Int.J.Curr.Microbiol.App.Sci (2017) *6*(3): 1534-1544

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 Volume 6 Number 3 (2017) pp. 1534-1544
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2017.603.176

Energy Budgeting and Sensitivity Analysis of Rice (*Oryza sativa*) – Wheat (*Triticum aestivum*) Cropping System in Indogangentic Plains of India

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Keywords

Energy analysis, Net energy, Rice, wheat cropping system, Sensitivity analysis.

Article Info

Accepted:
22 February 2017
Available Online:
10 March 2017

A B S T R A C T

Mechanization in Indo-Gangetic plains of India is increasing progressively for the past decades. Use of energy intensive inputs is increasing in a modern intensive agricultural production system. The effect of energy intensive inputs are directly associated with the cost of crop production and environmental issues. These necessities the need of energy input – output analysis. This paper presents the energy input-output analysis of rice (*Oryza sativa* L.) – wheat (*Triticum aestivum* L.) cropping system studied at Indian Institute of farming system research, Modipuram from 2011 to 2014. Results reveal the variations in energy consumption from rice (25819.4 MJ/ha) and wheat (17714.9MJ/ha). Nitrogenous fertilizer (25-33%), fuel (6.8-18.2%) and irrigation water (8.6 - 23.7%) consumed the bulk of the input energy in rice and wheat. Rice crop with the higher energy output produced higher energy use efficiency (7.6), energy use efficiency for grain (4.1) net energy (171399.2) and energy profitability (0.28), while the human energy profitability (162.9) was higher in wheat indicating that it was more labour energy efficient than rice. The consumption of direct (6522.7 MJ/ha) and indirect energy (19296.8 MJ/ha) was found higher in rice crop. Econometric model estimation emphasized that direct energy was found more positive on increasing rice and wheat yield. Thus sensitivity analysis also indicated marginal physical productivity of 0.96. Both rice and wheat were found energy intensive; in order to reduce the energy consumption crop diversification and farm mechanization would be the possible solution.

Introduction

Rice - wheat cropping system is one of the most important cropping systems of the country which contributes about 32 per cent to the national food basket (Dhillon *et al.*, 2010). Both rice and wheat is the most important staple food crop of millions of people in South East Asia, particularly in India. Therefore, their sustained high productivity is inevitable for achieving national food security (Chaudhary *et al.*, 2006).

Presently, the productivity of this cropping system is stagnated and became threatening to national food security (Gupta and Seth, 2007). Rice-wheat cropping system requires a huge amount of input energy for growing the seedlings, puddling, transplanting, irrigation, fertilizer and weed management.

Among different indicators of crop performance, the energy analysis is one of the most important. The net output energy of a cropping system can be assessed for planning of sustainable cropping systems. Unlike soil fertility, crop yield is inversely related to energy use efficiency, energy productivity, and energy intensiveness (Tuti *et al.*, 2012). Large scale implementation of low input agricultural practices and timely problem solving in the farm will contribute to overcome the energy crisis and which will be a considerable input in ensuring the national food security. Hence, the efficient use of energy is of main concern to maximize the system productivity and to achieve sustainability. Energy efficient cropping system will minimize atmospheric pollution by reducing the use of external inputs and promote farming as an economically sustainable production option to the future (Erdal *et al.*, 2007). However, with scarce and contamination of natural resources, the farm productivity is stagnating. Increasing the energy use efficiency is the only possible solution to lower the environmental hazard due to modern agricultural practices (Esengun *et al.*, 2007).

In developing countries like India, farm mechanization is a prime necessity to reduce human drudgery and to increase the output per unit area. This can only be achieved by shifting from traditional energy source i.e. human labour with substantial investments in farm machinery, water management practices, chemicals (fertilizers and pesticides), weed management practices, resource conservation practices, etc. (Amare and Endalew, 2016). These energy inputs and methods need to be evaluated to know their effectiveness and efficiency for future conservation of scarce natural resources. In this background, the energy analysis is done to quantify the energy investment in every step of crop production and for identification of economical and effective practices. The study was undertaken to estimate and compare the energy requirements of the production in rice and wheat.

