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Energy efficiency of integrated crop-livestock-fish farming system for lowland irrigated ecology of eastern region, India

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ABSTRACT

An integrated farming system (IFS) model was developed and assessed at ICAR-Research Complex for Eastern Region, Patna during 2015–19. The aim of the study was to analyze energy input-output relationship of the IFS model. The IFS model comprised of field crops, vegetables, fruits, green fodder, cattle, fish, duck and vermicomposting components. The analysis revealed total energy input in the IFS model as 112.62 GGJ and total energy output as 211.12 GJ. Energy use efficiency of the IFS model was analyzed to be 1.87, net energy gain recorded as 98.5 GJ. The direct and indirect energy inputs were estimated to be 14.06 GJ and 98.56 GJ, respectively while renewable and non-renewable energy inputs were estimated to be 85.04 and 27.58 GJ, respectively. Further, the total energy input in dairy unit was estimated to be 70.3 GJ of which 68.3 GJ was provided through feed, which accounted for 97% of total energy input in dairy unit, and 60% of the total energy input in IFS model. Furthermore, energy input in the forms of labour, fossil fuel, electricity, fertilizers and machinery was required maximum in the field crops while water energy input was required maximum in fish pond. Results showed that individual farming of fish, duck and cattle is not viable in terms of energy use efficiency. However, the IFS model as a whole was found to be energy efficient and can be adopted in lowland irrigated ecologies of the eastern region of the country.

Keywords: Energy, Integrated farming, Lowland irrigated ecology, Small and marginal farmer

The energy use efficiency of agricultural production systems has been considered as an indicator of crop performance. Hence, agricultural productivity evaluation based on energy input-output relationship is important to make efficient use of existing natural resources so as to ensure economic and environmental sustainability of farming practices. The energy consumption in agriculture has been increased in the form of fossil fuel, fertilizers, pesticides, herbicides, electricity and machineries, and causing environmental and human health problems (Fadvi *et al.* 2011, Kumar *et al.* 2019). The efficient use of energy in agricultural systems can minimize the environmental problems and destruction of natural resources (Erdal *et al.* 2007). The best way to lower the environmental harms caused due to extensive use of energy is to increase the energy use efficiency (Esengum *et al.* 2007). Various studies have revealed that yield and economical parameters increased linearly as level of fertility increased while reverse trend was observed with energy use efficiency (Tuti *et al.* 2012, Kumar *et al.* 2019). The energy input and energy output analysis provides farm planners an opportunity to assess the economic intersection of energy use (Ozkan *et al.* 2004). Increasing demand for food to meet food and nutritional security has resulted in intensive use of energy inputs and over-exploitation of the natural resources across the world (Kumar *et al.* 2019).

Agriculture is the main source of livelihood and employment in the eastern region of India where about 84% population is rural, and share of marginal farmers (<1 ha. land holding) is 67.0 % (Bhatt *et al*. 2011). Of the total geographical area of 71.84 million hectares, the net irrigated area is 14.36 million hectares and major agricultural productions of this region include rice, wheat, maize, vegetables and fish (Bhatt *et al*. 2016). Therefore, the present study was conducted to analyze energy input-output relationship of crop-livestock-fish IFS model developed for the small and marginal farmers under irrigated lowland ecosystems.

MATERIALS AND METHODS

An IFS model targeting small and marginal farmers of lowland irrigated ecology in the eastern region of India, was developed and assessed at the research farm of ICAR-Research Complex for Eastern Region, Patna (Bihar) during 2015–19. The geographical location of the site is 25.5941º N,

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85.13º E and 50 m amsl. The average data of all input and all output for the period of four years (2015–19) with the same components was considered for the analysis of energy input-output relationship. The IFS model consisted of crops (rice, wheat, maize, gram and mustard), vegetables (okra, tomato and cabbage), fruits (lemon, guava and banana), green fodder (sorghum, cowpea, berseem, oat and maize), cattle (2 nos), fish (catla, rohu and mrigal), duck (30 number, khaki campbell), and vermicomposting unit. Various energy indices were calculated using following formulae (Rahman and Barmon 2012, Soni *et al*. 2013).

$$\text{Energy use efficiency (EUE)} = \frac{\text{Total energy output}}{\text{Total energy input}}$$

$$\text{Net energy gain (NEG)} = \text{Total energy output} - \text{Total energy input}$$

$$\text{Energy profitability (EP)} = \frac{\text{Net energy gain}}{\text{Total energy input}}$$

$$\text{Direct energy (DE)} = \text{Labour} + \text{Fuel} + \text{Electricity}$$

$$\text{Indirect energy (IE)} = \text{Seed} + \text{Feed} + \text{Fertilizers} + \text{Chemicals} + \text{Machineries}$$

$$\text{Renewable energy (RE)} = \text{Labour} + \text{Manure} + \text{Feed}$$

$$\text{Non-renewable energy (NRE)} = \text{Fuel} + \text{Electricity} + \text{Seed} + \text{Fertilizers} + \text{Chemicals} + \text{Machineries}$$

$$\text{Human energy profitablity (HEP)} = \frac{\text{Total energy output}}{\text{Labour energy input}}$$

$$\text{Water energy profitablity (WEP)} = \frac{\text{Total energy output}}{\text{Water energy input}}$$

