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# Energy auditing of diversified rice–wheat cropping systems in Indo-gangetic plains

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## ABSTRACT

The field investigations were carried out for energy use analysis in terms of different input requirements and outputs harvested under the diversified rice–wheat cropping systems at the research farm of Project Directorate for Cropping Systems Research, Modipuram, Meerut, India during the year 2000–2004. The experiments were conducted on rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L. emend. Fiori and Paol) system involving 8 sequences using diversification, furrow irrigated raised bed system (FIRB) of sowing wheat, use of summer period for deep ploughing or raising legume crops for seed or green manure to study the energy dynamics of different diversified cropping systems. Results revealed that total energy use was highest in rice–potato–wheat (i.e. 77,601 MJ/ha in flat bed & 75,697 MJ/ha in raised bed) followed by rice–wheat–sesbania (i.e. 48,770 MJ/ha in flat & 47,830 MJ/ha in raised bed) and rice–wheat–greengram (i.e. 48,414 MJ/ha in flat & 47,482 MJ/ha in raised bed). In overall, the raised bed sowing of wheat in the cropping system consumed 6–11% less fertilizer energy than flat bed while saved up to 4.2% energy through irrigation. The total output energy of the system was recorded significantly higher in rice–potato–wheat system (i.e. 222,836 MJ/ha in flat bed & 218,065 MJ/ha in raised bed) in comparison to rice–wheat–greengram (i.e. 177,477 MJ/ha in flat bed & 175,125 MJ/ha in raised bed), rice–wheat–sesbania (i.e. 172,000 MJ/ha in flat bed & 168,919 MJ/ha in raised bed) and rice–wheat system (i.e. 156,085 MJ/ha in flat bed & 151,862 MJ/ha in raised bed). The significantly higher net return of energy was obtained in rice–potato–wheat system as compared to other systems. This system required about 75% more input energy but provided about 42% more output energy compared to conventional rice–wheat system. About 10% higher output energy was obtained through growing greengram in summer for grain and foliage incorporation while 14% gain obtained by green manuring sesbania, when compared to deep summer ploughing after wheat harvest.

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## 1. Introduction

Rice (*Oryza sativa* L.) – wheat (*Triticum aestivum* L. emend. Fiori and Paol) is the major cropping system in Indo-gangetic plains in India covering about 9.64 M ha area, which contributes about 32 percent to the national food basket [8]. In fact, rice and wheat are the major source of food, income and employment for millions of producers, traders and consumers. Therefore, their sustained high productivity is inevitable for national food security. In recent years, the rice–wheat system has started suffering a production fatigue, over mining of nutrients, decline in factor productivity, reduction in soil profitability, lowering of ground water table and build-up of pests including weeds, diseases and insects causing concern of sustainability. The scientific management of diversified rice–wheat

systems is considered answer to these problems [9]. But, diversified systems require increased use of energy input. The energy–agriculture relationship is becoming more and more important with the intensification of the cropping systems in resource scarce situations. The use of the energy resources has increased markedly with the advancement in the technology and general agricultural developments. Traditional, low energy farming is being replaced by modern systems, which require more energy use [3,5]. The energy is invested in various forms such as mechanical (farm machines, human labour, animal draft), chemical fertilizer, pesticides, herbicides, electrical, etc. Sufficient availability of the right energy and its effective and efficient use are prerequisites for improved agricultural production [16]. In the developed countries, increase in the crop yields was mainly due to increase in the commercial energy inputs in addition to improved crop varieties [7]. However, in developing countries, the primary objectives of mechanizing crop production are to reduce human drudgery and to raise the output of farm by either increasing the crop yield or increasing the area under

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cultivation. This can only be done by supplementing the traditional energy input i.e. human labour with substantial investments in farm machinery, irrigation equipment, fertilizers, soil and water conservation practices, weed management practices, etc. These inputs and methods represent various energies that need to be evaluated so as to ascertain their effectiveness and to know how to conserve them. Energy budgeting, therefore, is necessary for efficient management of scarce resources for improved agricultural production. It would identify production practices that are economical and effective. The information on energy use in different cropping systems is not available in the area of study. Therefore, in order to identify energy efficient cropping systems and for satisfactory energy output and net return, the present study has been undertaken (Fig. 1).

