excel and Visual Basic for Application program were used for analyses. The calculation formulas are given in the next section. Computed data were analyzed using SPSS Ver.11.05 to perform descriptive analysis and mean comparison.

2.3 Energy Identification and Energy Equivalents

For clear understanding of energy consumption for different farm operations of crops, the energy identification and energy accounting are given in a way such that the energy input classified on the basis of source and use as direct and indirect energy. The direct energy are the energy which are released directly from power sources for crop production while the indirect energy are those which are dissipated during various conversion processes like energy consumed indirectly in manufacturing, storage, distribution and related activities (Singh and Mittal, 1992; Pimentel, 1992). This study was intended to assess the energy input during field activities for different farm operations, total energy input and energy output for different crops and regions. Both direct energy and indirect energy inputs were considered as energy in farm operations except sequestered energy of mechanical power sources and implements. However, for the purpose of computation and analysis, three groups of energy resources were considered namely physical, chemical and biological energy inputs. The chemical and biological energy inputs were considered as indirect energy inputs. Whereas, physical energy inputs were considered as both indirect and direct energy inputs (Singh et al., 1994).

2.3.1 Direct Energy Inputs

The direct energy input is the energy consumption of physical energy resources for physical work during field operations. Field operations consume significant energy in agricultural production, with most of usage being fuel consumption (Bowers, 1992). Physical energy input such as human labor, draft animal and mechanical power sources have been considered as direct energy input. Energy equivalents of these power sources are given below.

a) Human labor: Human muscle power was inputs for physical work in field operation activities in crops productions. A power equivalent of 74.6 W (0.1 hp) for human labor was considered appropriate (Singh and Singh, 1992).

b) Draft animal: A power equivalent of 746 W (1.0 hp) for pair of bullocks was considered appropriate (Singh and Mittal, 1992). Single buffalo and pair of cattle are commonly used as draft animal in Thailand (Rijk, 1989; Chamsing and Singh, 2000). From the field survey, it was observed that the use of draft animal as power source was almost non existence.

c) Mechanical power sources: Commonly used mechanical power sources and implements for crop production in Thailand are given in Table 2. Energy consumed during farm operations is affected by many factors, including weather, soil type, depth of tillage, etc. Therefore, information on fuel consumption and working hours of mechanical power sources for different farm operation were used for calculation of mechanical energy inputs. These data were gathered from field survey by individual farmer at farm place level. In case of farmer using hired machine or no information on fuel consumption, the average and estimated value based on type and size of mechanical power source gathered from the field survey were adopted (Tables 2 and 3). The energy equivalent values of fuel (42.32 MJ/L for gasoline fuel and 47.78 MJ/L for diesel) were used for calculation. These values were inclusive of net energy value and energy sequestered to mine, refine and transport (Cervinka, 1980).

Table 2. Rated power of commonly used mechanical power sources in Thailand

Power source	Rated power (kW/unit)	Remark
Power tiller	7.5	Rating 6.0-9.0 kW
Tractor < 45 hp	16.4	Rating 13.4-26.1 kW
Tractor > 45 hp	56.0	Rating 48.5-97.0 kW
Irrigation pump	6.7	Rating 2.6-7.5 kW
Power thresher	100.0	Rating 9.0-111.9 kW
Power sprayer	1.1	Assumed 1.1 kW
Rice combine harvester	112.5	Rating 89.5-167.9 kW

Source: Singh and Anuchit (2000)

2.3.2 Indirect Energy Inputs

Indirect energy is energy used to produce equipment and other goods and services that are used in farm (Pimentel, 1992). Physical energy input in terms of energy sequester of mechanical power source, chemical and biological energy inputs were considered as indirect energy input. Chemical fertilizer, pesticide were considered as chemical energy input while seed and hormone were considered as biological energy input. Energy equivalents of these power sources are given below.

a) Physical energy input: Only indirect energy of mechanical power source was accounted. Energy for manufacturing, repair and maintenance as well as transportation and distribution of machinery and equipment were considered as energy sequestered or indirect energy input for mechanical power sources. The energy sequestered in manufacturing is energy used in producing the raw materials and energy required in the manufacturing process (Fluck, 1992). The standard unit for energy in manufacturing is MJ/kg of final product (Bower, 1992). In this study, the energy equivalent values suggested by Bowers (1992) were used for calculation. The energy equivalent value of 86.77 MJ/kg, which was estimated by Pimentel et al. (1973), was used to estimate energy for manufacturing including tires. The percent of energy for manufacturing (Table 3), estimated by Bower (1992), was used for estimating energy sequestered in repairs and maintenance, while 8.8 MJ/kg, estimated by Lower et al. (1977) was used for transportation and distribution. The weight of mechanical power sources and their equipment were reviewed from brochures of various manufacturers. Assumption values to calculate energy sequestered are given in Table 3.

