Agroecological Rice Farming: An Approach for Economic Benefit and Energy Efficiency in the Northern Mountainous Region of Vietnam

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Abstract

Agroecological production strategies not only accomplish goals of food security (SDG #2- zero hunger) but also contribute to mitigating climate change (SGD #12 action for climate) through utilizing biological processes to reduce chemical dependence that creates hazards for the environment and human health. To provide an explicit picture of how agroecological rice cultivation can promote sustainable development through economic improvement and energy-saving, in-depth face-to-face surveys of 30 households who are applying organic rice farming and ecological practices in Chieng Yen communes, Son La, Vietnam were conducted between January and June of 2022. Comparative analysis of energy input-output balances and economic efficiency analysis between conventional and agroecological methods of rice production showed that the agroecological rice cultivation method can save up to 63% of energy inputs. The economic benefits of organic rice farming per hectare also rose 3 times compared to conventional paddy. Hence, agroecological rice farming in the study area is recommended to adopt and scale up among smallholders in the northern mountainous region of Vietnam as a successful example of climate-smart agriculture which ensures food security, adaption, and mitigation to climate change. A comprehensive approach is taken in the study to analyze energy use and efficiency as a tool of the circular economy at the sectoral or activity levels, something rare of studies in Vietnam.

1. Introduction

Since policy shifts from a central planning system to a market-oriented economy in the 1980s (i.e., đổi mới), agricultural production in Vietnam has witnessed remarkable success, particularly in the growth of rice production, which has been sustained at over 4% per annum. Total rough rice yields raised from 19.2 million tons in 1990 [1] to approximately 42.7 million tons 30 years later [2]. Previously a rice-importing country, Vietnam has become one of the most five productive rice producers and the second-largest rice exporting country in the world [3] with average yields of 5.9 tons/ha [2].

However, Vietnamese rice production can be characterized by the overuse of chemical fertilizers, and pesticides. It is not only reducing yield and economic efficiency but also wasting scarce and costly resources such as fossil fuels, increasing greenhouse gas exposure, and seriously polluting the soil and water [1,4]. According to IRRI (2010) [5], between 1961 to 2005 total chemical fertilizer use increased over 22-fold from 89,000 to 1,985,000 tons, while arable land hardly increased (just over 1%). More notably, rice yield did not increase in line with the fertilizer consumption-about a 2% increase in yield after a 15-37% increase in fertilizer consumption [6]. Furthermore, N_2O emissions from rice are aggregated under fertilizer-borne emissions of all managed soils. It is estimated that the N_2O and CH_4 emissions in rice production account for 13.5% of the total national emissions which exceeds the total amount of GHG emitted from land transport [7].

To promote sustainable agriculture for smallholders in mountainous regions, organic farming was introduced to communities such as Chieng Yen commune, Van Ho district, Son La province in 2019 with the financial support of the Australian Government (DFAT/COWATERSOGEMA). Organic practices including no chemical fertilizers and ecological practices like flower strips along the field and plant-based homemade insecticides were introduced into the region. Hybrid varieties were also replaced by the local variety- "Te rau", which had previously been grown in the hills with less requirement of water, fertilizers, and field management. This variety is also known for its high quality of taste.

According to Ortiz-Canãvate and Hernanz [8], economics, energy, and the environment are the three 'E' elements that should be taken into consideration in any sustainable agricultural system, this study compared energy use between conventional and the agroecological methods of rice production. All energy inputs and outputs were quantified and compared in a matrix format. To gain a quicker and more precise energy analysis, the study used *input-output analysis* and *process analysis* presented to trace back the sequestered energy used in each of the principal production stages for each input item. This embodied energy value for each input was converted to a standardized energy unit (MJ) using conversion factors derived from the published literature. Subsequently, an input-output table for rice production was established that identified and quantified all the energy inputs to production, as well as those of the primary and secondary outputs (i.e., rice and by-products).

Through energy and economic analysis of conventional and organic rice cultivation, this study provides an overall picture of energy use in rice production in Vietnam and seeks sustainable rice production which not only reduces energy use and production costs but is also environmentally friendlier.

2. Materials and Methods

2.1 Energy analysis

2.1.1. Identifying energy inputs and outputs

The energy analysis of rice production was operationalized by quantifying energy inputs and outputs; the ratio between the inputs and outputs illustrates the *energy efficiency*. Thus, properly identifying the inputs and outputs plays a vital role in energy analysis. Through a combination of direct observations of rice production in Vietnam and literature review, the energy inputs identified for the study include direct energy (human labor, fossil fuels, and electricity) but exclude solar energy and indirect energy (machinery, fertilizers, agrochemicals, and seed). The principal energy outputs were associated with the main product (rice) and by-products (straw) (Figure 1).