## 2. Materials and methods

### 2.1. Site and climate

The field experiments were carried out at the research farm of the Project Directorate for Cropping Systems Research, Modipuram, Meerut, India during year 2000–01 to 2003–04. The site was located at 29.40° N latitude, 77.4° E longitude and at 237 m above mean sea level, and categorized in hot-dry semi-arid subtropical

climate with hot summers and cold winters. The mean annual rainfall of the site was about 750 mm and evapo-transpiration 1540 mm. The soil was sandy loam consisting of 64, 19 and 17 percent sand, silt and clay, respectively.

### 2.2. Experimental details

The field experiment was carried out to estimate the input; output energy use and net return energy of the different existing cropping systems. The 8 sequential treatment involved were rice–wheat (FB)–fallow (conventional), rice–wheat (FIRB)–fallow, rice–potato–wheat (FB), rice–potato–wheat (FIRB), rice–wheat (FB)–greengram (Grain + residue incorporation), rice–wheat (FIRB)–greengram (grain + residue incorporation), rice–wheat (FB)–sesbania green manure, rice–wheat (FIRB)–sesbania green manure, rice–wheat (FB)–deep summer ploughing and rice–wheat (FIRB)–deep summer ploughing were statistically analyzed in randomized block design (RBD) with three replications. The net plot size was 30 m<sup>2</sup>. For rice in *kharif*, all plots were harrowed twice and tilled once with tiller. Thereafter, water was flooded to about 10–15 cm depth for 24 h for the puddling in all treatments. The field was prepared for wheat crop with four harrowing, planking & leveling for flat bed method of sowing. In case of raised bed plots, one extra tilling was required for well-pulverized soil. Subsequently, raised bed planter was used for