Materials and Methods

The field experiments were carried out (2011-12 to 2013-14) to estimate the energy of inputs, outputs, energy use efficiency and net energy return of the rice-wheat cropping system at the research farm of the ICAR-Indian Institute of the Farming System Research, Modipuram, Meerut (Uttar Pradesh). For energy budgeting of this cropping system, three years average input and output data were considered. For rice in *Kharif*, all plots were ploughed twice and tilled once with a power tiller. Thereafter, water was flooded to about 10 cm depth for 24 h for puddling.

The field was prepared for the wheat crop with two harrowing, planking and leveling. The details of all inputs used in cropping system through various activities are given in table 2. The crop was raised on natural soil fertility and the nutritional requirements of the crop were met through application of mineral fertilizers and farmyard manure (FYM). The recommended dose of fertilizers and chemicals were applied as per the need of the crop. Pressure due to insect pests and diseases was generally low for most of the seasons during the experimental years. Once the crop was grown, harvested yields of main and by-products of each crop were measured.

Methods of energy calculation

An energy flux of rice-wheat cropping system was estimated using crop management and biomass production records. To study energy inputs and outputs of cropping system, a complete inventory of all the crop inputs (fertilizers, seeds, plant protection chemicals, fuels, human labor and machinery power) and outputs of both main and by-products was prepared. The energy value of cropping system was determined based on energy inputs and energy production for the individual crops in the system. Inputs and outputs were converted from physical to energy unit measures through conversion coefficients (Table 1).

The following equations were used to calculate different energy indices for rice – wheat cropping system.

Energy use efficiency=(Energy input (MJ/ha))/(Energy output (MJ/ha))
Net Energy=(Energy input (MJ/ha))-(Energy output (MJ/ha))
Energy profitability =(Net energy (MJ/ha))/(Energy input (MJ/ha))
Direct energy= Labour + Fuel + Electricity
Indirect energy=Seed + Feed + Fertilizers + Chemicals + Machineries +irrigation
Renewable energy =Labor + Organic Fertilizers

Non-renewable energy=Fuel + Electricity + Seed + Feed + Synthetic Fertilizers + Chemicals + Machineries

Human energy profitability = Output energy (MJ/ha) / Labour energy (MJ/ha)
Energy productivity = Crop economic yield (kg/ha) / Energy input (MJ/ha)

Production functions

The impact of direct, indirect, renewable and non-renewable energy on rice and wheat yield were evaluated by using Cobb–Douglas production function in following forms

$$lnY_i = \beta_0 + \beta_1 \ln(DE) + \beta_2 \ln(IDE) + \varepsilon_i \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$lnY_i = \gamma_0 + \gamma_1 \ln(RE) + \gamma_2 \ln(NRE) + \varepsilon_i \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where, *Yi* denotes the yield of the ith farmer, *DE*, *IDE*, *RE* and *NRE* are direct, indirect, renewable and non-renewable energy which are used for rice and wheat production respectively, βi and γi are the coefficients of variables, β_0 and $\gamma_0$are the constants and εi is the error term. For computation of above equation, data were used years wise.

The marginal physical productivity (MPP) technique was used to know the sensitivity of a different energy sources on productivity of the rice wheat cropping system based on the response coefficients of the inputs. The MPP of the various energy sources was computed using the β_j of the various energy inputs as under

$$MPP_{xj} = \frac{GM(Y)}{GM(X)_j} \times \beta_j \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where, MPP_{xj} MPP of jth input, β_j regression coefficient of jth input, GM (Y) geometric mean of productivity, GM (X_j) geometric mean of jth input on farm per hectare basis.

Return to scale

The return to scale is indicated by the sum of the coefficients ($\Sigma\beta_j$) derived from regression equations in Cobb–Douglas production function. If the sum of the coefficients is less than or equal to or greater than unity, then the returns to scale will be decreasing or constant, or increasing, respectively.

Results and Discussion

Crop yields and resource consumption

Resource consumption, outputs and by-products produced from rice – wheat cropping system is presented in table 2. The mean data of three years revealed that among different inputs the use of farm yard manure (7500 kg/ha in rice and 5000 kg/ha in wheat) was found higher followed by irrigation input in both the crops. The labor requirement (802.4 man hr/ha) for rice was more compared to wheat (414.6 man hr/ha) due to manual transplanting, frequent weeding in rice and maintenance needs.