The inputs such as labour, fuel, electricity, feed, seed, fertilizers, chemicals, machineries, water, and outputs including grains, vegetables, fruits, meat, milk, manure, eggs and other products/by-products of the IFS model were first converted from physical unit to energy unit (MJ or GJ) using published conversion factors (Table 1) and analyzed for the determination of various energy indices. Energy output from green fodder crops was estimated based on the dried biomass of green fodder. Fish fingerlings comprised of *Catla catla* (catla)*, Labeo rohita* (rohu) and *Cirrhinus mrigala* (mrigal) were stocked @10000 /ha. Various farm machineries were employed for different purposes like land preparations, irrigation, harvesting, threshing, transportation etc hence their energy was estimated based on their distributed weight. The distributed weight was derived as machinery unit weight/[economic life × 365 (366 for leap year × 8] (Soni *et al.* 2013).

RESULTS AND DISCUSSION

The energy input-output analysis of the current IFS model revealed total energy input as 112.62 GJ and total energy output as 211.1 GJ (Table 2). The feed, fertilizers and labour contributed as 66.2, 14.5 and 6.3% of the total energy input, which accounted together about 87% of the total energy input, and rest of the energy i.e. about 13% was contributed by fossil fuel, electricity, water, chemicals and machineries. The net energy gain was recorded to be 98.5 GJ. Energy use efficiency ratio (EUE) of the IFS model was calculated to be 1.87. The studies have shown EUE of different agricultural production systems like sugarcane and maize in isolation as 1.34 and 1.86, respectively from different regions of the world (Fadvi *et al.* 2011, Lorzadeh *et al*. 2011). The energy use efficiency of *Gher* farming system comprised of fresh water prawn, fish and HYV rice, and reported EUE ratio as 1.72, whereas prawn-fish cultivation alone resulted in EUE as 0.11 only (Rahman and Barmon 2012). Moreover, Soni *et al.* (2013) analyzed the energy input-output relationship among different agricultural production systems from rain-fed ecology of NE Thailand and reported EUE ratio of rice, vegetables and fish as 5.6–6.5, 0.37–2.2 and 0.45, respectively. Furthermore, Kumar *et al*. 2019 reported the EUE ratio of crop-livestock-poultry IFS as 2.27. In the current IFS model, the EUE from dairy sub-system was estimated to be 0.16, while Sefeedpari (2012) reported it as 0.26 which indicated inefficient use of energy in dairy sub-system. The value of EUE ratio from dairy unit was obtained lesser because of the energy stored in the body as muscles, tissues, bones and their calves were not accounted in the analysis. Further, results indicated that in isolation fish, duck and dairy sub-systems were not sustainable as they produced negative energy mileage, and resulted in inefficient use of energy.

In the current IFS model, direct and indirect energy inputs were estimated to be 14.06 GJ and 98.56 GJ, respectively, while renewable and non-renewable energy inputs were recorded as 85.04 and 27.58 GJ, respectively. The energy inputs in the forms of labour, diesel, electricity, fertilizers and farm machineries were required maximum in field crops. Moreover, water energy input was required maximum in the fish pond followed by fodder crops, field crops and vegetables, respectively. In the IFS model, the percentage share of energy input in the form of feed (66.2%) was highest followed by fertilizers (14.5%), labour (6.3%), diesel and electricity (6.2%) and water (5.6%). The NEG from the IFS model was estimated be 98.5 GJ, maximum from crops followed by green fodder, vegetable, fruits sub-systems, whereas fish, duck and dairy sub-systems produced negative energy mileage. The energy profitability analysis of different sub-systems revealed the highest energy profitability from green fodder sub-system followed by crops, vegetables and fruit sub-systems, whereas fish, duck and dairy sub-systems resulted in negative energy profitability. Moreover, the overall energy profitability of the studied IFS model was found to be 0.87 (Table 2). The HEP of the current IFS model as a whole unit, was estimated to be 29.46, and found to be maximum in green fodder sub-system followed by crop, vegetable and fruit sub-systems etc. The WEP analysis revealed maximum profitability in crop sub-system, subsequently followed by green fodder, fruit and vegetable sub-systems. Furthermore, the WEP of the IFS model as a whole was recorded to be 33.1/GJ.

