

Energy-efficiency indices of alternative cropping systems of North-West India

S.S. WALIA¹, R.S. GILL², C.S. AULAKH³ AND MANDEEP KAUR⁴

Punjab Agricultural University, Ludhiana, Punjab 141 004

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ABSTRACT

A field experiment was conducted during 2006-07 to 2008-09 at Ludhiana, to evaluate the energy input, energy output and energy-use efficiency of diversified cropping systems. The maximum rice (*Oryza sativa* L.)–equivalent yield (31.7 t/ha) was observed in maize [*Zea mays* (L.)]–potato [*Solanum tuberosum* (L.)]–onion [*Allium cepa* (L.)], which was closely followed by groundnut [*Arachis hypogaea* (L.)]–potato–pearlmillet [*Pennisetum glaucum* (L.) R. Br.] (fodder), (24.3 t/ha) and maize–potato–mungbean [*Vigna radiata* (L.) Wilczek] (22.8 t/ha) cropping system. The highest total energy input was reported for maize (*Zea mays* L.)–potato–onion (*Allium cepa* L.) (69,510 MJ/ha), which was closely followed by maize–potato–mungbean (62,660 MJ/ha) cropping system. Major proportion of energy was added through fertilizer (11.27–42.7%) and diesel (19.8–34.2%) in different cropping systems. The highest energy output was recorded in maize–wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.]–mungbean (5,14,300 MJ/ha), which was followed by maize–wheat (4,61,600 MJ/ha) and maize–potato–onion (4,37,800 MJ/ha). However, energy productivity was the highest in groundnut–toria (*Brassica rapa* var. toria) + gobhi sarson (*Brassica napus* subsp. Oleifera Var. annua) (0.82 kg/MJ) as compared to other cropping systems. The energy-use efficiency was the maximum in groundnut–toria+gobhi sarson (16.3) but specific energy was lowest for the same treatment.

Key words : Cropping system, Energy input, Energy output, Energy productivity, Specific energy

Energy is a critical aspect of a national development process. It is used in agricultural operations, in food processing and transportation, in the production of fertilizer, pesticides and farm equipment. The era of low-priced energy is now ending and energy conservation become obligatory because of rising cost of energy. In India, the availability of power on the farm has to be increased if productivity to be raised. More power is needed for timely and quality tillage as well as for irrigation, harvesting and threshing. The worldwide energy crisis caused by fuel shortage and high prices of petroleum has adversely affected the Indian economy. In order to mitigate the hardship, it is necessary to conserve non renewable energy sources and make better use of available conventional energy sources. In India, there is little additional land is available for agriculture. The increase in cropping intensity requires additional supply of energy for irrigation as well as for timely tillage and harvesting. The increase in productivity also requires additional mechanical power along with adequate use of fertilizers and wider use of mechanical and electrical power.

The production of crops in a system with high yield targets cannot be achieved without energy inputs to the system. The energy input is one of the key factors for successful crop production. Energy requirements for crop production system have been witnessing a dramatic diversification in agriculture (Dhaliwal and Kler, 1995). Agricultural intensification requires more energy and energy-input pattern for crop production depends on economic, technological and social constraints. Commercial and non-commercial energy are available in agricultural operations. Commercial energy inputs arrive on farm in many different forms, e.g. fuel, irrigation water, chemical fertilizer, machinery and pesticides (Khan and Hussain, 2007). Among field crops, legumes involve less energy than cereals and oilseeds. Rice production incurs much higher input of energy, mainly due to its high water and fertilizer requirements coupled with other practices like transplanting, harvesting and threshing. Inclusion of some crops in diversification may reduce the energy production as they are poor converters of it, so a suitable cropping system needs to be designed so that apart from higher productivity and profitability it must be efficient converter of energy (Kachroo *et al.*, 2012). Hence the present study carried out to find out the options for replacing the higher input energy required conventional rice–wheat cropping system

¹Corresponding author Email: sohanwalia72@yahoo.co.in

^{1,3}Agronomist; ²Assistant Soil Chemist, Punjab Agricultural University, Ludhiana, Punjab 141 004; ⁴Assistant Professor, Bathinda Road, Gurdaspur, Punjab 143 521

under irrigated conditions of Punjab.