Table 3. Data to calculate the energy sequestered and energy required in field operations

Power source	Unit weight (kg)	Energy for R&M (%)[1/]	Fuel (L/h)	Working hour (h/day)	Annual use	
					days/year	h/year
Human labor	-	-		8	100	800
- Sickle	0.2	0.0	-	8	20	160
Mechanical						
- Power tiller	350	0.61	2.1	6	70	420
- Moldboard plow	50	0.97		6	10	60
- 2 disk plow	70	0.97		6	10	60
- Comb harrow	75	0.61		6	20	120
- 4w-Tractor (<45 hp)	915	0.61	8	8	40	320
- 3 disk plow	265	0.97		8	20	160
- Disk tiller (5 disks)	450	0.97		8	20	160
- 4w-Tractor (>45 hp)	2 600	0.61	14	8	60	480
- 3-4 disk plow	315	0.97		8	40	320
- Disk tiller (7 disks)	578	0.97		8	40	320
- Irrigation pump	150	0.37	1.1	4	30	120
- Power sprayer	12	0.37	0.3	6	30	180
- Thresher (8 hp)	800	0.30	1.7	8	30	240
- Thresher (50 hp)	1 000	0.30	10.8	8	30	240
- Thresher (90 hp)	1 200	0.30	19.4	8	30	240
- Rice combine	5 700	0.61	36.6	6	90	540

Sources: Hunt (1983), Kammueng (1985), Rijk (1989) and Bowers (1992), Brochure from various companies

[1/] Energy for R&M refers indirect energy input used for repair and maintenance farm machinery expressed as percentage of energy for manufacturing of such machine.

b) Chemical energy input: Chemical fertilizers and pesticides are main sources for chemical energy inputs. The total chemical fertilizer input was calculated in terms of nitrogen equivalent. The energy equivalent value of 78.1, 17.4 and 13.7 MJ/kg for N, P_2O_5 and K_2O respectively (Mudahar and Hignett, 1987), were used for calculation of total fertilizer and energy inputs. Energy equivalents of 120 and 10 MJ/kg were used to calculate energy for pesticides, which may or may not require dilution respectively (Singh and Mittal, 1992).

c) Biological energy inputs: Mainly seeds and hormone were included as biological energy inputs. Existing data on hormones was used. The energy equivalent values for seed input were assumed higher than energy equivalent value of crop production output by 1 MJ/kg (Singh and Mittal, 1992).

2.3.3 Crop Production Output and Energy Equivalent

Crop production output consisted of main product and by products. Straw and bagasse were considered as by-products. The average ratio of grain and straw of Thai rice variety is about 1:1.5 and only a small amount of rice straw after harvesting was used. In this study, utilization of straw as by-product was assumed to be 20% of the paddy weight with an energy equivalent of about 12.5 MJ/kg. For sugarcane stem, about 20% is assumed as bagasse (National Energy Authority, 1981) with the energy equivalent of 7.9 MJ/kg. The energy equivalent values of crop production outputs are given in Table 4.

Table 4. Crop production outputs and their energy equivalent values

Crop	Energy equivalent (MJ/kg)
Rice	14.7
Maize	14.7
Sugarcane	2
Cassava	5.6
Soybean	25

Source: Singh and Mittal (1992)

2.4 Energy Ratio

The ratio of energy output of the production to input energy is termed as energy ratio or energy efficiency (Hadi, 2006). This expression is extensively used to measure the energy efficiency in agricultural and food systems. Pimentel et al. (1973) defined the energy ratio as the quotient of energy value of outputs and energy value of the sum of all direct and indirect inputs. The highest energy ratios are achieved in those systems having only human effort without fossil fuel input.

2.5 Computation of Energy Inputs and Outputs, and Energy Ratio

Following formulas were used for calculation of the energy inputs, and output as well as the energy ratio for each crops.

A sample calculation for energy input and output analysis is given in Table 5.

2.5.1 Total Energy Input

$$\text{Total energy input (MJ/ha)} = E_f + E_s \qquad \text{---- (1)}$$

Where,

E_f = energy input in farm operations (MJ/ha)

E_s = energy sequestered of machinery (MJ/ha)

Table 5. Energy input and output for different crop production in the central plain region

Item	Irrigated rice	Rainfed rice	Maize	Sugarcane	Cassava	Wet-season soybean
Energy input (MJ/ha)						
Direct energy inputs						
- Human labor	24.1	24.2	46.9	199.4	50.7	42.7
- Mechanical power source	4 760.0	3 739.5	3 332.2	6 098.3	4 568.1	4 425.3
Indirect energy inputs						
- Energy sequester	3 062.2	2 096.5	2 588.5	6 336.3	3 397.1	9 595.1
for mechanical power						
- Seed	2 637.1	2 283.6	290.3	106.6	165.6	2 322.3
- Chemical fertilizer						
N	8 232.8	4 758.0	4 730.0	11 077.6	2 796.2	2 203.0
P_2O_5	1 101.9	416.5	854.2		581.6	164.3
K_2O		50.9	129.2		371.8	102.7
-Herbicide	191.7	111.0	667.6	862.9	585.9	187.1
-Pesticide	461.0	-	-	-	-	830.0
Energy for farm operations	17 408.6	11 383.7	10 050.4	18 344.8	9 119.9	10 277.4
Total energy input	20 470.8	13 480.2	12 638.9	24 681.1	12 517.	19 872.5
Energy outputs (MJ/ha)						
-Main product	67 756.8	-	-	207 230.4	-	-
-By-product	13 551.4	-	-	41 446.1	-	-
Total energy output	**81 308.2**	**38 127.7**	**66 610.6**	**248 676.5**	**114 466.1**	**40 082.8**
Energy ratio	4.0	2.8	5.3	10.1	9.1	2.0