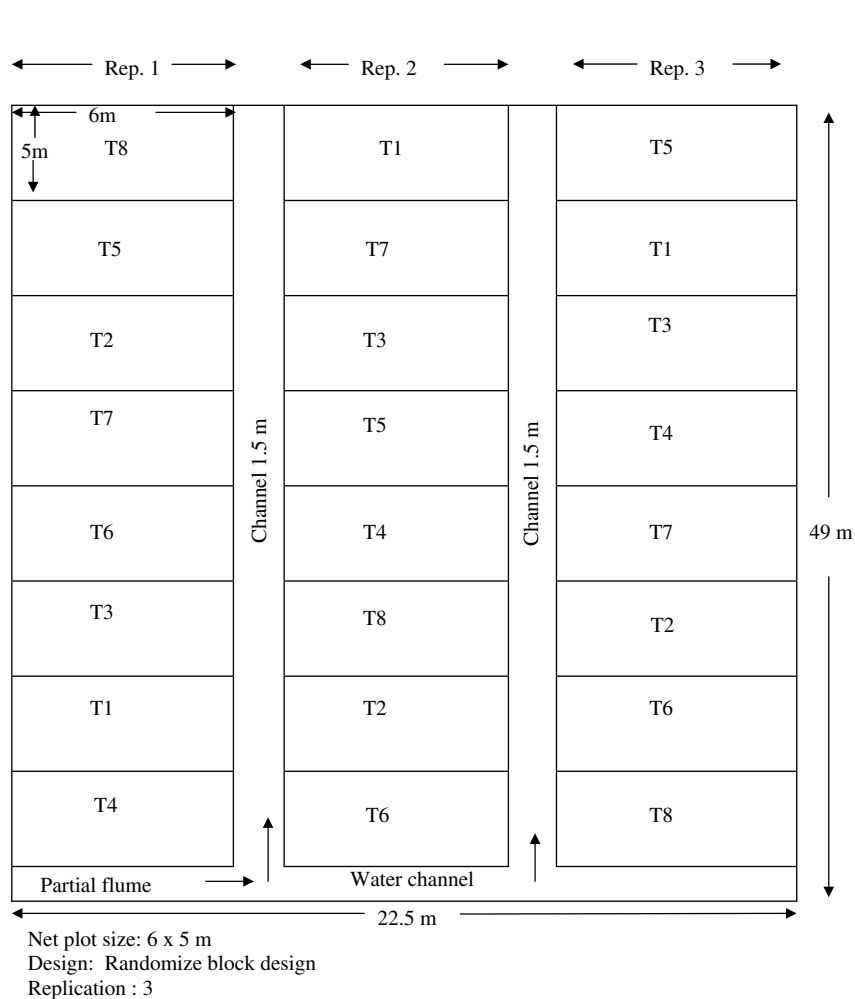


Fig. 1. Layout plan of experiments.

making raised bed and simultaneous sowing. Similarly, the field was also prepared for potato (*Solanum tuberosum*) planting. In conventional system field remained vacant during summer while in improved diversified systems deep ploughing was done with a tractor drawn vertical disc plough after wheat harvest during summer. The greengram [*Phasolus radiatus* (L) and sesbania (*Sesbania aculeate*) were grown as per treatment. The greengram residue was incorporated after two pickings of pods and sesbania grown for green manuring in rice–wheat system were incorporated in soil by harrowing twice after 54 days of sowing. The variety Saket-4 of rice, PBW-343 of wheat for normal sown condition, most suited PBW-226 of wheat for late sown condition (in treatment CS-2: & CS-3 only), Kufri Bahar of potato, K-851 of greengram and PDCSR-1 of Sesbania were used. All these crops were raised following standard package of practices.

### 2.3. Method of energy calculation

#### 2.3.1. Evaluation of manual energy input

Manual energy ( $E_m$ ) was determined using the following formula [20]:

$$E_m = 1.96N_mT_m\text{MJ}$$

Where,  $N_m$  = Number of labour spent on a farm activity;  
 $T_m$  = Useful time spent by a labour on a farm activity, h.

The energy coefficients used in the calculations are presented in Table 1. The total manual labour was recorded in each operation with working hours, which was converted in man-hour. All other factors affecting manual energy were neglected.

#### 2.3.2. Evaluation of mechanical energy use

Mechanical energy input was evaluated by quantifying the amount of diesel fuel consumed during the tillage, sowing, threshing and winnowing as prescribed methodology [20]. The total time spent was also recorded. Diesel consumption in pump was also recorded during irrigation. Hence, for every farm operation, the diesel fuel energy input was determined by:

$$E_f = 56.31D\text{ MJ}$$

Where, 56.31 = unit energy value of diesel,  $\text{MJ L}^{-1}$ ;  $D$  = amount of diesel consumed, L.

**Table 1**  
Energy conversion factors as adopted/advised.

Particulars	Units	Equivalent energy (MJ)
Human power		
Adults man	Man-hour	1.96
Woman	Woman-hour	1.57
Tractor	hour	332.0
Diesel	L	56.31
Chemical fertilizers		
Nitrogen (N)	kg	60.60
Phosphorus (P)	kg	11.10
Potash (K)	kg	6.70
Plant protection		
Superior chemical (Granular)	kg	120
Inferior chemical	kg	10
Liquid chemical	ml	0.102
Farm yard manure (FYM)	kg (dry mass)	0.30
Crop produce (grain)		
Rice	kg	14.70
Wheat	kg	15.70
Potato	kg	4.07
Greengram	kg	13.96

Source: [1,10].

#### 2.3.3. Other inputs energy

The other inputs used for different operations under different crop sequences and outputs obtained in terms of yield were used for calculating energy use in systems. The different field operations performed for completion of each activity in the experiment were measured in terms of time consumption for human/machinery, fuel consumption for the different operations and expressed as energy input in mega joules (MJ) using corresponding constants as detailed in Table 1. The farm production (i.e. grain yield) was also converted in terms of energy (MJ) output using three year average yield under different crops of selected sequences and units of energy as available [10]. The direct energy use was calculated for all field operation wise, namely, (i) land preparation (ii) puddling (iii) nursery raising & transplanting (iv) sowing/planting (v) Interculture/weeding (vi) crop management (vii) harvesting and threshing. The energy use inputs were also calculated based on input wise given source during crop period, namely, (i) seed (ii) chemical fertilizers (iii) Insecticides/pesticides/herbicides (iv) diesel (v) human labours, etc.

