Energy Budgeting of Sustainable Rice Based Cropping Systems in Sub Tropical India

Article *in* Ama, Agricultural Mechanization in Asia, Africa & Latin America · November 2014

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Energy Budgeting of Sustainable Rice Based Cropping Systems in Sub Tropical India

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Abstract

The field investigations were carried out for energy dynamics in terms of various input used and outputs harvested under rice (*Oryza satva L.*) based cropping systems at the research farm of Project Directorate for Farming Systems Research, Modipuram, Meerut, India during 2003 to 2007. The experiments were conducted with five rice planting methods, viz. direct seeding; 1) dry bed, drum seeding 2) wet bed, mechanical transplanting 3) puddled, mechanical transplanting 4) unpuddled and manual transplanting 5) puddled and three cropping systems involving rice (*Oryza satva L.*)-wheat (*Triticum aestivum L. emend. Fiori. Paol.*), rice-chickpea (*Cicer arietinum L.*) and rice-mustard (*Brassica Juncia L. czernj & coss.*) crops in randomized block design replicated three times. The results revealed that the input energy consumed was 40, 27, 14 and 7.7 percent in fertilizer, diesel fuel for irrigation, machineries, and labour of total energy used, respectively, for crop production in rice-wheat system. The comparison of different cropping systems shows that rice-chickpea consumed least input energy (i.e. 30,698 to 35,046 MJ/ha) followed by rice-mustard (varied from 36,195 to 40,543 MJ/ha) and rice-wheat (varied from 39,984 to 44,332 MJ/ha). System wise energy analysis indicated that the highest input energy (44,332 MJ/ha) was consumed in manually transplanted (puddled) followed by mechanically transplanted-puddled (43,686 MJ/ha) while lowest was mechanically transplanted-unpuddled (39,984 MJ/ha), direct seeded-dry bed (42,027 MJ/ha) and drum seeded-wet bed (42,197 MJ/ha) in rice-wheat system. The output energy was highest in drum seeded (212,798 MJ/ha) closely followed by direct seeded (211,350 MJ/ha) and lowest was manually transplanted in puddled (193,916 MJ/ha) which is statistically at par. The net return energy of the system was found to be high in drum seeded (170,595 MJ/ha) followed by direct seeded (169,271 MJ/ha) and lowest was in manually transplanted in puddled (149,390 MJ/ha) which were non-significant. The direct and drum seeded required about 5 percent less input energy and gave 8 to 9 percent higher output energy as compared to manually transplanted in puddled field. Whereas, in case of mechanically transplanted (unpuddled), it required 10 percent less input energy and provided 6 percent higher output energy, however, in puddled condition mechanically transplanted required 1.5 percent less input energy and gave 3 percent higher output energy as compared to manually transplanted (puddled). Similar pattern of energy dynamics were also found in rice-chickpea and rice-mustard systems.

Keywords: Energy input, output and net return energy, MTR energy, rice based cropping systems

Introduction

There has always been a close connection between energy and agriculture. In the past three decades it has been seen that the dependency of agriculture on energy has increased particularly for fossil fuels. Efficient energy use is important for sustainable agricultural production as it reduces pollution and improves financial viability. Due to increase in population and longevity of life combined with limited supply of arable land, there has been a rise in energy inputs to maximize yields (Stout, 1990). Agriculture has a dual role to play that is both as a supplier and user of energy. Agriculture has key role to play in mitigating climate change by substituting bio-energy for fossil fuels (Omar, 2003; Venturi and Venturi, 2003). The energy in agricultural production is invested in various forms like mechanical, chemical fertilizers, pesticides, and herbicides and electrical (Chaudhary *et al.*, 2009). The amount of energy used in agricultural production, processing and distribution needs to be adequate in order to feed the rising population and to meet other social and economic goals. Sufficiency in energy and its effective and efficient use are prerequisites for improved agricultural production. It has been seen that crop yields and food supplies are directly linked to energy (Singh *et al*., 2007). In developed countries, rise in crop yields were mainly attributed to rise in use of improved commercial energy inputs in addition to improved crop varieties (Lal *et al*., 2003). Effective energy use in agriculture is one of the conditions for sustainable agricultural production (Chaudhary *et al*., 2008), since it provides financial savings, fossil fuels preservation and air pollution reduction.

Agriculture uses large quantities of locally available non-commercial energy and commercial energy (Chaudhary *et al*., 2006a). Efficient use of different energy forms helps to achieve increased production, productivity, profitability and competitiveness of agriculture sustainability in rural living (Chaudhary *et al*., 2006b). Energy input-output relationships in cropping systems vary with crops being grown in sequence, by type of soils, nature of tillage operations for seedbed preparation, nature and amount of organic manure, chemical fertilizer, plant protection measures, harvesting and threshing operations and finally, the yield levels (Chaudhary *et al*., 2009; Lal *et al*., 2003; Chaudhary *et al*., 2006a).

