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Energy efficiency and economics of rice cultivation systems under subtropical Eastern Himalaya

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ABSTRACT

In the northeastern region (NER) of India (eastern Himalayas), rice (*Oryza sativa*) is grown in ~70% of cultivated land. Therefore, the identification of energy-efficient rice cultivation system is important to food security and sustainable intensification (SI). Thus, six rice cultivation systems, composed of conventional direct seeded (CT-DSR), conventional transplanted (TRP), no-till (NT) DSR, NT-TRP, system of rice intensification (SRI), and mechanized TRP, were evaluated for their energy and cost efficiency. Results showed that land preparation, application of chemical fertilizers, farm yard manure, and seeding and/or transplanting operations consumed >80% of energy input in all rice cultivation systems. Energy input was the highest in mechanized TRP (15371 MJ ha^{-1}) and the lowest in NT-DSR (9162 MJ ha^{-1}). Average grain yield obtained was the highest under SRI (4.72 Mg ha^{-1}), followed by CT-TRP (4.34 Mg ha^{-1}), mechanized TRP (4.23 Mg ha^{-1}), and NT-TRP (3.52 Mg ha^{-1}). Grain and biomass output energy was the highest in SRI system (148811 MJ ha^{-1}), followed by that for the conventional TRP and mechanized TRP. The NT-DSR system was the most energy-efficient rice cultivation practice (output–input ratio: 11.00), whereas mechanized TRP was the least energy efficient (output–input ratio: 8.6). The lowest energy input (2900 MJ Mg^{-1}) per unit of grain yield was recorded for the SRI system. Both the input–cost and the benefit–cost ratio in mechanized TRP were lower than that under SRI.

Introduction

Energy is one of the most important inputs in agricultural production process and is expended in every step starting from land preparation to value addition (Devasenapathy et al., 2009). Production, formulation, storage, distribution, and application of inputs are dependent on energy based on fossil fuel consumption which emits CO_2 and other greenhouse gases (GHGs) into the atmosphere (Lal, 2004; Sørensena et al., 2014). Energy use efficiency (EUE) of a cropping system depends on a range of factors such as soil type, tillage operation, fertilizers application, plant protection measures, harvesting, threshing operations, and grain and biomass yield (Baishya and Sharma, 1990; Clemens et al., 1995; Singh et al., 1997). Energy consumption in Indian agriculture is increasing day by day with the introduction of new agricultural machineries and other inputs (Das, 2012). However, the use of new machinery in agriculture and adoption of reduced tillage methods can reduce the energy need by 18–83% in different cultivation practices (Sørensen and Nielsen, 2005).

In the NER of India, rice (*Oryza sativa*) is the most important cereal crop cultivated on about 3.5 million ha (Mha), with a total production of 12.6 teragrams (Tg $= 10^{12}$ g $=$ 1 million Mg) comprising 7.7% and 9.5%, of Indias rice area and production, respectively (NEDFI, 2010). Rice is an energy-intensive crop, and a major component of its use is through use of fertilizer and farm yard manure (FYM) along with land preparation. The use of mineral fertilizers and pesticides increases yields in the conventional cropping system but simultaneously also increases the energy inputs in rice cultivation (Dalgaard et al., 2001; Hatirli et al., 2006). The per capita energy availability in the NER region is rather low compared to that for other parts of India. Therefore, the identification of energy-efficient rice cultivation system is necessary, particularly in the context of climate change, as the major share of total energy need in agricultural production system is non-renewable in nature (Sartori et al., 2005). The cost of cultivation is equally important for the resource-poor farmers of this region. Higher cost of cultivation relative to the returns from rice cultivation is a major concern among the rice farmers (Das et al., 2014). Mechanization of cultivation system involves higher amount of energy expenditure but reduces cost of cultivation (Mandal et al., 2002). Further, the mechanization ensures timeliness of agricultural operations, while increasing both

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the productivity and net returns over those performed by manual labor or draft animals. Therefore, it is important to identify an efficient rice cultivation system in terms of the EUE and the cost. The present study was undertaken with the objective to identify the energy- and cost-efficient cultivation system for sustainable rice production in the energy-deficient NER of India. The hypothesis tested was that rice cultivation practice which requires less tillage and inputs saves energy and reduces cost of cultivation.