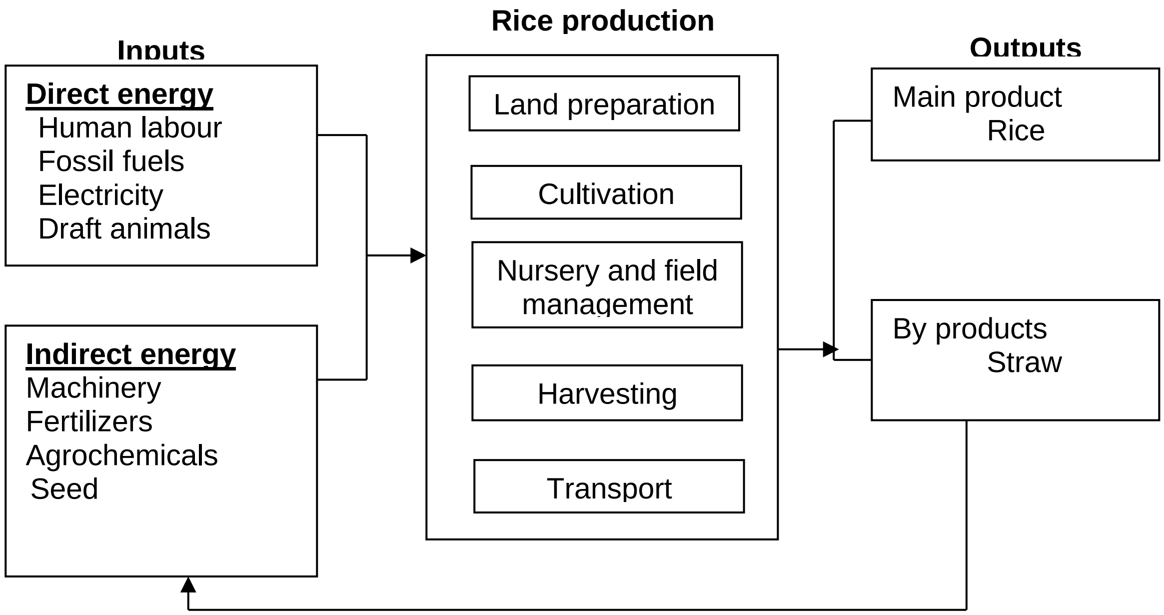

Figure 1: Flow sheets for energy balance in rice production

2.1.2. Energy equivalence and calculating energy inputs and outputs

Energy equivalence values are used to express the inputs and outputs in uniform energy units. A number of studies have produced generalized energy equivalence values [8, 9 10, 11, 12, 13] (Table 1)

2.1.3. Energy ratio, energy productivity, specific energy, and net energy gain

The energy ratio and energy productivity were calculated as following equations [14]:

$$\text{Energy use efficiency} = \frac{\text{Energy output (MJ ha}^{-1}\text{)}}{\text{Energy input (MJ ha}^{-1}\text{)}}$$

$$\text{Energy productivity} = \frac{\text{Rice output (kg ha}^{-1}\text{)}}{\text{Energy input (MJ ha}^{-1}\text{)}}$$

$$\text{Specific energy} = \frac{\text{Energy input (MJ ha}^{-1}\text{)}}{\text{Rice output (kg ha}^{-1}\text{)}}$$

$$\text{Net energy gain} = \text{Output energy (MJ ha}^{-1}\text{)} - \text{Input energy (MJ ha}^{-1}\text{)}$$

Table 1: Energy equivalents of inputs and output in rice production

Items	Unit/ha	Energy equivalent (MJ/ha)
Input		
Human labour	h	1.96
Water buffalo hour	h	7.58
Diesel fuel	l	47.8
Electricity	kWh	12
Machinery	kg	138
Chemical fertilizer		
Nitrogen fertilizer (N)	kg	78.1
Phosphorus (P_2O_5)	kg	17.4
Potassium (K_2O)	kg	13.7
Farmyard manure	kg	0.3
Pesticide	kg	
Insecticide	kg	160
Fungicide	kg	99
Herbicide	kg	85
Seed	kg	17
Output		
Rice	kg	14.7
Straw	kg	19.7
Manure	kg	0.3

2.2. Economic analysis

The current research also used input/output analysis for economic benefit analysis. The process was similar to the energy analysis and the same inputs and outputs per hectare were applied. The monetary value of machinery and water buffalo was calculated by their rent cost per hour. For machinery, this includes the capital, repair, and maintenance but not fuel. All prices of input and output were defined by the market prices in 2022 and the results of the analysis of the economic benefits were organized to show both a ratio of input and output as well as economic feasibility.