Lack of sufficient oil and the high price of oil products have forced some countries to be more and more energy efficient in all sectors, therefore, there is a need for the developing countries to invest on research for sustainable agriculture growth and proper energy use in developing countries , particularly in India. The vast experience in India shows rapid increase in production and productivity in agriculture due to the introduction of high yielding varieties seeds (HYV), use of fertilizers, use of energy intensive production, etc. The amount of energy used in agricultural production, processing and distribution would be significantly high in order to feed the expanding population and to meet other social and economic goals. Sufficient availability of the right energy at right time, its effective and efficient use is prerequisites for improved agricultural production. The increases in yields per hectare in the developed countries were as a result of commercial energy inputs, in addition to improved varieties (Faidley, 1992). The methodology to quantify energy consumption in agricultural production has been done by numerous studies by different researchers (Bridges and Smith 1979; Heslop and Bilanski 1989; Swanton *et al*. 1996; Vinten-Johansen *et al*. 1990; Zentner *et al*., 1984). The irrigation consumed the maximum energy in the all farm operations for both paddy (81.9 %) and wheat (31.08 %) crops. The energy need for raising crop depends upon variety of factors out of which technology level and agro climatic factors are most important (Mittal *et al*., 1992). It was suggested that steps should be initiated to rationalize the use of various forms of energy in wheat production so as to improve the efficiency of marginal, small and medium farms (Singh *et al*., 2007).

The primary objectives of mechanization of crop production were to increase the yield or area under production. These cannot be done with the traditional energy input that is labour but it can be achieved by farm machinery, irrigation equipment, fertilizers, soil and water conservation practices, weed management practices, etc (Chaudhary *et al*., 2008; Chaudhary *et al*., 2006b). These inputs need enormous energy and there is a need to conserve it. Therefore, there is a need to go for energy analysis which will tell us whether production practices are economically viable and effective. Further energy analysis which will helps to make sound management and policy decision and also for conservation.

With the aim of increasing production, the energy-agriculture relationship is becoming more and more important, as it is only source to increasing the productivity and further solving the problems of food security. It has been that rice and wheat has started showing signs of production stagnation and decline in productivity. Further, the traditional method of low energy farming is being replaced by modern high input is one of the concerns and reasons for stagnation. The present paper aims to analyse the energy relationship with rice production.

The objective of study is to analyze the energy of different rice establishment methods and to compare energetic of three rice based cropping systems. The attempt is made to audit energy input, output and return energy of three rice based cropping systems data obtained from farm studies under tillage managements in rice crop. The information on energy utilization in different rice-based cropping systems is not readily available. Therefore, in order to identify energy efficient rice based cropping systems and for satisfactory energy output, the present study has been undertaken.

Materials and Methods

Location, Climate and Soil

The study has undertaken at Project Directorate for Farming Systems Research, Modipuram, Meerut, U.P. India for a period of 2003-04 to 2006-07. It is situated at 29º 4′ N latitude and 77º 46′ E longitude at an elevation of 237 m above mean sea level and soil was sandy loam in nature with semi-arid subtropical climate.

Experimental Detail

The tillage treatments for kharif (rainy or mansoon season-June-September) crop included in the experiments were:

T_1 = Direct seeding (2 harrow + 2 cultivator + 2 planking): dry bed

T_2 = Drum seeding (2 harrow + 2 cultivator + 2 planking): wet bed

T_3 = Mechanical transplanting (2harrow + 2cultivator + 2 planking +2passes of puddler): puddled

T_4 = Mechanical transplanting (2 harrow + 2 cultivator +2 planking): unpuddled

T_5 = Manual transplanting (2 harrow + 2 cultivator + 2 planking +2 passes of puddler): puddled

The implements used for tillage were harrow (14-disc offset harrow in 580 mm diameter of discs, working width of harrow 1,700 mm and weighing 400 kg), cultivator (9 tines spring loaded, 72 mm wide with a tine spacing 200 mm and weighing 220 kg & width 530 mm and working width 2,140 mm), puddler (rotary type 330 mm diameter and total weighing 300 kg) and wooden planker for leveling.

The land preparation was done in dry field condition as described in each treatments then puddling was performed in treatment T_3 and T_5. In the Kharif crop, the mechanical transplanting was performed by self propelled rice transplanter with dimension (L × W × H: 2410 × 2131 × 1300 cm) and weighing 320 kg. The drum seeder with dimension (L × W × H: 1425 × 750 × 670 mm) and weighing 16 kg was used for sowing 8 row of sprouted rice with spacing of 200 mm. It is operated by two man power in wet field condition. In the Rabi crop, chickpea and mustard were sown after one harrowing plus one cultivator followed by one planking, however, wheat sowing was done in no till conditions. The sowing of above crops were done through bross roller metering —multicrop seed drill with dimension (L × W × H: 1850 × 650 × 1450 mm and weighing 300 kg) using 9 tines of inverted —T type furrow opener. with spacing of 200, 450 and 300 mm spacing for wheat, mustard and chickpea, respectively. Plantation of these crops were random in sequence of rice-wheat, rice-chickpea and rice-mustard crop in the study area.