Wheat utilized notable amount of fossil fuel (67.2 l/ha) because of tedious field preparation after rice harvest and for drill sowing of wheat seeds. Because of manual weeding and lesser incidence of insect pest, the use of insecticide/weedicide was nil in wheat while it was necessary due to higher weed and pest infestation in rice (12.2 kg/ha). As both rice and wheat are exhaustive in nature application of synthetic fertilizer was found higher. Among different nutrients, N application rate (106.4 and 97.6 kg/ha in rice and wheat, respectively) was generally higher to P (68.5 and 96.5 kg/ha in rice and wheat, respectively) and K (60.2 kg/ha in rice and wheat). The use of irrigation was found higher in rice (6000 m^3/ha) compare to wheat (1500 m^3/ha). The water usage in wheat was found lower because the crop was irrigated only at critical stages of crop growth while in rice,2 cm of water level was maintained up to dough stage. The yields of main and by-product of rice (7179 and7335 kg/ha) were found higher than wheat (4710 and 5048 kg/ha).

Energy input–output analysis

The energy consumption of rice and wheat are presented in table 3. The total energy input was found higher in rice (25819.4 MJ/ha) compare to wheat (17714.9 MJ/ha). It was mainly due to higher energy input in terms of N fertilizers, manure management (FYM application) and frequent irrigation in rice (Table 2) compare to wheat. Bockari-Gevao *et al.,* (2005) reported energy input of 12.4 GJ/ha for rice in Malaysia, which mostly depended on chemical fertilizer (7.7 GJ/ha). The total energy output was also found higher in rice (197218.7 MJ/ha) due to higher main and by-product yield of rice compare to wheat (Table 2).

Energy indices

Energy indices are presented in table 4. The energy use efficiency, energy profitability, and energy productivity of rice (7.6, 6.6 and 0.28 kg/MJ) and wheat (7.5, 6.5 and 0.27 kg/MJ) were found almost similar during the study period. This was mainly due to the large amount of available residues with a significant energy potential in addition to its main crop yield in both the crops. Energy use efficiency of main product (EUE_M) for rice (4.9) is higher than wheat due to higher average grain yield of rice than wheat (Table 2). Earlier scientists reported different EUE_M values for different crops like 7.2 for wheat (Singh *et al.,* 1997), 8.4 for maize (Hetz, 1992) and 0.8 for stake-tomato (Esengun *et al.,* 2006). Bockari-Gevao *et al.,* (2005) reported EUE_M for rice without irrigation was 8.86 for Malaysia. Rutger and Grant (1980) reported an EUE_M value of 1.03–1.76 for USA and 3.36–3.41 for Philippines for irrigated, where labor energy was not included during the calculation. Whereas in this study, EUE_M was found higher since intensive labour usage was included. The human energy profitability was found higher in wheat (162.9) compare to rice (125.4) due to higher energy output per unit of labour energy usage.

Percentage of energy consumption

Percent of energy usage from different sources are presented in table 5 (Fig. 1). It shows that indirect energy input in rice and wheat were around 75% of its total energy input. Rice consumes more indirect energy, out of which 25% from N fertilizer only followed by irrigation (23.7%). In wheat, the indirect energy input from N fertilizer (33.7%) was found higher followed by K fertilizer (13.3%). Among direct energy sources, Wheat consumed more direct energy, out of which 18.2% from fossil fuel. The usage of nonrenewable energy (Fig. 1) was found higher in both the crops (56.6% and 73.5% in rice and wheat, respectively). This was mainly due to higher reliance on synthetic fertilizers, agrochemicals and frequent irrigation in both the crops.

Table.1 Energy equivalents of inputs and outputs in agricultural production

Input	Unit	MJ/Unit	Reference
Labor	Man hr	1.96	Singh and Mittal (1992)
Fossil fuel (Diesel)	lit.	47.87	Cervinka (1980)
Electricity	kWh	3.6	Ozkana *et al.,* (2004)
Nitrogen (N)	kg	60.6	Singh and Mittal (1992)
Phosphorus (P_2O_5)	kg	11.1	Singh and Mittal (1992)
Potassium (K_2O)	kg	6.7	Singh and Mittal (1992)
Farm Yard Manure	kg	0.47	BeheshtiTabar *et al.,* (2010)
Insecticides/Pesticides/Weedicides	kg	120	Chaudhary *et al.,* (2009)
Insecticides/Pesticides/Weedicides	Lit.	102	Chaudhary *et al.,* (2009)
Fungicide	kg	97	Pimentel (1980)
Machinery including self-propelled	kg	68.4	Singh and Mittal (1992)
Animal Plough	Pair-hr	10.1	Singh and Mittal (1992)
Electric motor	kg	64.8	Singh and Mittal (1992)
Irrigation	m^3	1.02	Tuti *et al.,* (2012)
Plastic	kg	90	Canakci and Akinci (2006)
Seeds (Rice and Wheat)	kg	14.7	Jackson *et al.,* (2010)
Output			
Rice	kg	14.7	Jackson *et al.,* (2010)
Wheat	kg	14.7	Singh and Mittal (1992)
Straw (wheat, rice)	kg *	12.5	Singh and Mittal (1992)