MATERIALS AND METHODS

The study was conducted at Punjab Agricultural University, Ludhiana during 2006–07, 2007–08 and 2008–09 under All-India Co-ordinated Research Project on Integrated Farming Systems. The soil was sandy loam, having pH 7.2, electrical conductivity 0.40 dS/m, organic carbon 0.53% and available N, P and K of 186, 44 and 132 kg/ha respectively. Ten cropping systems were replicated 4 times in randomized complete block design, viz. rice–wheat; maize–wheat; maize–wheat–summer mungbean; maize–potato–summer mungbean; maize–potato–onion; cotton–wheat; Cotton–African sarson (*Brassica carinata* A. Braun); cotton–*gobhi sarson* transplanted; summer groundnut–*toria+gobhi sarson*; summer groundnut–potato–pearlmillet. Rice ‘PR 114’, maize ‘Paras’, cotton ‘LH 1556’, summer groundnut ‘M 522’ were grown during rainy (*kharif*) season; and wheat ‘PBW 343’, late sown wheat after cotton ‘PBW 373’, potato ‘Kufri Chandermukhi’, *gobhi sarson* ‘GSL 1’, African sarson ‘PC 5’, onion ‘Punjab Naroya’ during *rabi* season and pearl millet ‘PCB 15’, summer mungbean ‘SML 668’ during summer season were raised under irrigated conditions. All crops were grown as per recommended agronomic practices. The yield of *rabi*, *kharif* and summer crops were converted into rice-equivalent yield (REY) by multiplying yield with prevailing price of produce and divided by price of rice in different years. The profitability of systems was calculated by dividing net returns/ha in a sequence by 365 days.

Energy values for various input and outputs used in the experimentation are given in Table 1 (Singh and Mittal, 1992). The total energy input for a given cropping system was calculated by adding the energy requirement for human labour, diesel, herbicides, farmyard manure (FYM) and fertilizers used in that sequence. The energy output was calculated by accumulating the main product and by-product produced from different cropping systems. Subtracting input energy from output energy derived the net return of energy. The output:input ratio was worked out by dividing the total energy generated from main product and by-product by the total energy used for raising the crop in the unit area. The energy input and output were computed as Mega Joule (MJ) by using different formulae. The energy efficiency (EE) and specific energy (SE) were worked out as per Dazhong and Pimental (1984).

$$EE = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}; SE = \frac{\text{Total system output (MJ/ha)}}{\text{Rice equivalent yield (t/ha)}}$$

Energy output efficiency (MJ/ha/day) and energy productivity were calculated by:

$$\text{Energy output efficiency} = \frac{\text{Energy output (MJ/ha)}}{\text{Duration of the system (days)}}$$

$$\text{Energy productivity} = \frac{\text{Rice-equivalent yield (kg/ha)}}{\text{Energy input (MJ/ha)}}$$

RESULTS AND DISCUSSION

Energy input in cropping patterns

Energy inputs for different cropping systems was computed for 3 years (Table 2). Total energy inputs in different cropping patterns under this study was in range from 20,000 to 69,510 MJ/ha. Fertilizer accounted for a major share of energy input (22–42.7%) followed by seed (0.8–35.5%), diesel (19.8–34.2%), organic fertilizer (0–10.2%) and irrigation (7.2–9.4%). The energy input through human labour (3.7–10.1%) was minimum followed by herbicides (0.72–1.70%). The highest energy input was required for fertilizers (39.4–49.2%) for different cropping systems (Khan and Hussain, 2007). The highest energy input was recorded in maize–potato–onion pattern (69,510 MJ/ha) followed by maize–potato–mungbean (62,660 MJ/ha) and groundnut–potato–pearlmillet fodder, (50,930 MJ/ha), whereas in existing rice–wheat cropping system total 43,900 MJ/ha energy was required. The lowest energy input was required for groundnut–*toria+gobhi sarson* (20,000 MJ/ha) followed by cotton–African sarson, which was obvious for a two-crop pattern. The highest energy inputs required for potato-based cropping system might be due to the use of costly inputs like seed, fertilizer, pesticides and irrigation. The three-crop pattern with a wheat required energy inputs next to potato-based cropping system.