Crop Management

The five rice planting methods were carried out random in sequence of rice-wheat, rice-chickpea and rice-mustard in randomized block design replicated three times. The dimensions of individual plots were 33 m × 4 m for rice and 10 m × 4 m for wheat, chickpea and mustard crop. The rice (cv. PHB 71) was sown at 20 cm apart with seeding rate @ 40 kg/ha. Crop cultivars used were PBW 243 of wheat, avrodhi of chickpea and varuna of mustard were sown 100, 75 and 6 kg seed rate/ha, respectively. The fertilizer doze for rice was 150 : 60 : 60 (N : P : K) kg/ha and 5.5 (Zn) kg /ha, for wheat and mustard it was 120 : 60 : 60 (N : P : K) except chickpea where 20 (N) kg/ha was applied along with P and K. Full dose of P and K were applied at time of land preparation by broadcasting. Nitrogen was applied in four equal splits in rice, three splits in wheat and mustard and single dose in chickpea crop. All the crops were grown under assured irrigated conditions, seeding of rice were done in direct drilling through zero till drill and drum seeder and the transplanting were done by mechanical transplanter and manual. Weedy rarely formed a problem in the upland rice after application of pendimethalin 35 EC at the rate of 1.25 kg a.i./ha in direct and drum seeded rice and butachlor 50 EC at rate of 1.5 kg a.i./ha as pre-emergence herbicide applied after 3 days of transplanting, followed by one hand weeding 30 days after sowing in all plots. Isoproturon was sprayed 35 days after sowing at the rate of 1.25 kg a.i./ha in all plots to control weeds in wheat.

Energy Budgeting

Energy inputs such as labour, machinery, irrigation, diesel fuel, chemical fertilizers, pesticides, consumption of electricity, etc were taken into consideration. In terms of outputs, rice, wheat, chickpea and mustard yields were used to estimate the energy and the unit used was mega joule (MJ). The energy inputs of each cropping system were evaluated. Energy coefficients for each process in the cropping system were taken from the literature. Different methods were used to calculate the energy used by different machinery, pesticides, fertilizers, yield energy outputs, etc which were given below.

Human Labour Energy

It is reported (Doering, 1980) that 68 percent of human energy is consumed for 8 hours of work per day, 21 percent for 6 hours of other activities, and 11 percent for 10 hours of rest. In Indian condition, 1.96 and 1.57 MJ/person-h energy coefficients from adult male and woman were used to obtain the human energy from average body weight, age and daily activities, a human labour (Gopalan *et al*., 1978; Binning *et al*., 1983). The following formula was used to calculate human energy input.

$$E_m = C_e N_m T_m M_J \qquad (1)$$

Where,

C_e = 1.96 and 1.57 MJ/person-h energy coefficients from adult male and woman

N_m = Number of labour spent on a farm activity

T_m = Useful time spent by a labour on a farm activity, h

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.

Irrigation energy

In the experiment, the 7-12 HP diesel engine coupled to a centrifugal water pump to raise water from underground sources for irrigation of crop production was used. Diesel consumption in pump was recorded during each irrigation as per volume of water for every crop. Hence, for each crop irrigation, the diesel fuel was used to calculate the input energy. In this paper, the irrigation energy input was computed according to the formula used for fuel energy calculation.

Fuel energy

The majority of farm operations such as tilling, sowing, threshing and winnowing, etc were performed by diesel operated tractor in different crop production. Mechanical energy input was evaluated by quantifying the amount of diesel fuel consumed during various operations (Omar, 2003). The total time spent was also recorded. The operation wise input energy calculations were performed form diesel fuel.

The density of petroleum diesel is about 0.85 kg/l (7.09 lb/gal). When burned, diesel typically releases approximately 38.6 MJ/l (Safa and Tabatabaeefar, 2002). However, (Pimentel, 1976) suggests a higher diesel energy coefficient of 47.78 MJ/l (Esengun *et al*., 2006). However, in India, the diesel energy coefficient of 56.31 MJ/l was suggested by different researchers (Gopalan *et al*., 1978; Binning *et al*., 1983). The energy input of diesel fuel is calculated using the following formula:

$E_f = DEC \times AFC$ ....(2)

Where,

Ef = Fuel input energy, MJ/ha

DEC = Diesel energy coefficient, 56. 31 MJ/l

AFC = Amount of fuel consumed, l/ha

Machinery

The total lifetime energy cost of machinery is estimated by aggregating the combined costs of raw materials, fabrication, spare parts, and maintenance. The average energy demand value of a piece of equipment is equal to 109 MJ/kg (Pimentel, 1992). This value was obtained from steel production energy of 62.8 MJ/kg (Doering, 1980), fabrication and assembly energy of 8.4 MJ/kg, and repair and maintenance energy of 37.7 MJ/kg (Fluck, 1985). The energy for production and maintenance for machinery was taken 76 MJ/kg for tractor and combines and 111 MJ/kg for tillage implements (Arvidsson Johan, 2010). Key machinery considered in this paper were four-wheeled used for land preparation, sowing and transportation. The characteristics of these machines are given in **Table 2**. To calculate the energy input used in machinery production or repair, the following formula was used.