* By-product is dry mass

Table.2 Resource inputs and outputs in rice - wheat cropping system

Resource inputs/ha	Unit	Rice	Wheat
Direct			
Labour	man hr	802.4	414.6
Fossil fuel (Diesel)	l	36.5	67.2
Electricity	kWh	889.9	222.5
Indirect			
Seed	kg	24.3	103.3
Nitrogen (N)	kg	106.4	97.6
Phosphorus (P_2O_5)	kg	68.5	96.5
Potassium (K_2O)	kg	60.2	60.2
Farm Yard Manure	kg	7500.0	5000.0
Insecticide/Weedicide	kg	12.2	0.0
Fungicide	kg	1.2	0.0
Machinery	kg	1.4	1.4
Animal Ploughing	hr	-	-
Irrigation	m^3	6000.0	1500.0
Resource Output/ha			
Main	kg	7179	4710
Byproduct	kg	7335	5048

Table.3 Energy of Inputs and Outputs of rice – wheat system (MJ/ha)

Particulars	Rice	Wheat
Direct		
Labor	1572.8	812.6
Fossil fuel (Diesel)	1746.02	3218.5
Electricity	3203.9	801.0
Indirect		
Seeds	357.5	1519.1
Nitrogen (N)	6450.5	5914.1
Phosphorus (P_2O_5)	760.5	1070.9
Potassium (K_2O)	403.2	403.2
Farm Yard Manure	3525	2350
Insecticide/Weedicide	1459.0	0.00
Fungicide	124.4	0.00
Machinery including self-propelled	96.7	95.5
Animal Ploughing	-	-
Irrigation	6120	1530
Total Energy Input (MJ/ha)	25819.4	17714.9
Energy Output (MJ/ha)		
Energy (main)	105531.3	69237.0
Energy (byproduct)	91687.4	63099.9
Total Energy Output (MJ/ha)	197218.7	132336.9

Table.4 Energy Indices for rice - wheat system (MJ/ha)

Indices	Rice	Wheat
Energy Use Efficiency	7.6	7.5
Energy Use Efficiency ^{M*}	4.1	3.9
Net Energy(MJ/ha)	171399.2	114622.0
Net Energy ^{M*}(MJ/ha)	79711.9	51522.1
Energy Profitability(MJ/ha)	6.6	6.5
Human Energy Profitability	125.4	162.9
Energy Productivity (kg/MJ)	0.28	0.27
Direct Energy (MJ/ha)	6522.7	4832.1
Indirect Energy (MJ/ha)	19296.8	12882.8
Renewable Energy (MJ/ha)	5097.8	3162.6
Non-renewable Energy (MJ/ha)	14601.7	13022.3

Note: ^{M*}- Main product

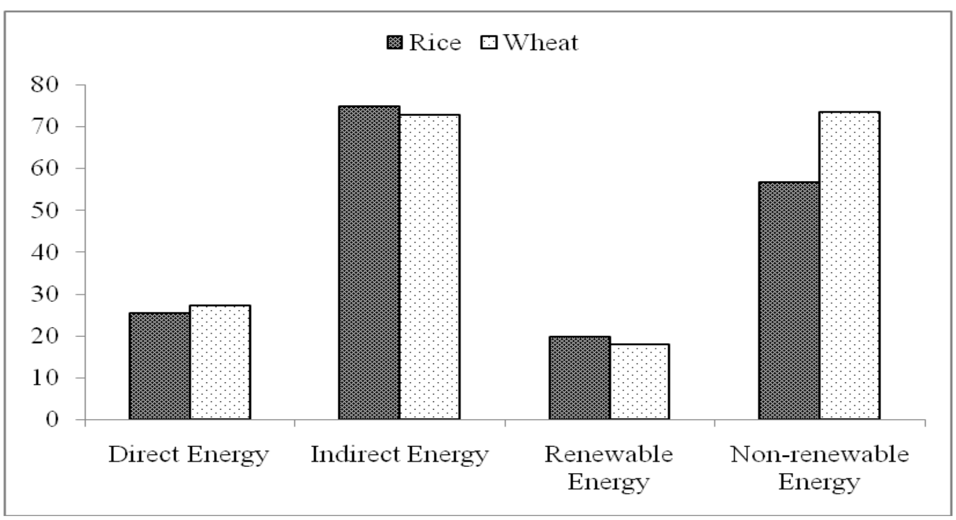
Table.5 Percentage of energy shared by different inputs in rice-wheat cropping system