2.3. Data collection and analysis

To obtain energy consumption data of farms producing rice in both conventional and SRI practices, a 30-farm survey was conducted between January and June 2022 in Ban Buot, Chieng Yen commune, Van Ho district, Son La province using a face-to-face questionnaire approach. This area was selected because it was one of the forerunners in applying organic farming and ecological engineering of flower strips surrounding rice paddies in the mountainous region of Vietnam. Flower strips are a common measure to promote biodiversity and ecosystem service conservation since they aesthetically enrich production landscapes and provide supplementary food resources and shelter for natural enemies and pollinators.

In addition, indirect surveys were made at the local agencies (e.g., the Agricultural Department of the Local District Council) and Farmers' Associations to obtain the overall picture of general rice production and how agroecology practice had been implemented in the village. Furthermore, to get detailed technical information about machinery and agrochemicals, interviews were conducted with respondents at some machinery and agrochemical shops.

Collected data was imported into a matrix and tabulated in excel.

3. Results and Discussion

3.1. Energy analysis

The energy analysis result showed that although organic farming requires slightly higher labor for preparing homemade insecticides from natural ingredients like ginger, garlic, chilies; weeding and planting flower strips, it is highly effective in terms of the energy consumption through the cut-off of all chemical fertilizers. In conventional farming, farmers in the villages used about 50kg of Nitrogen and 3,000kg of Potassium (equal to 34,000MJ of energy) for one-hectare rice cultivation.

Many other studies also showed that chemical fertilizers have been overused in agriculture and are the main source of energy consumption in rice production. In the Philippines, chemicals accounted for more than 50% of energy consumption [15]. In Vietnam, chemical fertilizers comprised 64% of the total energy used in rice production [16]. Agroecological farming not only reduces the vulnerability of farmers in the context of energy crisis but also highly contributes to mitigating climate change through the reduction of 63% energy compared to conventional farming methods (Table 2). Hence, agroecological farming practices are recognized as one of sustainable solutions to increase resilience to climate change for ethnic minority communities in the Northern Mountainous Region of Vietnam [17].

Although the outputs of organic farming with local varieties reached only slightly more than 4tons/ha, which is lower than the hybrid variety (more than 6 tons/ha), the efficiency of energy in agroecological rice farming is still double the conventional one (Table 3) and even higher than the system of rice intensification (SRI) practice [16]. The energy output–input ratio also indicates that per MJ of energy consumed, there are 0.12kg of rice produced in the conventional method and 0.22kg in the agroecological method. Specific energy shows that the conventional method requires 8.22MJ of energy to produce one kilogram of rough rice, in the organic farming method only 4.04MJ of energy is consumed to produce 1kg of rice, which means one kilogram of organic farming can save about 4MJ compared to conventional farming.

Table 2. Energy inputs and outputs in conventional and agroecological methods of rice production

Item	Unit /ha	Energy per unit	Conventional rice farming		Organic rice farming		Difference (MJ ha^{-1})	Difference (%)
			Quantity (ha)	Total value (MJ ha^{-1})	Quantity (ha)	Total value (MJ ha^{-1})		
Total input				**54178**		**20228**	**-33950**	**-62.66**
Labor	h	1.96	2030	3979	2100	4116	137	3.45
Machinery	h	62.7	107	6705	107	6705	0	0.00
Diesel (liter/h)	L	56.31	8	469	8	469	0	0.00
Fuel (liter/h)	L	47.8	99	4732	99	4732	0	0.00
Chemical fertilizer			3050	34072	0	0	-34072	-100.00
Nitrogen (N)	*kg*	*12.44*	*50*	*622*	*0*	*0.00*	*-622*	*-100.00*
Phosphorus (P_2O_5)	*kg*	*66.14*	*0*	*0*	*0*	*0.00*	*0*	
Potassium (K_2O)	*kg*	*11.15*	*3000*	*33450*	*0*	*0.00*	*-33450*	*-100.00*
Farmyard manure	kg	0.3	7000	2100	7000	2100.00	0	0.00
Pesticide	kg	295	0.05	15	0.00	0.00	-15	-100.00
Seed	kg	17	100	1700	100	1700.00	0	0.00
Electricity	kWh	11.93	34.0	406	34	405.62	0	0.00
Total output				**291740**		**203550**	**-88190**	**-30.23**
Rough rice	kg	14.7	6593	96917	4600	67620.00	-29297	-30.23
Straw	kg	19.7	9890	194823.15	6900	135930	-58893	-30.23

It is also noted that by product (straw) contains a large amount of energy (194823.15MJ). Hence, the net energy gain in the conventional method is higher than the agroecological rice farming. However, in the conventional method, straw was often left on the field or burnt which led to the loss of mass energy. In organic farming, straw was collected and composted with animal manure, which can make use of a huge amount of energy from agricultural residuals.