$Eim = (MTR \times M) / (L \times C_e)$....(3)

Where:

E_{im} = Machinery input energy, MJ/ha

MTR = Energy used to manufacture, transport and repair (for tractor, 76 MJ/kg and farm machinery, 111 MJ/kg)

M = Mass of machinery, kg

L = Life of machinery, h

C_e = Effective Field Capacity of farm machinery, h/ha

Pesticides, insecticides and herbicides

The application of pesticides, insecticides and herbicides are mostly used in all crops areas because of the massive attack of insect, pest and various kinds of weeds. The manufacture of pesticide consumes approximately 101.2 MJ and 238 MJ/l of energy for insecticides and herbicides, respectively (Doering, 1980). Almost similar figures were suggested by (Pimentel, 1992; Anon, 2004; Hulsbergen *et al*., 2001). The amount of pesticide energy input (120 MJ/kg) is adopted as per reported by (Binning *et al.,* 1983).

The energy input of pesticides is computed using the following formula:

$Ep = PEC \times APA$.............(4)

Where:

Ep = Pesticide input energy, MJ/ha

PEC = Pesticide energy coefficient: 120 MJ/kg for insecticide or 238 MJ/kg for herbicide

APA = Amount of pesticide applied, kg/ha

Fertilizers

Energy requirements for the production and transport of commercial chemical fertilizers as estimated by (Samootsakorn, 1982) are 80 MJ/kg, 14 MJ/kg and 9 MJ/kg for N as anhydrous ammonia, P as normal super phosphate (P_2O_5) and K as muriate of potash (K_2O), respectively. Approximately the same amount of energy for N is also estimated by (Pimentel 1992; Chamsing *et al*., 2008; Tippayawong *et al*., 2003). In India, the fertilizer energy coefficient is used as 60.6 MJ/kg for N, 11.10 MJ/kg for P and 6.70 MJ/kg for K (**Table 1**). The energy input of fertilizer N, P and K was calculated using the formula:

$Efr = NEC \times ANA$ ....(5)

Where:

Efr = Fertilizer input energy, MJ/ha

NEC = Fertilizer energy coefficient, 60.6 MJ/kg for N 11.10 MJ/kg for P or 6.70 MJ/kg for K

ANA = Amount of nutrient ap-

Table 1 Energy conversion factors as adopted /advised

Particulars	Equivalent energy (MJ)
Human Power	
(a) Adults man, Man-hour	1.96
(b) Woman, Woman-hour	1.57
Tractor, hour	332.00
Diesel, liter	56.31
Farm machinery, kg	62.70
Chemical Fertilizers, kg	
Nitrogen (N)	60.60
Phosphorus (P)	11.10
Potash (K)	6.70
Plant protection, kg	
Superior chemical (Granular)	120.00
Inferior chemical	10.00
Liquid chemical, ml	0.102
Farm Yard Manure, kg (dry mass)	0.30
Crop Produce (grain), kg	
Rice	14.70
Wheat	15.70
Chickpea	15.06
Mustard	22.64

Source: Gopalan *et al*. (1978) & Binning *et al*. (1983)

plied, kg/ha

Yield energy output

The crop yield data considered in this paper are obtained from experiment conducted during 2003-2007. 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 (Gopalan *et al*., 1978). In the calculations, the energy equivalents used as in **Table 1** for different crops was adopted. The following formula is used to calculate the yield energy output:

$EOut = YEC \times YH$...................(6)

Where:

EOut = yield energy output, MJ/ha

YEC = yield energy coefficient, 14.70, 15.70, 15.06 and 22.64 MJ/kg of rice, wheat chickpea and mustard yield

YH = yield per ha, kg/ha

Statistical Analysis

The net return and output energy data were subjected to analysis of variance as per the procedure given (Little and Hills, 1978), 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 = ($\sqrt{2}$ V E 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.

Results and Discussion

Energy Utilization in Farm Machineries Operation

Energy used to manufacture, transport and repair of machinery (i.e. farm power & farm machinery) MTR is calculated and given **Table 2**. The energy use in fuel and machinery for tillage and sowing operation in various crops are shown in **Table 3**. The MTR energy was highest in direct seeding (T_1) treatment (1,232 MJ /ha) followed by manual transplanting (T_5) (1197 MJ/ha) and lowest was mechanical transplanting (620 MJ/ha) in unpuddled field (T_4) respectively. It was due to the greater mass and numbers of machineries used for the field operation and crop establishment. The manual transplanting (T_5) consumed highest operational energy (6,455 MJ/ha) and lowest 3,467 MJ/ha in drum seeding (T_2) in wet field condition. The mechanical transplanting in puddled field (T_3) consumed second largest energy followed by 3,972 and 3,656 MJ/ha in direct seeding (T_1) and mechanical transplanting in unpuddled field (T_4). The largest energy was invested in the field where puddled operation was performed due to higher diesel energy used (Chaudhary *et al*., 2004; Chaudhary *et al*., 2006c).