2.5.2 Energy Input in Farm Operations (E_f)

$$\text{Energy input in farm operation (MJ/ha)} = \sum_{k=1}^{k=r} (Phy + Chem + Bio)_k \qquad \text{---- (2)}$$

Where,

Phy = Physical energy input in farm operation k^{th} (MJ/ha)

Chem = Chemical energy input in farm operation k^{th} (MJ/ha)
Bio = Biological energy input in farm operation k^{th} (MJ/ha)
k = Farm operation k^{th}

2.5.2.1 Physical Energy Input

Total physical energy input for each farm operation was calculated as the summation of energy inputs from human labor, draft animal and mechanical power sources.

(a) Labor Energy Input

Labor energy input (MJ/ha) $= \sum_{l=1}^{l=s} \frac{\left[\left(0.268 L_f . wd_{lf}\, wh_{lf}\right) + \left(0.268 L_h . wd_{lh}\, wh_{lh}\right)\right]_l}{Ap}$ -- (3)

Where,

L_f and L_h = number of family labor and hired labor (person)
wd_{lf} and wdl_h = number of working days for family labor and hired labor (day)
wh_{lf} and wh_{lh} = number of working hour for family labor and hired labor (h/day)
Ap = planted area (ha)
l = time for applying input for time l^{th}

(b) Mechanical Energy Input

Mechanical energy input in field operations (MJ/ha)

$$= \sum_{l=1}^{l=s} \frac{\left[\left(MF_f N_{mf} . wd_{mf} . wh_{mf} F_{eq}\right) + \left(MF_h N_{mh} . wd_{mh} . wh_{mh} . F_{eq}\right)\right]_l}{Ap} \qquad \text{----- (4)}$$

Where,

MF_f and MF_h = Fuel consumption of power source machine (L/h) for owned and hired machine
N_{mf} and N_{mh} = number of owned farm machine and hired machine
Wd_{mf} and wd_{mf} = working day of owned farm machine and hired machine (day)
wh_{mf} and wh_{mf} = working hour for owned farm machine and hired machine (h/day)
F_{eq} = Energy equivalent of fuel (MJ/L), 42.32 MJ/L for gasoline fuel and 47.78 MJ/L for diesel fuel
Ap = planted area (ha)

2.5.2.2 Biological Energy Inputs

Seed and other hormones were considered as biological energy resources input. During field survey, it was observed that the use of hormones in crop production was no longer practiced. Therefore, only seeds were considered to calculate biological energy input.

Total seed input (MJ/ha)

= amount of seed applied (kg/ha) x energy equivalent of seed (MJ/kg) ---- (5)

2.5.2.3 Chemical Energy Input

(a) Fertilizer (MJ/ha)

Total fertilizer input (MJ/ha)

$$= \sum_{l=1}^{l=s} \left[\sum_{n=1}^{n=u} \frac{\left[N.N_{eqv}\right]_n}{Ap} + \sum_{n=1}^{n=u} \frac{\left[P_2O_5.P_{eqv}\right]_n}{Ap} + \sum_{n=1}^{n=u} \frac{\left[K_2O.K_{eqv}\right]_n}{Ap} \right]_l \quad \text{----- (6)}$$

Where,

N_{eqv} = Energy equivalent values of N = 78.1 MJ/kg
P_{eqv} = Energy equivalent values of P_2O_5 = 17.4 MJ/kg
K_{eqv} = Energy equivalent values of K_2O = 13.7 MJ/kg

N = compound fertilizer rate applied x percentage of N ingredient (kg)
P_2O_5 = compound fertilizer rate applied x percentage of P_2O_5 ingredient (kg)
K_2O = compound fertilizer rate applied x percentage of K_2O ingredient (kg)
n = compound fertilizer for applied time l^{th}

(b) Herbicide Energy Input (MJ/ha)

Total herbicide input (MJ/ha) $= \sum_{l=1}^{l=s} \sum_{n=1}^{n=u} \left(Her.Heqv\right)_n$ ----- (7)

Where,
Her = Applied rate (kg or lit/ha) of herbicide l^{th} for applied time k^{t}
Heqv = Energy equivalent (MJ/kg or lit) of herbicide l^{th}

(c) Pesticide Energy Input (MJ/ha)

Total pesticide input (MJ/ha) $= \sum_{l=1}^{l=s} \sum_{n=1}^{n=u} \left(Pes.Peqv\right)_n$ ----- (8)

Where,
Pes = Application rate (kg or lit/ha) of herbicide with applied time k^{th}
Peqv = Energy equivalent (MJ/kg or lit) of pesticide l^{th}

2.5.3 Energy Sequestered in Mechanical Power Sources and their Equipment

Energy sequestered in machinery for each farm was calculated as following formula.

$$\text{Total energy sequestered (MJ/ha)} = \frac{\sum_{m=1}^{m=t} \left[\left(M + T + R\right)/L\right]_m}{Aa} \quad \text{---- (9)}$$

Where,
M = Energy sequestered in manufacturing for machinery m^{th}(MJ)
= Weight of machinery m^{th} (kg) x 86.77 (MJ/kg)
T = Energy sequestered in transportation or distribution for machinery m^{th} (MJ)
= Weight of machine or equipment (kg) x 8.8 (MJ/kg)

R = Energy for repair and maintenance for machinery m^{th} (MJ)
= Energy in manufacturing (MJ) x conversion factor
Aa = Annual planted area (ha)
L = Economic life of machinery m^{th}

2.5.4 Energy Output

Energy output was considered of main product and by-product.