Table 1 Energy conversion factor of the resource input/output/by-products

Resource input/output/by-product	Unit	Energy eq. (MJ/unit)	Reference
Labour	h	1.96	(Singh and Mittal 1992)
Diesel fuel	l	47.87	
Electricity	kWh	3.6	(Ozkan *et al.* 2004)
Nitrogen	kg	60.6	(Tuti *et al.* 2012)
Phosphorous	kg	11.1	
Potassium	kg	6.7	
Zinc sulphate	kg	20.9	
Farm machinery	kg	62.7	
Herbicides	kg	254.45	(Pimental *et al.* 1980)
Insecticides	kg	184.63	
Water	m^3	1.02	(Tuti *et al*. 2012)
Minerals	kg	2.0	(Wells 2001)
Seed of rice, wheat, maize, gram, cowpea, oat, sorghum	kg	14.7	(Singh and Mittal 1992)
Mustard	kg	25.0	
Okra, tomato, cabbage	kg	0.8	(Tuti *et al*. 2012)
Banana	kg	5.35	(Gopalan *et al*. 1971)
Lemon	kg	2.88	(Singh and Mittal 1992)
Guava	kg	2.6	
Berseem	kg	10.0	
Duck	kg	5.44	(Gopalan *et al*. 1971)
Fish fingerlings	kg	4.52	(Rahman and Barmon 2012)
Okra, lemon, guava	kg	1.9	(Singh and Mittal 1992, Tuti *et al*. 2012)
Banana	kg	4.85	(Gopalan *et al*. 1971)
Fish	kg	4.61	(Rahman and Barmon 2012)
Egg	kg	7.57	(Gopalan *et al*. 1971)
Cow milk	l	3.15	Estimated
Urine	l	0.34	Estimated
Manure	kg	0.3	(Taki *et al*. 2012)
Vermicompost	kg	0.5	(Ram and Verma 2015)
Straw (rice and wheat)	kg	12.5	(Singh and Mittal 1992)
Residue of gram	kg	11.23	
Residue of tomato, cowpea, cabbage, okra, banana	kg	10.0	(Tuti *et al*. 2012)
Green fodder (based on dried mass), residue of mustard, maize, fuel wood	kg	18.0	(Singh and Mittal 1992)

For ensuring food and nutritional security, intensive use of energy input in agricultural production systems is threatening human health as well as environment, hence energy budgeting of agricultural production systems is essential to make them sustainable and profitable (Taki *et al.* 2012, Soni *et al*. 2013). Further, renewable energy input should be maximised to curtail non-renewable energy inputs in agricultural production systems so as to enhance productivity, profitability and to bring sustainability in agricultural production systems (Moreno *et al.* 2011, Zarini *et al*. 2015). Present study revealed that current IFS model was energy efficient and can be encouraged to be adopted by the small and marginal farmers of lowland irrigated ecologies of eastern region, India. Findings revealed that in individual manner farming of fish, duck and cattle are not profitable in terms of net energy gain and energy utilization. Energy input in the form of feed had highest contribution followed by fertilizers, labour, fossil fuel and electricity etc, hence, there is need and possibility for improvement in feed quality. The inorganic fertilizers contributed significantly to the total energy input which need to be managed well, and use of organic manures should be encouraged to lessen the use of inorganic fertilizers. Precision agriculture, efficient irrigation methods, rainwater harvesting could be adopted to

Table 2 Energy analysis of the IFS model and its components

Energy indices	Crop	Vegetable	Fruit	Fodder	Fish	Duck	Dairy	Vermicompost	IFS
	14.53	4.32	3.32	5.92	3.94	7.79	70.29	2.51	112.62
Total energy output	114.96	11.69	6.72	61.20	2.51	1.65	11.59	0.80	211.12
Energy use efficiency ratio	7.91	2.70	2.03	10.02	0.64	0.21	0.16	0.27	1.87
Net energy gain	100.4	7.3	3.4	55.1	-1.42	-6.14	-58.7	-2.1	98.5
Energy profitability	6.91	1.70	1.03	9.02	-0.36	-0.79	-0.84	-0.73	0.87
Direct energy input	4.89	1.44	0.67	2.23	1.34	1.15	1.85	0.49	14.06
Indirect energy input	9.63	2.89	2.65	3.87	2.60	6.65	68.45	2.44	99.17
Renewable energy input	1.98	0.91	0.97	1.03	0.96	7.19	69.08	2.93	85.04
Non-renewable energy input	12.55	3.41	2.35	5.07	2.98	0.60	1.22	0.01	28.19
Human energy profitability	63.75	14.06	11.59	78.97	5.13	2.63	8.85	1.63	29.46
Water energy profitability	83.49	14.32	19.38	47.13	1.23	-	-	-	33.11

Values are in GJ.

improve energy use efficiency of integrated farming system in the eastern region of India. Moreover, use of bio-fuels and solar energy in farming systems may be of assistance in improving energy use efficiency.

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