Table 2 Energy for different machineries used for each operation

Particulars	Farm Power	Farm Implement	Total Energy, MJ/ha
Energy for harrow, 14 discs	Tractor	Harrow	
Mass, kg	10,000	400	
Field capacity, h/ha	0.45	0.45	
Life, h	12,000	2,500	
MTR energy, E_{im}, MJ/ha	140.7	39.5	180.2
Energy for cultivator, 9 tines		Cultivator	
Mass, kg	10,000	220	
Field capacity, h/ha	0.4	0.4	
Life, h	12,000	2,000	
MTR energy, E_{im}, MJ/ha	158.3	30.5	188.9
Energy for peg type puddler		Puddler	
Mass, kg	10,000	90	
Field capacity, h/ha	0.4	0.4	
Life, h	12,000	2,500	
MTR energy, E_{im}, MJ/ha	158.3	10.0	168.3
Energy for multi crop seed drill		Seed drill	
Mass, kg	10,000	300	
Field capacity, h/ha	0.32	0.32	
Life, h	12,000	2,000	
MTR energy, E_{im}, MJ/ha	197.9	52.0	249.9
Energy for self propelled transplanter		Rice transplanter	
Mass, kg	0	320	
Field capacity, h/ha	0	0.74	
Life, h	0	3,000	
MTR energy, E_{im}, MJ/ha	0	16.0	16.0
Energy for drum seeder		Drum seeder	
Mass, kg	0	16	
Field capacity, h/ha	0	0.15	
Life, h	0	1,000	
MTR energy, E_{im}, MJ/ha	0	11.8	11.8
Energy for wooden planker			
Mass, kg	10,000	0	
Field capacity, h/ha	0.52	0	
Life, h	12,000	0	
MTR energy, Eim, MJ/ha	121.8	0	121.8

MTR energy - Energy in MJ/ha used to manufacture, transport and repair machinery (i.e. farm power & farm machinery)

The amount of diesel in tillage and puddling operation was highest in mechanical transplanting with puddled (T_3) field (91 l/ha) followed by manual transplanting in puddled (T_5) field (81 l/ha). However, the higher input energy used in manual transplanting was because of more contribution of labour energy (10 %) as compared to other treatments in total operational energy up to the crop establishment (**Table 3**). It was noticed that 356 man-h/ha labour used in manual transplanting (T_5), however, 125 man^{-h}/ha labour consumed in mechanical transplanting (T_3 & T_4). Result revealed that the direct seeding (T_1) saved about 34 percent and drum seeding (T_2) saved about 46 percent energy input as compared to manual transplanting (T_5) in machineries used up to crop establishment. Similar results were also reported by authors (Chaudhary *et al*., 2006d).

When compared the energy in between Rabi (winter season) crop, the chickpea and mustard consumed 2,083 MJ/ha. However, the wheat used only 627 MJ/ha up to crop establishment. It was due to the fact that the wheat crop sown in no-till conditions, whereas, other two crops like mustard and chickpea were sown in the field after one harrowing + one cultivator + one planking and the machine used was multi crop seed drill that consumed about 2,083 MJ/ha energy.

Source-Wise Energy Utilization Pattern

The item/source wise energy dynamics is presented in **Table 4**. The different sources are utilized for the crop production. It is revealed that the highest energy was consumed in fertilizer followed by diesel fuel for pumping irrigation water, operational energy in machineries, labours and seed in all cropping systems (Chaudhary *et al*., 2006a). Very less amount was consumed in chemical applied for insect, pest and herbicides. This pattern was also seen in other two cropping systems. It was noticed that input energy consumed 40, 27, 14 and 7.7 percent in fertilizer, diesel fuel for irrigation, machineries, and labour of total energy used, respectively, for crop production in rice-wheat system. The trends are in agreement with other workers (Chaudhary *et al*., 2009). However, the energy spent in seed and insecticides, pesticides & herbicides was found to be 5 and 2 percent respectively. The less share of total input energy of different inputs was observed in rice-chickpea and rice-mustard system, which was 38 & 48 percent as fertilizer, 25 & 23 percent as diesel in irrigation, 20 & 17 percent as machinery and 5 & 9 percent as labour respectively. This highest input energy in fertilizer was due to higher energy invested for manufacturing and transportation which resulted the more value of energy coefficient. The second rank of energy consumed in the form of diesel fuel in centrifugal pump for irrigation purposes (Chamsing *et al*., 2008; Chaudhary *et al*., 2006d) which was also due to greater energy coefficient of diesel fuel for manufacturing of petroleum materials. The machinery part also consumed good amount of input energy (i.e.10 %) because of MTR energy and diesel fuel energy. The total labour consumed was about 8 percent of total input energy in rice-wheat system.

When compared operation wise energy among treatments of rice-

Table 3 Energy consumed in farm machineries used for tillage and sowing operation during crop establishment in different crops

Items	Diesel		Human		Machinery (MTR), MJ/ha	Total Energy, MJ/ha
	Quantity, l/ha	Energy, MJ/ha	Quantity, man^{-h}/ha	Energy, MJ/ha		
Kharif crop (Rice)						
T_1: Direct seeding (2 harrow + 2 cultivator + 2 planking)-dry bed	47	2,647	48	94	1,232	3,972
T_2 : Drum seeding (2 harrow + 2 cultivator + 2 planking)-wet bed	41	2,309	84	165	994	3,467
T_3 : Mechanical transplanting (2 harrow + 1 planking +2 passes of puddler)- puddled	91	5,124	116	227	835	6,186
T_4 : Mechanical transplanting (2 harrow + 2 planking)- unpuddled	51	2,872	84	165	620	3,656
T_5 : Manual transplanting (2 harrow + 2 cultivator + 1 planking +2 passes of puddler)- puddled	81	4,561	356	698	1,197	6,455
Rabi crops						
Wheat (No-till)	24	338	20	39	250	627
Chickpea (1 harrow + 1 cultivator + 1 planking)	18	1,295	24	47	741	2,083
Mustard (1 harrow + 1 cultivator + 1 planking)	18	1,295	24	47	741	2,083