Furthermore, positive changes in the environment were obviously observed by farmers. All farmers agreed that the soil became more supple and porous when using organic farming methods. Also, ecological engineering with flower strips also brings effective results in reducing pests. Thereby, considerable time is saved when spraying homemade insecticides.

Table 3. Energy ratio in rice production

	Conventional rice farming	**Agroecological rice farming**
Energy use efficiency	5.38	10.06
Energy productivity (kg MJ^{-1})	0.12	0.23
Specific energy (MJ kg^{-1})	8.22	4.40
Net energy gain (MJ)	237562	183322

3.2. Economic analysis

Economic inputs and outputs of rice production in the conventional and organic farming methods are shown in Table 3. The study results indicate that organic farming reduces total economic inputs by 18million VND (€750) compared to the conventional method. The economic outputs increase nearly two-fold from 41million VND (€1708) to 76million VND (€3167). With organic farming, the farmers can sell products at three times higher prices than the conventional method. Hence, even if the productivity is lower, the benefits of organic farming are significantly higher both through reducing the input cost and increasing the value of outputs.

Notably, the improvement in the economic efficiency ratio (0.9 and 0.4 agroecological and conventional methods respectively) is still much lower than the energy ratio. There are several reasons that explain this. First, the high cost of inputs, especially human labor, comprises over 75% of the total cost. However, this cost is often underestimated or not included in the revenue of households since the labor is often mobilized from members of the family or swapped with others in the village. Secondly, the economic value of by-products is underestimated in the market. Straw contains a large energy value; however, it is considered a non-commercial product and commands very low prices. This raises the question of whether the energy value of products is properly used for the highest economic benefits. How to increase the economic value of rice straw, therefore, requires further research.

Table 4. Comparison of economic inputs and outputs between conventional and agroecological rice production methods

Item	Unit /ha	Conventional rice farming			Agroecological rice farming			Difference (1000 VND)	Difference (%)
		Price per unit (1000 VND)	Quantity (ha)	Total value (1000 VND)	Price per unit (1000 VND)	Quantity (ha)	Total value (1000 VND)		
Total input				**100,821**			**82,591**	**-18,230**	**-18.08**
Labour	h	30	2030	60,900	30	2100	63,000	2,100	**3.45**
Machinery	h	60	107	6,417	60	107	6,417	0	**0.00**
Diesel (litre h^{-1})	L	23	8	192	23	8	192	0	**0.00**
Fuel (litre h^{-1})	L	25	99	2,475	25	99	2,475	0	**0.00**
Chemical fertilizer			3050					0	
Nitrogen (N)	kg	20	50	1,000	20	0	0	-1,000	**-100**
Potassium (K_2O)	kg	8	3000	24,000	8	0	0	-24,000	**-100**
Farmyard manure	kg	86	7000	600	86	7000	600	0	**0.00**
Pesticide	kg	3,600	0.05	180	3,600	0.00	0	-180	**-100**
Herbal pesticide	Lump sum	0	0	0	0	0	4,850	4,850	
Seed	kg	50	100	5,000	50	100	5,000	0	**0.00**
Electricity	kWh	1.7	34.0	58	1.7	34	57.8	0	**0.00**
Total output				**41,206**			**74,750**	**33,544**	**81.40**
Rice	Kg	4	6593	26,372	14	4600	64,400	38,028	**144.20**
Straw	kg	1.5	9890	14,834	1.5	6900	10,350	-4,485	**-30.23**

1 USD = 24,500 VND, 1 EURO= 23,890

4. Conclusions

With a view to comparing energy and economic efficiency between conventional and agroecological rice farming methods, this study conducted a face-to-face survey of farming households in Chieng Yen commune, Van Ho district, Son La province, Vietnam. Through analysis of energy input-output balances, combined with economic efficiency analysis, it showed that organic farming combined with ecological methods is a more sustainable form of rice production, both in terms of energy and economic efficiencies. A hectare of paddy rice grown agroecological can save up to 63% of energy inputs. This efficiency is thanks to the removal of chemical fertilizers during cultivation. Such results imply that a more environmentally-friendly method in agricultural production contributes significantly not only to energy conservation and the environment but also doubles income for farmers. Therefore, developing agroecological farming with local varieties should be considered one of the promising climate-smart agriculture practices to enhance resilience for farmers and mitigate climate change. However, more changes still need to be made to improve the energy-efficiency, such as further reducing inputs from human labor and fossil fuels while increasing the use of straw as a huge energy source.

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