Total energy output (MJ/ha) = (Yield x E_{eq}) + (By-product x E_{eq}) ---- (10)

Where, E_{eq} = Energy equivalent value of main product or by-product.

2.5.5 Energy Ratio

Energy ratio = Total energy output (MJ/ha) / Total energy input (MJ/ha) --- (11)

3. RESULTS AND DISCUSSION

Two approaches of data analysis and discussion on energy input for different crops were implemented - energy input for farm operations including contribution of their energy input resources, - and total energy input in crop production. The efficient use of energy in terms of energy ratio is also obtained.

3.1 Energy Input in Farm Operations for Different Crops

Physical energy and material were main energy inputs in farm operations. Human labor and mechanical power were sources of physical energy inputs, while seed as biological energy input, and fertilizers, herbicides and pesticides remained as chemical energy inputs. Contribution of energy input in farm operation for different crops is presented in Fig. 1. It shows that energy input varied with the cultivated crop and prevailing region. Energy input in farm operations sugarcane production was the highest (14.48-18.65 GJ/ha) in all regions. For irrigated rice, rainfed rice, maize, wet-season soybean and cassava, it varied between 1.79-18.49, 10.09-13.11, 9.79-12.79, 5.21-10.03 and 4.95-9.13 GJ/ha respectively. Energy input for dry-season soybean production remained the lowest (5.31-7.86 GJ/ha). Energy from material inputs (chemical fertilizers, herbicides and pesticides) was the highest contribution compared with physical energy input except for cassava and wet-season soybean production. On an average, material input energy contributed was 68.6% of energy input to farm operations for all crops, except for cassava and soybean production, physical energy inputs contributed 50.6-66.8%, which was higher than physical energy input in other crops.

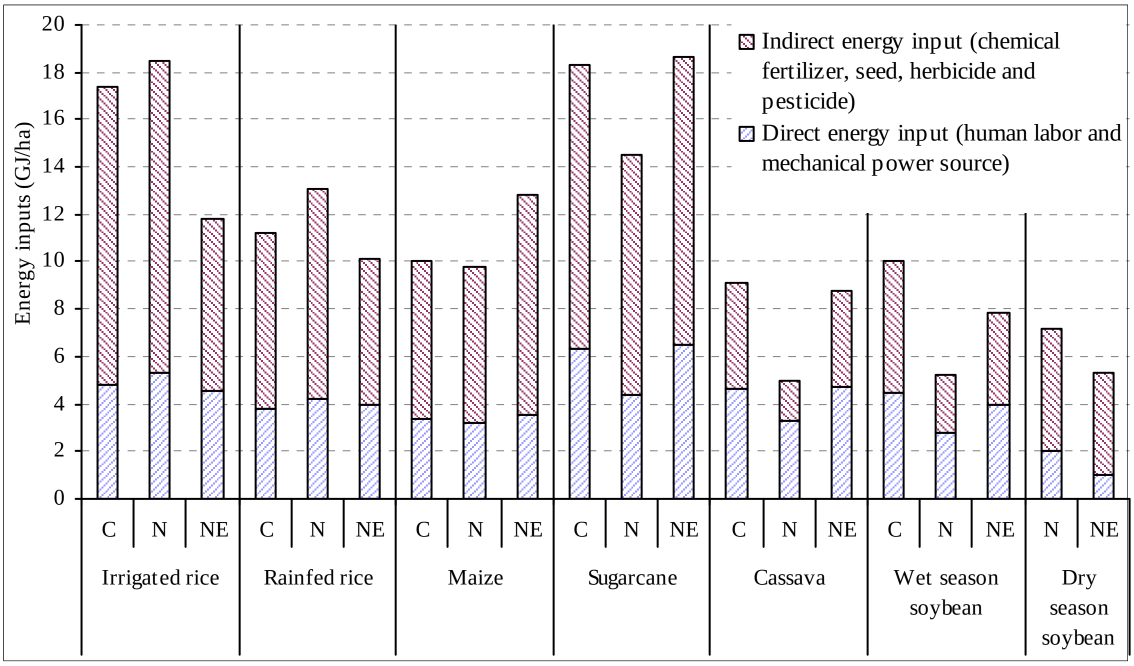

Figure 1. Total energy input in farm operations for different crops and regions (C=the Central plain, N=the North and NE=the Northeast)

Energy inputs in farm operations, among regions, for each crop were significantly different. Energy input in farm operations for irrigated rice, rainfed rice was the highest in the North followed by in the Central and the Northeast while for maize and sugarcane was the highest in the Northeast followed by in the Central and the North. For cassava and wet-season soybean energy input in the North was the lowest as compared to other regions. This trend showed that energy input in farm operations depended on crop grown and the region. The level of energy input among the Central and North for irrigated rice and rainfed rice production was not significantly different, but it was higher than that in the Northeast and lower than that in the Northeast in case of maize production. Whereas, the energy input between the Central and Northeast for sugarcane, cassava and wet-season soybean was not significantly different but higher than that in the North.