### 2.4. Statistical analysis

The net return and output energy data were subjected to analysis of variance as per the standard procedure [11] and treatment means were compared using critical difference (CD) defined as least significant difference beyond which all the treatment differences are statistically significant as  $CD = (\sqrt{2VE^{r-1}})t_{5\%}$  where VE is the error variance,  $r$  the number of replications of the factor for which CD is calculated  $t_{5\%}$  the table value of  $t$  at 5% level of significance at error degree of freedom.

## 3. Results and discussion

### 3.1. Operation-wise input energy utilization pattern

Farm operation-wise energy usage for rice based cropping systems is shown in Table 2. The highest amount of energy was required in the crop management operation in all the systems, which varied from 61% to 66% followed by land preparation ranged from 12% to 19%. The sowing/planting consumed 5–8% energy except in potato crop where 17–19% energy was consumed while 5–9% energy was used in harvesting & threshing operations. The intercultural/weeding used very less energy (about 1%) of the total input energy in the systems. In case of rice crop where energy input in puddling recorded from 4% to 7% whereas in nursery raising & transplanting operations it varied from 2% to 3%. The raised bed system of raising wheat saved energy use in irrigation (about 1.5–4.15%) in comparison to flat bed system of cropping. The green manuring crop used about 11–12% input energy.

The crop management operations used highest amount of input energy in all the systems which varied from 26,721 MJ/ha in rice–wheat (raised bed) to 48,792 MJ/ha in rice–potato–wheat (flat bed) cropping system followed by land preparation ranging from 7652 MJ/ha in rice–wheat–sesbania (flat) to 9598 MJ/ha in rice–potato–wheat (flat). In sowing/planting, the energy use varied from 2365 MJ/ha in rice–wheat (flat bed) to 3681 MJ/ha in rice–wheat (raised bed)–sesbania, while it varied from 3031 MJ/ha to 4414 MJ/ha in harvesting & threshing and 2878 MJ/ha in puddling operation. However, in the rice–potato–wheat system, energy use in sowing/planting varied from 13,578 MJ/ha to 14,254 MJ/ha which stands second in rank after the crop management. It was due to more energy consumed in the form of potato seed. The higher input energy used in crop management was due to the higher energy consumed in irrigation and chemical fertilizers.

Comparison among the cropping systems in different operations shows that in case of land preparation, the maximum energy was

**Table 2**  
Operation-wise input energy use in different cropping systems (MJ/ha).

Treatments	Land preparation				Nursery raising & transplanting	Sowing/ planting	Interculture/ weeding	Crop management	Harvesting/ threshing
	Summer ploughing	Seedbed preparation	Puddling	Total					
CS-0: Rice–wheat (FB)–fallow	1423	3955	2878	8256	1347	2365	549	28,733	3031
CS-1: Rice–wheat (FIRB)–Summer ploughing	1423	4438	2878	8739	1347	3040	470	26,721	3031
CS-2: Rice–potato–wheat (FB)–Summer ploughing	1423	5297	2878	9598	1347	13,578	706	48,792	3579
CS-3: Rice–potato–wheat (FIRB)–Summer ploughing	1423	5273	2878	9575	1347	14,254	627	46,314	3579
CS-4: Rice–wheat (FB)–greengram	0	4999	2878	7878	1347	2659	706	31,931	3893
CS-5: Rice–wheat (FIRB)–greengram	0	5483	2878	8361	1347	3335	627	29,919	3893
CS-6: Rice–wheat (FB)–sesbania	0	4774	2878	7652	1347	3005	549	31,803	4413
CS-7: Rice–wheat (FIRB)–sesbania	0	5257	2878	8136	1347	3681	470	29,791	4413

FB – flat bed and FIRB – furrow irrigated raised bed.