Methodology

Experimental site and climate

Experimental data for different agronomic practices were obtained various inputs used and outputs of six rice cultivation systems. These systems included conventional direct seeded (DSR), conventional transplanted (TRP), NT-DSR, NT-TRP, system of rice intensification (SRI), and mechanized TRP (Table 1). These experiments were conducted in lowland and upland Agronomy and Agricultural Engineering research farms of the Indian Council of Agricultural Research (ICAR) Complex for the North Eastern Hill (NEH) Region, located at Umiam, Meghalaya, India. These data were obtained from field experiments conducted for five consecutive rainy seasons (June–November 2006–2010). The research farm is located at 25^{O}30′ N latitude and 91^{O}51′ E longitude, at an elevation of 950 m (lowland) and 961 m (upland) above mean sea level. The experimental site falls under a per-humid subtropical climate, with the average minimum and maximum temperature during cropping season ranging from 7.8 °C to 20.5 °C and from 20.5 °C to 24.5 °C, respectively (Fig. 1). The patterns of rainfall and temperature during the cropping seasons of 2005 to 2011 are presented in Fig. 2. The relative humidity of the experimental period varied between 53.46% and 79.71%. Soil of the experimental site is classified as Typic

Table 1
Details of management practices, inputs used, and outputs in different rice cultivation systems.

	Conventional		No-till		SRI[a]	Mechanized
	DSR[b]	TRP[c]	DSR	TRP	TRP	TRP
A. Inputs						
1. Land preparation						
Ploughing and levelling						
Power tiller with rotavator (h ha^{-1})	15.8	23.6	0	0	23.6	27.3
Diesel (l ha^{-1})	31.6	47.2	0	0	47.2	54.6
Human (male-h ha^{-1})	15.8	23.6	0	0	23.6	27.3
Rectification of ridges (male-h ha^{-1})	34.8	36	0	0	33	0
2. Seeding/transplanting						
Seed (kg ha^{-1})	58.6	44.4	58.8	45.8	8.1	67.2
Nursery raising (female-h ha^{-1})	0	87.6	0	91.8	64.8	92.4
Direct sowing (female-h ha^{-1})	69	0	145.2	0	0	0
Manual transplanting (female-h ha^{-1})	0	145.2	0	174	162	0
Machine transplanting						
Transplanter (h ha^{-1})	0	0	0	0	0	6.4
Diesel (l ha^{-1})	0	0	0	0	0	7.68
Human (male-h ha^{-1})	0	0	0	0	0	6.6
3. Water management (male-h ha^{-1})	12	31.2	12	31.8	43.2	29.4
4. Fertilizer and manure application						
FYM (t ha^{-1})	5	5	5	5	10	5
Application of FYM (female-h ha^{-1})	48	48	48	48	72	48
Nitrogen (N) (kg ha^{-1})	60	64	60	60	80	80
Phosphorus (P_2O_5) (kg ha^{-1})	60	60	60	60	60	60
Potassium (K_2O) (kg ha^{-1})	40	40	40	40	30	40
Fertilizer application (female-h ha^{-1})	18	18	18	18	18	18
5. Weeding						
Cono-weeding (male-h ha^{-1})	0	0	0	0	60.6	61.8
Hand weeding (female-h ha^{-1})	288	210	349.2	260.4	60.6	61.8
Cono weeder (h ha^{-1})	0	0	0	0	60.6	61.8
6. Pesticide application						
Herbicide (l ha^{-1})	0	0	1.5	1.5	0	0
Insecticide (l ha^{-1})	1.5	1.5	1.5	1.5	1.5	1.5
Knapsack sprayer (h ha^{-1})	24	24	36	36	18	0
Power sprayer(h ha^{-1})	0	0	0	0	0	8
Petrol (l ha^{-1})	0	0	0	0	0	8
Human (male-h ha^{-1})	24	24	36	36	18	8
7. Harvesting						
Reaper (h ha^{-1})	0	0	0	0	0	6.1
Diesel (l ha^{-1})	0	0	0	0	0	7.32
Human (male-h ha^{-1})	61.8	73.4	61.2	72	70.2	6.1
Human (female-h ha^{-1})	62	71	65	67	70	0
8.Threshing						
Pedal thresher (h ha^{-1})	80.4	114	78	111.6	140.4	0
Engine operated thresher (h ha^{-1})	0	0	0	0	0	9.2
Diesel (l ha^{-1})	0	0	0	0	0	22.8
Human (male-h ha^{-1})	42	60	36	60	72	30
Human (female-h ha^{-1})	38.4	54	42	51.6	68.4	24
B. Outputs						
1. Rice grain (kg ha^{-1})	3144	4342	3012	3524	4720	4230
2. Straw (kg ha^{-1})	4180	5528	4518	4542	6354	5573