Energy output of different cropping patterns

Total energy output was computed from main product and by-product of different cropping and it ranged from 3,00,400 to 5,14,600 MJ/ha (Table 3). The mean of 3 years revealed that the highest total energy output was obtained from maize–wheat–mungbean followed by maize–wheat and maize–potato–onion. The next highest energy output was obtained from maize–potato–mungbean and conventional rice–wheat cropping system. The significantly lowest energy output was obtained from cotton–*gobhi sarson* over rest of cropping systems. Wheat containing maize-based cropping pattern showed highest energy output might be due to higher by-product energy of wheat compared to other winter (*rabi*) crops. The energy output from cotton containing 3 crop patterns was lower than that of potato and wheat containing cropping pattern. Potato containing cropping pattern produced higher main product energy due to higher productivity of potato tuber com-

pared to other *rabi* crops, but it was not so high like main product yield because of higher percentage of moisture and less amount of calorie (energy) in potato tuber (Kachroo *et al.*, 2012).

Productivity of different cropping patterns

The maize–potato–onion, summer groundnut–potato–fodder pearl millet and maize–potato–summer mungbean gave 31.7, 24.3 and 22.8 t/ha rice-equivalent yield respectively, which was significantly more than most predomi-

nant rice–wheat (13.4 t/ha) system; clearly elucidated the superiority of these systems over rice–wheat system. The higher rice-equivalent yield in these cropping systems may be owing to high yield of potato and onion crops. The addition of short-duration potato between 2 crops increased system productivity. These results confirm the findings of Khaurb *et al.* (2003). The maize–wheat–summer mungbean cropping system gave 3.4 t/ha more rice-equivalent yield than maize–wheat system. The rice-equivalent yields of maize–wheat, cotton–wheat, cotton–

Table 1. Equivalents for various sources of energy

Particulars	Units	Equivalent energy (MJ)
Inputs		
Human labour	Man-hour	1.96
Diesel	Litre	56.31
Electricity	KWh	11.93
Chemical fertilizers		
N	Kg	60.60
P ₂ O ₅	Kg	11.10
K ₂ O	Kg	6.70
Farmyard manure	Kg	0.3
Chemicals (i) Superior chemicals (chemicals requiring dilution at the time of application)	Kg	120
(ii) Inferior chemicals (chemicals not requiring dilution at the time of application)	Kg	10
Seed (i) Output of crop production system and not processed	Kg	-Same as that of output of crop production system
(ii) Output of crop production system and is processed before using it for seed	Kg	- add 1.5, 1.0 and 0.5 MJ/kg for potato, groundnut and other seeds respectively to the equivalent energy of the product of crop production system
Irrigation		
(i) Man	Man-hour	1.96
(ii) Electricity	KWh	11.93
(iii) Submersible pump	HP	68.4
Each 7.5 cm Irrigation requires 10 hr/ha and Irrigation pump is of 15 hp		
Output		
Rice grain	Kg	14.7
Maize grain	Kg	14.7
Wheat grain	Kg	14.7
Maize stalk	Kg	18.0
Rice straw	Kg	12.5
Wheat straw	Kg	12.5
Potato	Kg	3.60
Onion	Kg	1.60
Mungbean	Kg	14.7
Bajra fodder	Kg	18.0
Cotton	Kg	11.8
Groundnut seed	Kg	25.0
Toria seed	Kg	25.0
African sarson	Kg	25.0
Gobhi sarson	Kg	25.0
By products		
Straw, vines etc.	Kg	12.5
Fuel wood, stalks etc.	Kg	18.0
Leaves, vines and straw from vegetables	Kg	10.0