recorded in rice–potato–wheat (flat bed) i.e. 9598 MJ/ha and was lowest in rice–wheat (flat bed)–sesbania i.e. 7652 MJ/ha. In threshing and harvesting, the maximum energy use was 4414 MJ/ha in rice–wheat–sesbania followed by rice–wheat–greengram (3893 MJ/ha), rice–potato–wheat (3580 MJ/ha) and rice–wheat (3031 MJ/ha). This was because of the diesel consumed in machinery for green manuring operation in rice–wheat–sesbania system. The puddling and nursery raising & transplanting were accomplished in all cropping system for rice crop only, which consumed 2878 MJ/ha in puddling and 1347 MJ/ha in nursery raising & transplanting respectively. The interculture/weeding operation consumed less amount of energy use which varied from 470 MJ/ha to 706 MJ/ha only. The energetic of mechanized crop production system consumed less input energy. This is in agreement with results [13].

The deep ploughing performed during summer in rice–potato–wheat and rice–wheat systems consumed input energy of 1423 MJ/ha. However, 5557 MJ/ha and 5913 MJ/ha energy used as inputs in greengram (grain + crop residue use) and sesbania, respectively. The total input energy use was 48,259 MJ/ha (flat bed), 47,328 MJ/ha (raised bed) and 48,743 MJ/ha (flat bed), 47,812 MJ/ha (raised bed) in rice–wheat–greengram and rice–wheat–sesbania, respectively.

### 3.2. Source-wise energy utilization pattern

The total input energy of system was slightly higher (i.e. 1.91–2.46%) in flat bed than raised bed sowing of wheat in all cropping systems (Table 3). The input energy saving in raised bed was due to saving virtual water through irrigation and fertilizer energy. It was mainly due to less area in contact with irrigation water in furrow irrigated raised bed (FIRB) crop system which leads the less consumption of fertilizer. The amount of water consumed in production process of a product is called the “virtual water” as not contained anymore in the product. The second largest share of input energy was through energy used for irrigation of crops (21–31%). The saving of irrigation water was 4.5% in raised bed than flat bed crops. As per literature 1 kg of wheat production requires about 1654 L of water [19]. Therefore, as per saving of 4.5% in present investigation around 75 L of water/kg grain could be saved in terms of virtual water which is the main issue in country like India. The total energy use was recorded maximum in rice–potato–wheat (i.e. 77,601 MJ/ha in flat bed & 75,697 MJ/ha in raised bed) followed by rice–wheat–sesbania (i.e. 48,770 MJ/ha in flat & 47,830 MJ/ha in raised bed), rice–wheat–greengram (i.e. 48,414 in flat & 47,482 MJ/ha in raised bed) and rice–wheat (i.e. 44,280 MJ/ha in flat bed & 43,349 MJ/ha in raised bed). The total input energy use was higher due to the inclusion of potato crop in the rice–wheat cropping system which has taken about 45–46% higher energy of the total energy in the systems whereas in rice and wheat it varied from 34%

to 35% and 19% to 21% (Table 4). However, in case of rice–wheat cropping system, the rice consumed about 59–61% energy while wheat consumed only 39–41% energy of the total system input energy. This result is agreement with [15,18]. Further, it was revealed that the maximum energy use was consumed in terms of chemical fertilizers followed by diesel for irrigation, diesel for machinery, human labour and seed in all cropping systems except in rice–potato–wheat system wherein energy use in terms of seed occupied third rank instead of diesel for machinery and other inputs shown same trend as above. The fertilizer consumed from 33% to 38% of the total input energy followed by diesel used in irrigation (21–31%), diesel for machinery (15–24%), human and seed both (5–8%) except in seed (16%) in rice–potato–wheat system and pesticide/insecticide (1–2%). The trends are other workers in agreement with [12,17]. The energy use was recorded highest in chemical fertilizer for rice–potato–wheat (i.e. 28,744 MJ/ha in flat bed and 26,926 MJ/ha in raised bed) followed by rice–wheat–greengram and rice–wheat–sesbania (i.e. same in both system 18,068 MJ/ha in flat and 16,250 MJ/ha in raised bed) and rice–wheat (i.e. 16,412 MJ/ha in flat bed and 14,594 MJ/ha in raised bed) [6]. It was, further, seen from Table 3 that the raised bed cropping system consumed less fertilizer energy, which varied 6–11% than flat bed in all the systems. Another issue is leaching of NO<sub>3</sub> due to fertilizer application. The NO<sub>3</sub> leaching was more in the flat bed crops so that fertilizer requirement was more. The raised bed sowing of wheat in the cropping system consumed 6–11% less fertilizer energy than flat bed. It was due to less contact area during furrow irrigation system that had less chance to leach as NO<sub>3</sub> in to the ground water. However, it was also seen in sandy loam soil, there is study beyond 2.20 m leach of NO<sub>3</sub> was almost negligible if fertilizer was applied up to 80 kg/ha [14]. In our field condition, the ground water table was about 10 m and also sandy loam soil; there is no chance to reach the nitrate to pollute the ground water. Moreover, the less fertilizer was required in raised bed crops and also it was applied in three split during the crops.