3.1.1 Physical Energy Input in Farm Operations

Physical energy inputs in farm operations for production of different crops in each regions are given in Fig. 2. It shows that physical energy input in farm operations of sugarcane production was the highest (4.36-6.48 GJ/ha) followed by irrigated rice, cassava, rainfed rice, maize, wet-season soybean and dry-season soybean production. It varied between 4.6-5.37 GJ/ha for irrigated rice, 3.31-4.76 GJ/ha for cassava, 3.76-4.18 GJ/ha for rainfed rice, 3.21-3.55 GJ/ha for maize, 2.76-4.47 GJ/ha for wet-season soybean and 0.91-1.92 GJ/ha for dry season soybean.

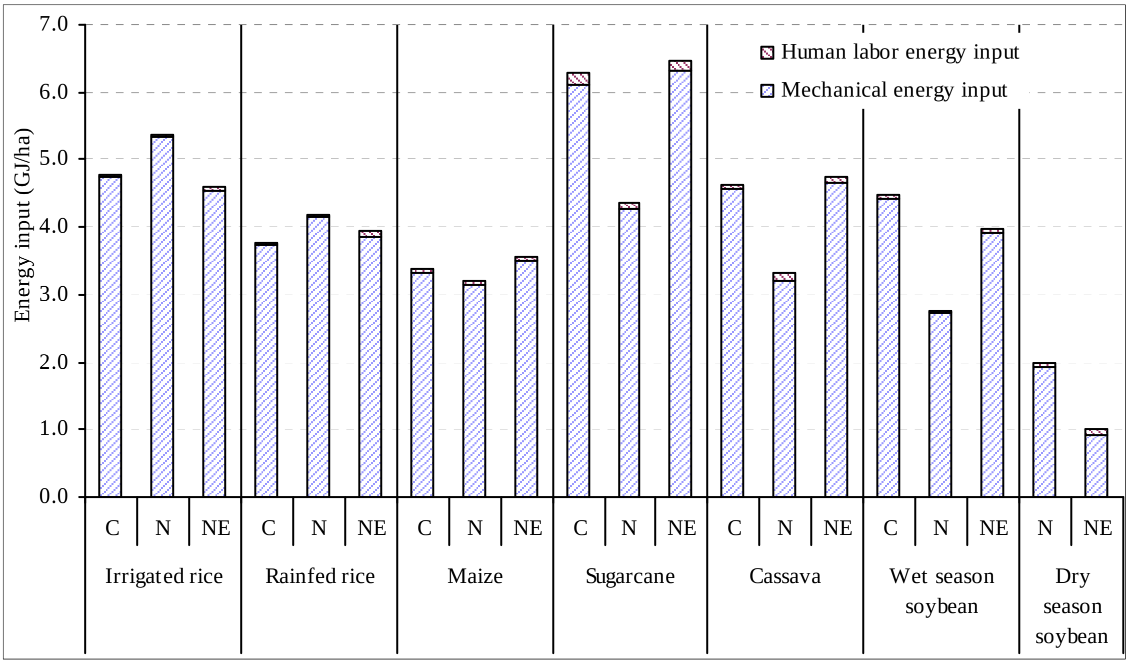

Figure 2. Physical energy input in farm operations for different crops and regions (C=the Central plain, N=the North and NE=the Northeast)

Mechanical energy was the highest input to total physical energy inputs for different crops and regions. It contributed about 89.3-99.5% of total physical energy input for all crops. Contribution of mechanical energy input for wet season soybean was the lowest. This was due to minimum tillage and no-tillage generally practiced for dry-season soybean production. Contribution of energy from human labor for rice production (both irrigated and rainfed rice) was the lowest compared to other crops with only 0.02-0.03 GJ/ha for the Central plain and the North. This was due to pre-germinated broadcasting for irrigated rice, direct broadcasting for rainfed rice. Harvesting by rice combine harvester were commonly practiced in these regions with less human labor requirement. Whereas human energy input in the Northeast was rather high (0.07-0.11 GJ/ha) because of manual transplanting, manual harvesting and threshing with rice thresher. Contribution of energy input from human labor for sugarcane production was the highest (0.16 GJ/ha). It was followed by human labor energy input for cassava production (0.09 GJ/ha), while for maize and soybean production it were 0.7 and 0.6 GJ/ha respectively. The variation in energy inputs for farm operations among regions for each crop depended on cultural practices and type of machinery used, and farm operation required (especially for land preparation and harvesting).