Particulars	Rice	Wheat
Direct Sources		
Labor	6.1	4.6
Fossil fuel (Diesel)	6.8	18.2
Electricity	12.4	4.5
Indirect Sources		
Seed	1.4	8.6
Nitrogen	25	33.4
Phosphorus	2.9	6
Potassium	13.7	13.3
Farm Yard Manure	1.6	2.3
Insecticide/Weedicide	5.7	0
Fungicide	0.5	0
Machinery	0.4	0.5
Irrigation	23.7	8.6

Table.6 Econometric estimation results of direct energy, indirect energy, renewable energy, nonrenewable energy forms

Energy input source	Coefficients	MPP
$lnYi = \beta_0 + \beta_1 \ln(DE) + \beta_2 \ln(IDE) + \varepsilon_i$		
Direct energy	0.93	0.96
Indirect energy	0.29	0.26
Constant	-2.38	
R^2	0.98	
Return to scale $(\sum_{i=1}^{n} \beta_i)$	1.24	
$lnY_i = \gamma_0 + \gamma_1 \ln(RE) + \gamma_2 \ln(NRE) + \varepsilon_i$		
Renewable energy	0.78	0.82
Nonrenewable energy	0.28	0.26
Constant	-0.57	
R^2	0.98	
Return to scale$(\sum_{i=1}^{n} \gamma_i)$	1.07	

Fig.1 Percentage of energy consumed from different sources of energy



Econometric model performance of rice – wheat production

The regression coefficient of DE, IDE, RE and NRE forms were found positive (Table 6). The impact of DE (0.93) and RE (0.78) was more than IDE (0.29) and NRE (0.28). The coefficients RE and NRE inputs indicate that 1% increase will lead to 0.78% and 0.28% increase in productivity, respectively.

The result also revealed that the impact of DE (0.93) was high in enhancing rice and wheat yield. The return to scale value for model 1 and 2 were 1.24 and 1.27., respectively (Table 6) which implies increase in return to scale. The MPP values of DE, IDE, RE and NRE were 0.96, 0.26, 0.82 and 0.26, respectively (Table 6). It indicates that with increase in input of 1MJ energy in DE, IDE, RE and NRE would lead to an additional increase in rice and wheat yield by 0.96, 0.26, 0.82 and 0.26 kg ha^{-1}, respectively. The positive MPP value of inputs indicates production will increase with increase in input. However, the present study reveals that the productivity of rice and wheat will be more with per unit increase of DE and RE as compare to IDE and NRE.

It is concluded that the energy use efficiency of crops can be quantified and stratified for optimization of energy gains in production systems. Among all energy input components in rice and wheat, synthetic fertilizers contributed more followed by fuel and irrigation water. The consumption of indirect energy source was more in both the crops showing exhaustive nature of these crops. The rice crop was more energy efficient with respect to energy use efficiency, net energy, energy productivity than wheat. However, higher human energy profitability in wheat crop indicates that wheat is more labour efficient than rice. The model indicates sensitivity towards direct and renewable energy which means with an increase in input of direct and renewable energy per unit yield of rice and wheat would increase equi proportionately.

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How to cite this article:

Paramesh, V., N. Ravisankar, Bappa Das, K. Viswanatha Reddy and Narendra Pratap Singh. 2017. Energy Budgeting and Sensitivity Analysis of Rice (*Oryza sativa*) – Wheat (*Triticum aestivum*) Cropping System in Indogangentic Plains of India. *Int.J.Curr.Microbiol.App.Sci.* 6(3): 1534-1544. doi: https://doi.org/10.20546/ijcmas.2017.603.176