[a] System of rice intensification.
[b] Direct-seeded rice.
[c] Transplanted rice.

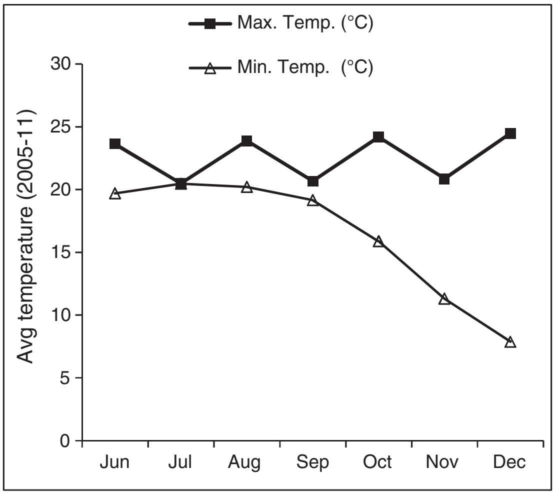

Fig. 1. Average maximum and minimum temperature during the cropping season.

Table 2
Properties of the soils of upland and lowland experimental fields.

Soil properties	Upland	Lowland
Texture	Sandy loam	Sandy clay loam
Bulk density (Mg m^{-3})	1.30	1.23
Organic carbon (g kg^{-1})	12.3	25.6
Available N (kg ha^{-1})	244	277
Available P (kg ha^{-1})	7.74	8.95
Available K (kg ha^{-1})	225	258
pH	4.96	5.10

Paleudalf (Bhattacharya et al., 1994). Important soil physicochemical properties of upland and lowland experimental fields are presented in Table 2.

Experimental management practices

The management practices followed and inputs used in six rice cultivation systems are summarized in Table 3. In conventional DSR, two ploughing operations were performed at 15 and 2 day before sowing (2× rotary tilling by power tiller). In all other transplanted systems, however, three rotary tiller operations were performed by a power tiller. Two power tiller operations were performed 15–20 days before and the third just a day before the transplanting (except NT-TRP system). Seeding was performed manually by opening furrows with an adjustable furrow opener in conventional DSR and NT-DSR. The rice nurseries for all TRP methods were sown on the same day, but transplanting date varied as per the requirement of different systems. For SRI, 10-day-old seedlings with single seedling $hill^{-1}$ were transplanted at 25 × 25 cm spacing. For conventional and mechanized systems, 25 day-old seedlings with three seedlings $hill^{-1}$ were transplanted at a spacing of 20 × 15 cm and 24 × 15 cm, respectively.