3.1.2 Energy Input from Material Input in Farm Operation

Energy from material inputs included chemical energy from fertilizer, herbicide and pesticide, and biological energy from seeds. Fig. 3 shows that energy from material inputs for sugarcane production was the highest (10.12-12.18 GJ/ha), followed by irrigated rice, rainfed rice, wet-season soybean, maize, dry-season soybean and cassava in the range of 7.2-13.16, 6.14-7.48, 6.58-9.24, 4.29-13.13, 2.45-5.57 and 1.64-4.51 GJ/ha respectively. Energy input from fertilizer remained the highest contributor for all crops and regions, followed by energy input from seed, herbicide and pesticide respectively. Energy from material input, among regions, for each crop production was significantly different and their trend was similar with energy input in farm operations as mentioned earlier.

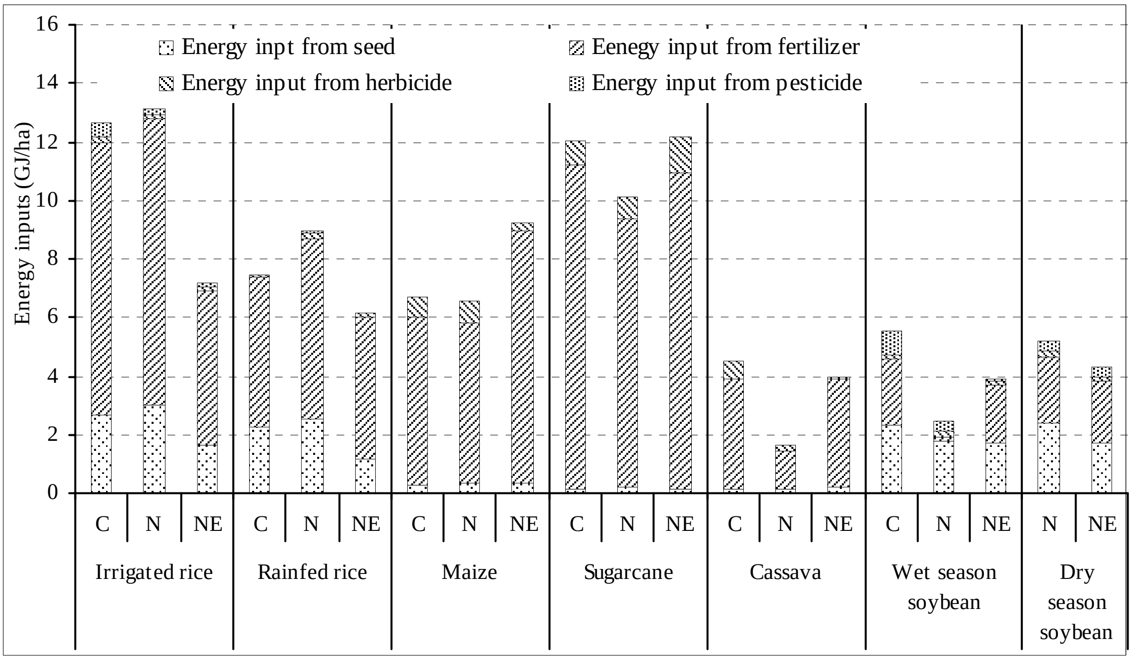

Figure 3. Contribution of energy from material inputs for different resources, crops and regions (C=the Central plain, N=the North and NE=the Northeast)

3.1.3 Physical Energy Input for Different Farm Operations

Depending on farm operations and crop production, physical energy input for different farm operations and crops were different. Land preparation and harvesting demanded high physical energy input, while for other farm operations physical energy input was rather low. Physical energy input in harvesting for both irrigated and rainfed rice production was the highest followed by land preparation. Contribution of human energy input for rice production was less than contribution for other crops. This was probably because mechanization level for rice production was higher than that for other crops, especially for harvesting, rice combine harvesters are widely used. For other crops, mostly harvesting was done by human labor, therefore, contribution of energy input from human labor was rather high.

3.2 Total Energy Input for Different Crops

Total energy input for different crops varied among the regions (Fig. 4). Total energy input for wet-season soybean in the Central plain was the highest (24.64 GJ/ha), followed by in the Northeast and the North with average total energy input of 22.08 and 21.16 GJ/ha. Total energy input for cassava production was the lowest (8.81-12.53 GJ/ha). Total energy input for other crops and their contributing energy resources are given in Fig. 4. The figure shows that instead of contribution of energy input from direct physical energy input and energy from material input, energy sequester of mechanical power sources was the main cause of variation of total energy input for different crops. It is different than the results showed by energy input in farm operations (Fig. 1). High contribution of energy sequester is probably related to the number and size of agricultural machinery and their utilization. For example, high contribution of energy sequester for irrigated rice in the Northeast was due to large number of machinery but low utilization.