Source: Singh and Mittal (1992)

African *sarson*, cotton–*gobhi sarson* (transplanted) sequences were statistically at par with the prevalent rice–wheat cropping system. The sole oilseed cropping system groundnut–*toria* + *gobhi sarson* excelled the rice-equivalent yield by 23.1% over rice–wheat system. To diversify rice–wheat system, several options are available which not only give more productivity than rice–wheat system but also ensure the rational use of resources and result in substantial saving of irrigation water. Gill and Ahlawat (2006) reported that in Punjab crops like soybean, maize, basmati rice, cotton and summer groundnut in rainy season are viable and remunerative alternatives to the nutrient and water exhaustive rice crop while crops like potato, Indian mustard, vegetable pea, grain pea, sunflower and onion, as regularly or intermittently, can substitute wheat.

Specific energy, energy-output efficiency and energy productivity

The average of 3 years showed that rice–wheat cropping system showed significantly highest specific energy 3.28 MJ/kg over other diversified cropping systems. The cropping system with the second highest specific energy was maize–potato–mungbean (2.80 MJ/kg). Significantly low specific energy of 1.24 MJ/kg was needed for raising the complete oilseed cropping system (groundnut–*toria*+*gobhi sarson*). Kachroo *et al.*, (2012) also reported similar findings. However, maize-based cropping system consumed specific energy in the range of 2.25–2.71 MJ/ha/day.

It was observed that maize-based cropping systems have highest energy output efficiency (1,410–1,820 MJ/

Table 2. Energy values ($\times 10^3$ MJ/ha) in various inputs in system based crop diversification

Cropping system	Human labour	Diesel	Seed	Herbicides	Irrigations	FYM	Fertilizers	Total input
Rice–wheat	1.62 (3.7)	12.54 (32.2)	1.82 (4.9)	0.41 (0.8)	8.95 (7.2)	3.00 (8.1)	15.56 (42.7)	43.90
Maize–wheat	1.52 (4.1)	11.97 (32.2)	1.82 (4.9)	0.29 (0.8)	2.68 (7.2)	3.00 (8.1)	15.89 (39.8)	37.18
Maize–wheat–mungbean	1.77 (4.1)	14.82 (34.2)	2.39 (5.5)	0.47 (1.1)	3.58 (8.3)	3.00 (6.9)	17.25 (39.8)	43.28
Maize–potato–mungbean	3.14 (5.0)	14.82 (23.7)	16.17 (25.8)	0.48 (0.8)	4.77 (7.6)	6.00 (9.6)	17.27 (27.6)	62.66
Maize–potato–onion	3.12 (4.5)	14.82 (21.3)	15.63 (22.5)	0.53 (0.8)	6.86 (9.9)	6.00 (8.6)	22.55 (32.4)	69.51
Cotton–wheat	1.77 (5.1)	11.97 (34.3)	1.74 (5.0)	0.35 (1.0)	3.28 (9.4)	3.00 (8.6)	12.83 (36.7)	34.94
Cotton–african sarson	2.27 (7.7)	9.50 (32.2)	0.32 (1.1)	0.49 (1.7)	2.68 (9.1)	3.00 (10.2)	11.27 (38.2)	29.54
Cotton– <i>gobhi sarson</i> (T)	3.06 (10.1)	9.50 (31.5)	0.25 (0.8)	0.39 (1.3)	2.68 (8.9)	3.00 (9.9)	11.27 (37.4)	30.15
Groundnut– <i>toria</i> + <i>gobhi sarson</i>	1.96 (9.8)	5.70 (28.5)	2.60 (13.0)	0.72 (3.6)	1.49 (7.5)	0.00 (-)	7.53 (37.7)	20.00
Groundnut–potato–fodder pearl millet	3.06 (6.0)	10.07 (19.8)	18.07 (35.5)	0.72 (1.4)	4.47 (8.8)	3.00 (5.9)	11.54 (22.0)	50.93