The diesel consumed for irrigation of crops was highest in rice–potato–wheat (i.e. 16,274 MJ/ha in flat bed and 15,598 MJ/ha in raised bed) followed by rice–wheat–greengram and rice–wheat–sesbania (same in both system 14,810 MJ/ha in flat bed and 14,584 MJ/ha in raised bed) and rice–wheat system (i.e. 13,458 MJ/ha in flat and 13,233 MJ/ha in raised bed). The trend was in agreement with other workers [2,4]. However, the raised bed system saved energy use in irrigation about 1.5 percent to 4.15 percent in comparison to flat bed in all cropping systems. The diesel used in machinery purpose was recorded higher in rice–potato–wheat (i.e. 11,994 MJ/ha in raised bed and 11,318 MJ/ha in flat bed) in comparison to rice–wheat–sesbania (i.e. 10,924 MJ/ha in raised bed and 9742 MJ/ha in flat bed) and rice–wheat system (i.e. 10,192 MJ/ha in raised and 9010 MJ/ha in flat bed). This was possibly due to



**Table 3**

Level and pattern of energy use in different crops and cropping systems (MJ/ha).

Energy Source	Rice–wheat			Rice–potato–wheat				Rice–wheat–greengram				Rice–wheat–sesbania			
	Rice	Wheat	Total	Rice	Potato	Wheat	Total	Rice	Wheat	Greengram	Total	Rice	Wheat	Sesbania	Total
<i>Flat bed grown wheat</i>															
Seed	441	1570	2011	441	10,138	1570	12,149	441	1570	279	2290	441	1570	625	2636
FYM	0	0	0	0	4500	0	4500	0	0	0	0	0	0	0	0
Fertilizers	8206	8206	16,412	8206	12,332	8206	28,744	8206	8206	1656	18,068	8206	8206	1656	18,068
Pesticides/insecticide	383	248	630	383	255	248	885	383	248	128	758	383	248	0	630
Diesel (irrigation)	10,079	3379	13,458	10,079	2816	3379	16,274	10,079	3379	1351	14,810	10,079	3379	1351	14,810
Diesel (machinery)	5349	3660	9010	5349	3829	2140	11,318	3942	3660	1014	8615	3942	3660	2140	9742
Human labour	1882	878	2760	1882	972	878	3732	1866	878	1129	3873	1866	878	141	2885
Total Energy	26,340	17,940	44,280	26,340	34,841	16,420	77,601	24,917	17,940	5557	48,414	24,917	17,940	5913	48,770
<i>Furrow irrigated raised bed grown wheat</i>															
Seed	441	1570	2011	441	10,138	1570	12,149	441	1570	279	2290	441	1570	625	2636
FYM	0	0	0	0	4500	0	4500	0	0	0	0	0	0	0	0
Fertilizers	8206	6388	14,594	8206	12,332	6388	26,926	8206	6388	1656	16,250	8206	6388	1656	16,250
Pesticides/insecticide	383	248	630	383	255	248	885	383	248	128	758	383	248	0	630
Diesel (irrigation)	10,079	3153	13,233	10,079	2816	2703	15,598	10,079	3153	1351	14,584	10,079	3153	1351	14,584
Diesel (machinery)	5349	4843	10,192	5349	3829	2816	11,994	3942	4843	1014	9798	3942	4843	2140	10,924
Human labour	1882	808	2689	1882	972	792	3646	1866	808	1129	3802	1866	808	141	2815
Total Energy	26,340	17,009	43,349	26,340	34,841	14,516	75,697	24,917	17,009	5557	47,482	24,917	17,009	5913	47,839