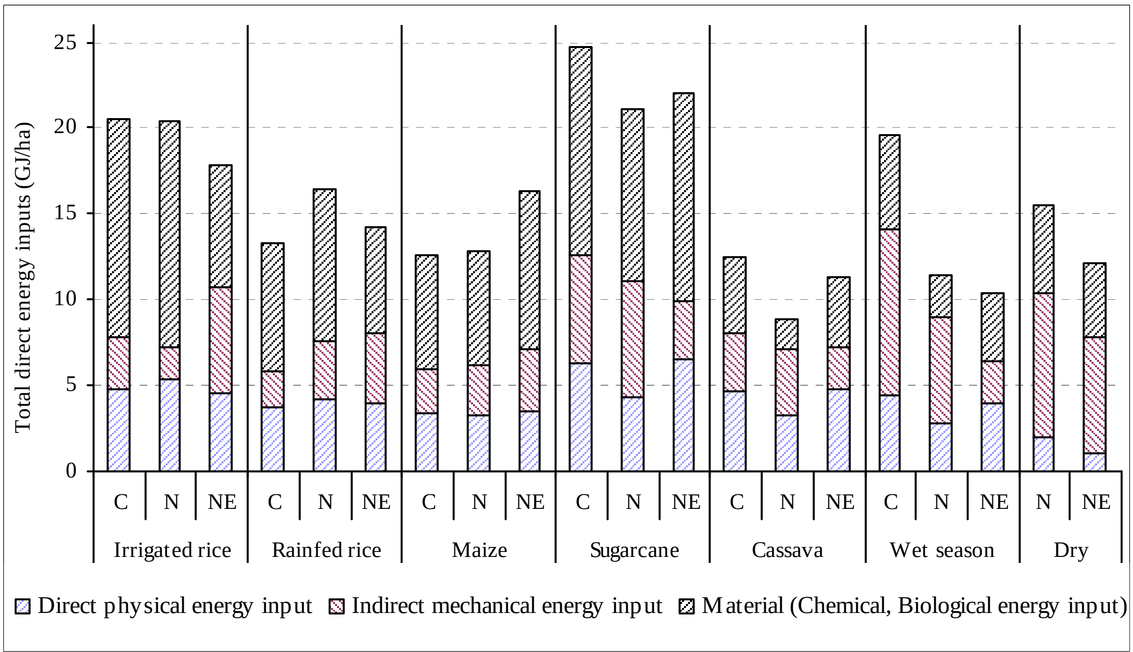

Figure 4. Total energy input for different crops in each region
(C=the Central plain, N=the North and NE=the Northeast)

3.3 Energy Output for Different Crops

Energy output included main product and by-product. By-products of rice and sugarcane were considered. Total energy output for sugarcane production was the highest (206.1-248.6 GJ/ha), followed by energy output for cassava, irrigated rice, maize, rainfed rice, wet-season soybean and dry-season soybean in range of 76.85-114.46, 54.16-81.31, 64.06-66.61, 38.13-47.83, 29.03-40.08 and 37.53-39.07 GJ/ha respectively (Fig. 5). The figure revealed that energy output among regions for each crop were almost similar, except irrigated rice in the NE, rainfed rice in the Central plain, cassava in the North and wet-season soybean.

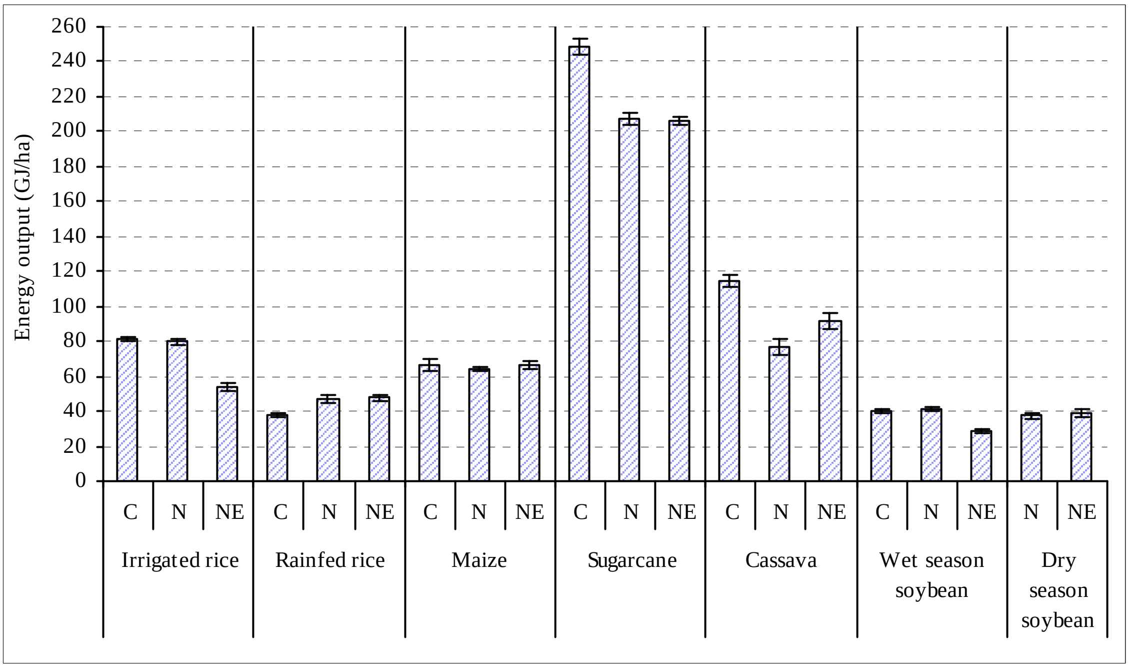

Figure 5. Total energy output for different crops in each region (C=the Central plain, N=the North and NE=the Northeast)