wheat system, the mechanical transplanting in unpuddled field (T_4) used lowest diesel energy for pumping of irrigation water (i.e. 10,699 MJ/ha) which is 15 percent less than manual transplanting (T_5). However, the direct seeded (T_1) required less diesel pumping energy about 9 percent in comparison to manual transplanting. This is because of the direct seeded rice (T_1) is sown in dry field by use of machinery, however, manual transplanted rice is done puddled field. Moreover, the puddling operation required significant water pumping energy in manual transplanting in puddled condition (Chaudhary *et al*., 2008).

Human labour energy input was obviously the highest in the manual transplanting (T_5) due to more number of labour required for transplanting, whereas, drum seeded (T_2) treatment also required same amount of human energy, it was because of higher labour invested in manual weeding purpose. Moreover, labours energy also consumed for operation of the drum seeder in wet field condition. However, the lowest human energy consumed in mechanical transplanting puddled field (T_3) which was 13 percent less in comparison to manual transplanting (T_5). Less labour energy consumed in mechanical transplanting was because of mechanization in transplanting of seedlings which attributed about 250 man-h/ha in manual transplanting (T_5) as compared mechanical 50 man^{-h}/ha in T_3 & T_4. Moreover, the less labour energy was spent in weeding operation as when puddling operation was performed in treatment. Seed energy input was apparently high for direct (T_1) and drum seeded, T_2 (2,452 MJ/ha), especially for manual transplanting, T_5 (1,938 MJ/ha), because more quantity of seeds was required for direct seeding by seed drill and drum seeder as compared to manual transplanting where seedlings are required to transplant of the rice crop. Moreover, for growing of seedlings requires less seed input (30 kg/ha) in T_5 as compared to 60 kg/ha in T_1 & T_2. Similar pattern are also sown in rice-chickpea and rice-mustard.

Operation-Wise Input Energy Utilization Pattern

The operation wise input energy dynamics is presented in **Table 5**. The energy consumed in land preparation was varied from 3,007 to 7,222 MJ/ha in rice-wheat, 4,519 to 8,835 MJ/ha in both the systems as rice-chickpea and rice-mustard. Energy input for land preparation on average all treatments contributed

Table 4 Energy dynamics (MJ/ha) of item wise of different cropping systems after various rice crop establishments

Treatments	Seed	Fertilizers	Pesticides/ Insecticide	Diesel (Pump)	Machinery			Labour	Total Energy
					Diesel	MTR	Total		
Rice-wheat									
T_1	2,452	18,364	881	11,487	3,998	1,482	3,363	3,363	4,2027
T_2	2,452	18,364	881	12,163	3,660	1,244	3,434	3,434	42,197
T_3	2,011	18,364	681	12,107	6,476	1,085	2,964	2,964	43,686
T_4	2,011	18,364	681	10,699	4,223	870	3,136	3,136	39,984
T_5	1,938	18,364	681	12,557	5,913	1,447	3,434	3,434	44,332
Mean	2,173	18,364	761	11,803	4,854	1,226	6,080	3,266	42,445
Rice-chickpea									
T_1	1,786	12,526	753	8,109	3,942	1,972	3,653	3,653	32,741
T_2	1,786	12,526	753	8,784	3,604	1,734	3,724	3,724	32,911
T_3	1,345	12,526	553	8,728	6,419	1,576	3,254	3,254	34,400
T_4	1,345	12,526	553	7,320	4,167	1,361	3,426	3,426	30,698
T_5	1,271	12,526	553	9,179	5,856	1,937	3,724	3,724	35,046
Mean	1,507	12,526	633	8,424	4,798	1,716	6,514	3,556	33,125
Rice-mustard									
T_1	1,063	18,364	553	8,784	3,942	1,972	3,559	3,559	38,238
T_2	1,063	18,364	553	9,460	3,604	1,734	3,630	3,630	38,408
T_3	622	18,364	353	9,404	6,419	1,576	3,160	3,160	39,897
T_4	622	18,364	353	7,996	4,167	1,361	3,332	3,332	36,195
T_5	549	18,364	353	9,854	5,856	1,937	3,630	3,630	40,543
Mean	784	18,364	433	9,100	4,798	1,716	6,514	3,462	38,656

T_1: Direct seeding (2 harrow + 2 cultivator + 2 planking)-dry bed;
T_2: Drum seeding (2 harrow + 2 cultivator + 2 planking)-wet bed;
T_3: Mechanical transplanting (2 harrow + 2 cultivator + 2 planking +2 passes of puddler)- puddle;
T_4: Mechanical transplanting (2 harrow + 2 cultivator + 2 planking)- unpuddled;
T_5: Manual transplanting (2 harrow + 2 cultivator + 2 planking +2 passes of puddler)- puddled