machinery use in preparation of raised bed and it also required well-pulverized seedbed as compared to flat bed method of sowing. In case of energy use in human labours, the maximum energy use was in rice–wheat–greengram (i.e. 3873 MJ/ha in flat bed and 3802 MJ/ha in raised bed) followed by rice–potato–wheat (i.e. 3732 MJ/ha in flat and 3646 MJ/ha in raised bed), rice–wheat–sesbania (i.e. 2885 MJ/ha in flat and 2815 MJ/ha in raised bed) and rice–wheat (i.e. 2760 MJ/ha in flat and 2689 MJ/ha in raised bed). More energy in rice–wheat–greengram system was consumed because of the human labours used in two pickings of greengram pods and threshing. The energy used in seed was higher in rice–potato–wheat (i.e. 12,149 MJ/ha in both case as flat and raised bed), possibly because of more seed used in potato crop than other crop (varied from 2011 to 2636 MJ/ha) in the systems. It was due to higher energy use in terms of potato seed. This is in agreement with other results [12].

### 3.3. Energy production (output) pattern

The total output energy of the system was recorded significantly higher in rice–potato–wheat system (i.e. 222,836 MJ/ha in flat bed wheat & 218,065 MJ/ha in raised bed wheat) in comparison to rice–wheat–greengram (i.e. 177,477 MJ/ha in flat bed wheat &

175,125 MJ/ha in raised bed wheat), rice–wheat–sesbania (i.e. 172,000 MJ/ha in flat bed wheat & 168,919 MJ/ha in raised bed wheat) and rice–wheat system (i.e. 156,085 MJ/ha in flat bed wheat & 151,862 MJ/ha in raised bed wheat) as detailed in Table 4.

The net return energy was significantly higher in rice–potato–wheat system (i.e. 145,235 MJ/ha in flat bed wheat & 142,368 MJ/ha in raised bed wheat) in comparison to other systems such as rice–wheat–greengram (i.e. 129,063 MJ/ha in flat bed wheat & 127,642 MJ/ha in raised bed wheat), rice–wheat–sesbania (i.e. 123,230 MJ/ha in flat bed wheat & 121,080 MJ/ha in raised bed wheat) and rice–wheat (i.e. 111,805 MJ/ha in flat bed wheat & 108,519,921 MJ/ha in raised bed wheat). The rice–wheat system gained significantly lower net return energy than other cropping systems (Table 5). The higher output–input energy difference was possibly because of potato crop in the system, which contributed about 36% of the total output energy followed by wheat (29%) and rice (34%) in both flat and raised bed grown wheat in cropping systems. Rice and wheat in rice–wheat system contributed about 48% and 51% of the total output energy respectively. However, the dual purpose greengram grown for grain + residue and sesbania for the purpose of the green manuring contributed about 2% energy. The output–input ratio was found more or less same in rice–wheat, rice–wheat–greengram, rice–wheat–sesbania (i.e. 3.4–3.5)

**Table 4**

Input energy, output energy and net energy return of different crops (MJ/ha).