3.4 Energy Ratio

Energy ratio for different crops and regions varied between 2.0-10.1 (Fig. 6). High energy ratios were corresponding to high efficiency in use of energy and low mechanization level. Figure also shows that both wet-season and dry-season soybeans exhibited the lowest energy ratios (2.0-3.7 and 2.4-3.2). The next efficient utilization of energy input was for rainfed and irrigated rice (3.25-6.58). Sugarcane showed the highest energy ratio (9.3-10.1), followed by cassava (8.1-9.1), irrigated rice (3.0-4.0) and maize (2.9-3.4). This high energy ratio indicated lower inputs - especially low level of mechanization. Average energy ratio of selected crop production of the country was calculated to be 5.20. This ratio is higher than the ratio of Turkish (1.18) in crop year 2000 (Ozkan et al., 2004) but lower that the ratio of Bangladesh (8.11) in crop year 2000/01 (Alam et al., 2005). Energy ratio for rice, maize and sugarcane production were depended on area and were nearly of the same range as India which were 2.15-12.75 for rice, 4.83-17.02 for maize and 5.82-6.67 for sugarcane production (Singh et al., 1997).

4. CONCLUSIONS

Analysis of energy consumption for various major crops in three geographical regions of Thailand showed that energy input in farm operations for sugarcane production was the highest (14.48-18.65 GJ/ha). For irrigated rice, rainfed rice, maize, wet-season soybean and cassava, it varied between 1.79-18.49, 10.09-13.11, 9.79-12.79, 5.21-10.03 and 4.95-9.13 GJ/ha respectively. Energy input in dry-season soybean production was the lowest with a range of 5.31-7.86 GJ/ha. About 62% and 38% of energy input in farm operations was from material and physical energy inputs respectively. Energy from fertilizer was the highest contribution followed by energy from seed, pesticide and herbicide. Energy from mechanical power source contributed average of 97.8% of physical energy input in farm operations, while the remaining energy input was from human labor. Total energy input for sugarcane in the Central plain was the highest (24.68 GJ/ha). The lowest was energy input in cassava production In the Northeast (8.81 GJ/ha). Energy sequester of mechanical power source was the main cause of variation of total energy input for different crops. The high contribution of energy sequesters was corresponding to number and size of agricultural machinery holding and their utilization. Energy ratio for different crops and regions showed high variation (2.0-10.1). Both wet-season and dry-season soybean gave the least energy ratios (2.0-3.7), followed by rainfed and irrigated rice. Sugarcane showed the highest energy ratio (9.3-10.1), followed by cassava and maize. Average energy ratio of selected crop production of the country was calculated to be 5.2. Energy ratios for rice, maize and sugarcane production depended on the region.

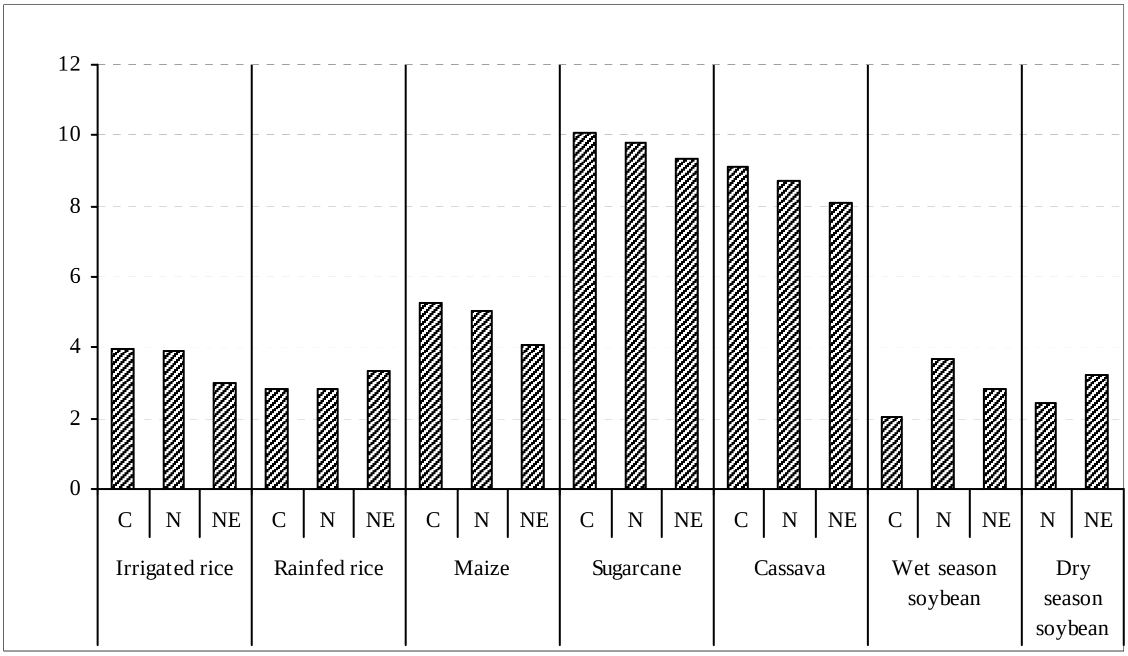

Figure 6. Energy ratio for different crops and regions (C=the Central plain, N=the North and NE=the Northeast)

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