11, 19 and 16 percent of total energy inputs for rice-wheat, rice-chickpea and rice-mustard, respectively. However, the puddled field in manual transplanting (T_5) consumed highest input energy for land preparation i.e. 7,322 MJ/ha. The similar pattern is shown in other two systems. In rice-wheat system, lowest energy consumed for land preparation in T_4 treatment than T_5 (i.e. 59 %), however, direct and drum seeding (T_1 & T_2) required about 53 percent less energy than manual transplanting in puddled field (T_4). It was due to no tillage operation was performed in flooded water (i.e. puddling) for rice crop establishment in treatment T_1 & T_2. The higher energy was spent due to puddling operation in T_3 (6,945 MJ/ha) and T_5 (7,322 MJ/ha) other than tillage operation in dry field (Chaudhary *et al*., 2004; Chaudhary *et al*., 2006c). Seed and sowing input consumed about 9 and 6 percent of total input energy in rice-wheat and both rice-chickpea, rice-mustard, respectively. In weeding and intercultural operation spent about 3 percent of total input energy in all systems, whereas, it was noticed from **Table 5** that the puddled field condition consumed very less energy (941 MJ/ha) as compared to unpuddled condition as direct/ drum seeded (T_1 and T_2 i.e. 1411 MJ/ha) in rice-wheat systems.

The highest energy is invested in the fertilizer application in all cropping systems, which varied from 12,526 to 18,364 MJ/ha i.e. 43 percent of total input energy (Chaudhary *et al*., 2009; Chaudhary *et al*., 2006b; Gopalan *et al*., 1978). The second rank in consuming the input energy has got to provide the irrigation to the crops, which is about 26 percent of total energy use for crop production (Chaudhary *et al*., 2008; Chamsing *et al*., 2008). In comparison among the treatment, it revealed that direct (T_1) and drum seeded (T_2) (i.e. 11,942 MJ/ha) consumed higher irrigation energy (i.e about 12 %) as compared to transplanted rice treatment (i.e. 10,528 MJ/ha). This is because of less water requirement in whole crop production in manual transplanting (T_5) after the seedling transplanted in field. The direct (T_1) and drum seeded (T_2) rice required 2 to 3 irrigations more where it was seeded in field one month before that of transplanted rice crop. Meanwhile, the same day the, sprouted rice seed were placed in the field for seedling growth for transplanted rice. The harvesting and threshing spent about 6 and 2 percent in plant protection of crop of total input energy.

Energy Dynamics in Systems

The system wise energy dynamics are presented in **Table 6**. The comparison of different cropping systems, the rice-chickpea consumed less input energy (i.e. 30,698 to 35,046 MJ/ha) followed by rice-mustard (varied from 36,195 to 40,543 MJ/ha) and rice-wheat

Table 5 Operation wise energy dynamics (MJ/ha) different cropping systems after various rice crop establishments

Treatments	Land Preparation	Seed & sowing	Intercultural / weeding	Fertilizer	Plant protection	Irrigation	Harvesting & Threshing	Total Input Energy, MJ/ha
Rice-wheat								
T_1	3,385	3,667	1,411	18,364	881	11,942	2,378	42,027
T_2	3,385	3,837	1,411	18,364	881	11,942	2,378	42,197
T_3	6,945	3,851	941	18,364	681	10,528	2,378	43,686
T_4	3,007	3,851	1,176	18,364	681	10,528	2,378	39,984
T_5	7,322	4,119	941	18,364	681	10,528	2,378	44,332
Mean	4,807 (11.4)*	3,865 (9)	1,176 (2.8)	18,364 (43.3)	761 (2)	11094 (26.3)	2,378 (5.6)	42,445 (100)
Rice-chickpea								
T_1	4,897	2,944	1,254	12,526	753	8,485	1,882	32,741
T_2	4,897	3,114	1,254	12,526	753	8,485	1,882	32,911
T_3	8,457	3,128	784	12,526	553	7,071	1,882	34,400
T_4	4,519	3,128	1,019	12,526	553	7,071	1,882	30,698
T_5	8,835	3,396	784	12,526	553	7,071	1,882	35,046
Mean	6321 (19)	3142 (9.4)	1019 (3.1)	12526 (37.8)	633 (1.9)	7637 (23.03)	1882 (5.7)	33159 (100)
Rice-mustard								
T_1	4,897	2,222	1,254	18,364	553	9,223	1,725	38,238
T_2	4,897	2,392	1,254	18,364	553	9,223	1,725	38,408
T_3	8,457	2,406	784	18,364	353	7,809	1,725	39,897
T_4	4,519	2,406	1,019	18,364	353	7,809	1,725	36,195
T_5	8,835	2,674	784	18,364	353	7,809	1,725	40,543
Mean	6,321 (16)	2,420 (6.3)	1,019 (3)	18,364 (47.5)	433 (1.1)	9,936 (25.7)	1,725 (4.5)	38,656 (100)

*Parenthesis values are given in percent of total input (varied from 39,984 to 44,332 MJ/ha). The reduction in input energy was about 22 and 14 percent in rice-chickpea system as compared to rice-wheat and rice-mustard system. System wise energy analysis indicated that the highest input energy was (44,332 MJ/ha) consumed in manually transplanted (puddled) followed by (43,686 MJ/ha) in mechanically transplanted (puddled) and lowest was 39,984, 41,2027 and 42,197 MJ/ha in mechanically transplanted (unpuddled) and drum seeded, respectively in rice-wheat system. The input energy of treatment manually transplanted (T_5) was found higher due to higher use of inputs as in tillage and sowing operation as compared to direct and drum seeded (T_1 and T_2) in which the tillage operation was minimum (Chaudhary *et al*., 2006d).