Type of energy	Rice–wheat		Rice–potato–wheat			Rice–wheat–greengram			Rice–wheat–sesbania		
	Rice	Wheat	Rice	Potato	Wheat	Rice	Wheat	Greengram	Rice	Wheat	Sesbania
<i>Flat bed grown wheat</i>											
Input energy	26,340	17,940	26,340	34,841	16,420	24,917	17,940	5557	24,917	17,940	5913
	(59)	(41)	(34)	(45)	(21)	(52)	(37)	(11)	(51)	(37)	(12)
Output energy	74,959	81,125	75,499	83,761	63,576	81,575	92,272	3630	79,292	92,709	0
	(48)	(52)	(34)	(37)	(29)	(46)	(52)	(2)	(46)	(54)	(0)
Output–input ratio	2.7	4.6	2.7	2.4	3.7	3.1	4.9	0.7	3.1	4.9	0.0
Net energy return	48,619	63,185	49,159	48,920	47,156	56,658	74,332	–1927	54,375	74,769	–5913
<i>Furrow irrigated raised bed grown wheat</i>											
Input energy	26,340	17,009	26,340	34,841	14,516	24,917	17,009	5557	24,917	17,009	5913
	(61)	(39)	(35)	(46)	(19)	(52)	(36)	(12)	(52)	(36)	(12)
Output energy	74,740	77,123	77,039	79,202	61,823	83,271	88,225	3630	79,228	89,691	0
	(49)	(51)	(35)	(36)	(29)	(48)	(50)	(2)	(47)	(53)	(0)
Output–input ratio	2.8	4.6	2.7	2.3	4.1	3.1	5.1	0.7	3.1	5.2	0.0
Net energy return	48,400	60,114	50,699	44,361	47,307	58,354	71,216	–1927	54,311	72,682	–5913

Values in parenthesis show the percentage of crop energy of total system energy.

**Table 5**

Input and output and net return energy of different cropping systems (MJ/ha).

Cropping System	Input energy	Output energy	Input–output ratio	Net energy return
CS-0: Rice–wheat (FB)–fallow	44,280	156,085	3.5	111,805
CS-1: Rice–wheat (FIRB)–Summer ploughing	43,349	151,862	3.5	108,513
CS-2: Rice–potato–wheat (FB)–Summer ploughing	77,601	222,836	2.8	145,235
CS-3: Rice–potato–wheat (FIRB)–Summer ploughing	75,697	218,065	2.8	142,368
CS-4: Rice–wheat (FB)–greengram	48,414	177,477	3.5	129,063
CS-5: Rice–wheat (FIRB)–greengram	47,482	175,125	3.5	127,642
CS-6: Rice–wheat (FB)–sesbania	48,770	172,000	3.4	123,230
CS-7: Rice–wheat (FIRB)–sesbania	47,839	168,919	3.5	121,080
SEm±	10,977	9059	–	11,556
CD at 5%	23,542	19,430	–	24,785

compared to rice–potato–wheat (2.8). Numerically, maximum net return energy was obtained in rice–potato–wheat system than other systems. It means that about 42 percent higher output energy was gained in rice–potato–wheat system than rice–wheat system with inclusion of potato in the system.

It revealed from Table 5 that total output energy obtained in rice–wheat system after green manuring were 177,477–175,125 MJ/ha and 168,919–172,000 MJ/ha through inclusion by greengram (dual purpose) and sesbania, whereas, in rice–wheat system after deep summer ploughing it was 151,862–156,085 MJ/ha. So, it is clear that about 10% and 14% higher output energy was obtained after green manuring by greengram after due pickings and sesbania, respectively, as compared to deep ploughing in rice–wheat system.

#### 4. Conclusions

It may be concluded that the energy use efficiency of cropping systems can be quantified and stratified for optimization of net energy gains in production systems. The total input energy of system was slightly higher (i.e. 1.91–2.46%) in flat bed than raised bed sowing of wheat in all cropping system. But, the raised bed cropping system followed for growing wheat in cropping systems consumed less fertilizer energy, which varied 6–11% than flat bed in all the systems. The raised bed system saved energy use in irrigation about 1.5–4.15% in comparison to flat bed in all cropping systems. In present investigation, rice–potato–wheat system was found to be high input use (about 75%) system, which produced about 42% higher output energy than rice–wheat system with inclusion of potato in the system. The rice–wheat system with inclusion of green manuring crops (i.e. greengram and sesbania) produced about 10 and 14% higher output energy than rice–wheat summer ploughing system.

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