Table 3. Rice-equivalent yield (t/ha), irrigation water application and energy pattern of different cropping systems (3 years mean)

Cropping system	Rice-equivalent yield (t/ha)	Duration (days)	Irrigation water applied (cm)	Energy output ($\times 10^3$ MJ/ha)	Energy balance ($\times 10^3$ MJ/ha)	Energy-use efficiency	Specific energy (MJ/kg)	Energy output efficiency ($\times 10^3$ MJ/ha/day)	Energy productivity (kg/MJ)
Rice–wheat	13.4	270.3	224.3	370.9	370.6	8.4	3.28	1.37	0.31
Maize–wheat	13.7	253.7	73.7	461.6	461.3	12.4	2.71	1.82	0.37
Maize–wheat–mungbean	16.8	308.3	98.3	514.6	514.3	11.9	2.57	1.67	0.39
Maize–potato–mungbean	22.8	248.0	105.0	409.1	408.9	6.5	2.80	1.65	0.36
Maize–potato–onion	31.7	310.0	148.7	437.8	437.5	6.3	2.25	1.41	0.46
Cotton–wheat	13.0	359.7	77.0	331.5	331.1	9.5	2.69	0.92	0.37
Cotton–African sarson	13.0	351.3	71.0	316.9	316.6	10.7	2.30	0.90	0.44
Cotton– <i>gobhi sarson</i> (T)	12.1	345.7	66.0	300.4	300.1	10.0	2.51	0.87	0.40
Groundnut– <i>toria</i> + <i>gobhi sarson</i>	16.5	309.7	72.3	326.5	326.2	16.3	1.24	1.08	0.82
Groundnut–potato–fodder pearl millet	24.3	272.7	102.0	359.8	359.6	7.1	2.12	1.33	0.48
SEM \pm	0.72	7.88	-	6.34	6.18	0.25	0.03	0.02	0.01
CD (P=0.05)	2.23	23.95	-	18.89	18.48	0.72	0.10	0.06	0.03

ha/day); however, cotton-based cropping patterns were less efficient in energy output efficiency (790–920 MJ/ha/day) as compared to other cropping patterns.

Average maximum energy productivity was obtained in groundnut–toria + gobhi sarson (0.67 kg/MJ) might be due to its lowest total input energy requirement (20 MJ). Inclusions of vegetables in a cropping system increase the energy productivity by 34.4–75.0% as compared to rice–wheat cropping pattern. The energy-use efficiency was the highest in groundnut–toria + gobhi sarson cropping system (16.3), followed by maize–wheat cropping system (12.4); both these cropping systems recorded significantly higher energy-use efficiency over rice–wheat cropping system. Thus there is sufficient scope to replace rice–wheat cropping system with other cropping systems without any decline in economic yield rather it improved substantially. The results support the findings of Walia *et al.* (2011).

The maize–potato–onion system gave the highest productivity (32.0 t/ha) and energy ($2,329 \times 10^4$ Kcal) and used 75.6 cm less water than rice–wheat system with a productivity margin of 19.1 t/ha/annum. Maize–potato–summer mungbean cropping system gave 22.9 t/ha/annum productivity and $2,638 \times 10^4$ Kcal energy with total irrigation water used as 105 cm; thereby indicating the net saving of irrigation water to the extent of 119.3 cm (Table 3). The summer groundnut–potato–pearlmillet (fodder) system gave 24.7 t/ha productivity with 102 cm irrigation water leading to 122.3 cm saving of water.

Based on this study, it can be concluded that the con-

ventional rice–wheat cropping system which is less energy productive can be replaced with groundnut–toria+gobhi sarson and maize–potato–onion cropping patterns, which may be competent to produce more profit per unit cost of cultivation under irrigated conditions of Punjab.

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