Energy Production (Output) Pattern

In rice-wheat system, the output and net return energy are found to be non-significant among the treatments. However, the output energy was highest in drum seeded, T_2 (212,798 MJ/ha) closely followed by direct seeded, T_1 (211,350 MJ/ha) and lowest was 193,916 MJ/ha in manually transplanted in puddled (T_5) which is statistically at par. The net return energy of the system was found to be high in drum seeded, T_2 (170,595 MJ/ha) followed by direct seeded, T_1 (169,271 MJ/ha) and lowest was 149,390 MJ/ha in manually transplanted in puddled (T_5) which were significant at par. In rice-chickpea, the output energy in the direct and drum seeded (T_1 & T_2) were significantly higher compared to other treatments (T_3, T_4 & T_5) which were statistically at par. The study revealed about 11 and 9.5 percent higher output energy was used in direct (T_1) and drum seeded (T_2) in comparison to manual transplanting (T_5), whereas, the net return energy were 15 and 14 percent higher. The similar pattern of energy was also found in net return energy in rice - chickpea systems.

The direct and drum seeded (T_1 & T_2) required about 5 percent less input energy and gave 8 to 9 percent higher output energy as compared to manually transplanted in puddled field (T_5). Whereas, in case of mechanically transplanted T_4 (unpuddled), it required 10 percent less input energy and provided 6 percent higher output energy. However, in puddled condition mechanically transplanted T_3 required 1.5 percent less input energy and gave 3 percent higher output energy as compared to manually transplanted (puddled) T_5. Similar pattern of energy dynamics were also found in rice-chickpea and rice-mustard systems. The input energy in manually transplanted (T_5) treatment was found higher due to higher use of inputs as in tillage operations, sowing operation as compared to direct seeded (T_1) and drum seeded (T_2) in which the tillage operation was minimum so that energy consumed in diesel was very less (Chaudhary *et al*., 2006c; Chaudhary *et al*., 2006d). The fertilizer consumed highest input energy and it was due to use of chemical fertilizer. The irrigation has second rank in consuming the input energy it was because of higher use of fossil energy (i.e. diesel). The output energy and net return energy was found higher in drum seeded and direct seeded due to its higher grain yield resulted by good crop establishment in minimum tillage and unpuddled field (Chaudhary *et al*., 2009). The output and input ratio was found to be high in T_4 (5.2) and followed by T_1 and T_2 (5.0) and lowest was in T_5 (4.6).

Table 6 Input, output and output energy pattern (MJ/ha) of different cropping systems as influenced by rice planting methods (4 year pooled data)

Treatments	Input, energy, MJ/ha	Output, energy, MJ/ha	Net return, energy, MJ/ha	Output-input ratio
Rice-wheat				
T_1	42,027	211,361	169,271	5.0
T_2	42,197	212,711	170,595	5.0
T_3	43,686	199,463	155,980	4.6
T_4	39,984	206,613	166,333	5.2
T_5	44,332	193,483	149,390	4.4
SEm ±	-	6,119	6,119	0.15
CD at 5 %	-	NS	NS	NS
Rice-chickpea				
T_1	38,238	166,410	128,885	4.4
T_2	38,408	166,927	129,377	4.3
T_3	39,897	152,197	113,279	3.8
T_4	36,195	152,055	116,339	4.2
T_5	40,543	149,253	109,725	3.7
SEm ±	-	2,262	2,262	0.065
CD at 5 %	-	7,492	7,491	0.22
Rice-mustard				
T_1	32,741	153,078	121,050	4.7
T_2	32,911	155,559	123,505	4.7
T_3	34,400	141,541	108,120	4.1
T_4	30,698	139,939	109,720	4.6
T_5	35,046	138,392	104,361	3.9
SEm ±	-	1,831	1,931	0.06
CD at 5 %	-	6,064	6,065	0.19

Conclusions

The results revealed that the rice-wheat consumed highest input energy but it also produced highest output energy which leads to highest net return energy as compared to rice-chickpea and rice-mustard system. The highest input energy could be consumed in fertilizer followed by diesel fuel for pumping irrigation water, operational energy in machineries, labours and seed under all cropping systems. Very less energy was consumed in respect of chemical applied for insect, pest and weed control purposes. The direct and drum seeded saved about 34 and 46 percent, respectively, in input energy as compared to manual transplanting for machineries. Further, drum and direct seeded treatments produce highest net return in case of rice-wheat about 15 and 14 percent as compared to manual transplanting. Thus, it was concluded that the direct and drum seeded treatment is advisable for saving energy under rice based cropping systems in tropical India.

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