The nursery for SRI was prepared using a modified mat nursery (MMN) method (Patel et al., 2008; Das et al., 2014) in which the seedlings were raised in 4 cm thick layer of soil arranged on a firm surface covered with plastic sheet. A wooden quadrant, 1 × 1 m^2 area and 4 cm high, was used to shape the nursery bed. The soil mixture was prepared by mixing 3 ingredients as follows: 75–80% soil, 15–20% well-decomposed FYM, and 5% rice hull ash. Pre-germinated seeds were sown at a rate of 50 g m^{-2}. Seedlings for machine transplanting were grown in aluminum trays of 80 × 26 cm dimension according to the specific transplanter. The soil mixture described above was used to a depth of 2 cm, and seed rate was 1 kg m^{-2}. For conventional and NT-TRP, nursery was grown on raised bed of 1 × 5 m area and 10 cm height. The seedbeds were sprinkled with water manually as and when required. Single seedling of one and half leaf stage was transplanted per hill in the SRI system. Seedlings were transplanted within 30 minutes of uprooting them from the nursery to avoid wilting and reduce transplanting shock in case of SRI. Transplanting in mechanized system was done using an 8-row self-propelled paddy transplanter.

Supplemental irrigation was not given to rice under any system of cultivation because rice is grown as a rain-fed crop in the NER of India. The rainwater was managed by maintaining field bunds of 20 cm height and 30 cm width. The recommended method of water management especially for SRI (alternative drying and wetting) could not be followed because of frequent and heavy rains in the NER. Instead, the excess rainwater was diverted out of the field through drainage channels.

For a better nutrient management, FYM was applied 20-day ahead of transplanting and incorporated with ploughing and/or seeding operations. The supply of nitrogen (N), phosphorous (P), and potassium (K) was ensured through recommended rates of application of urea, single super phosphate, and muriate of potash. Half of the N and full dose of P and K were used as basal application, and the remaining half dose of N was top dressed in two equal proportions at tillering and panicle initiation stages of the crop. There were three hand-weedings performed in the conventional DSR, two in conventional TRP, and three in NT-DSR and NT-TRP. Two cono-weedings and one hand weeding were provided

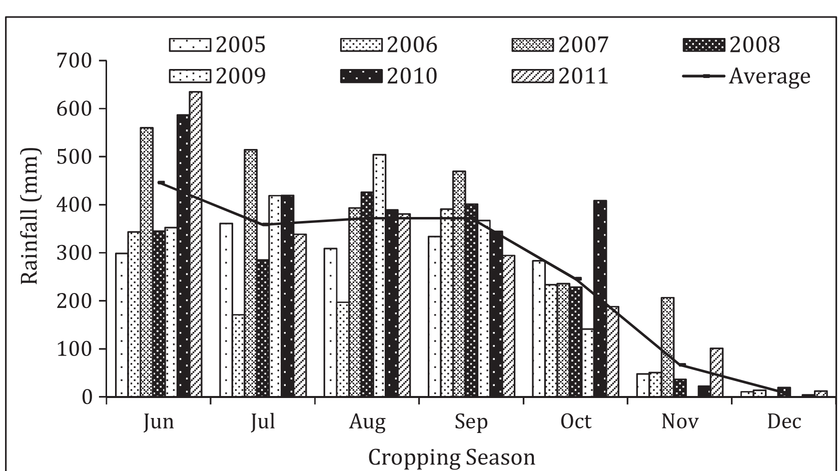

Fig. 2. Average monthly rainfall and distribution pattern during the cropping season.

Table 3
Energy equivalent for different inputs and outputs.

Particulars	Unit	Equivalent energy (MJ)	Reference
A. Inputs			
1. Human labor			
(a) Adult man	Man-hour	1.96	Mittal and Dhawan (1988)
(b) Women	Woman-hour	1.57	Mittal and Dhawan (1988)
2. Animal	Pair-hour	14.05	Mittal and Dhawan (1988)
3. Diesel including lube	1	56.31	Mittal and Dhawan (1988)
4. Petrol	l	48.23	Mittal and Dhawan (1988)
5. Electricity	kWh	11.93	Mittal and Dhawan (1988)
6. Machinery			
(a) Electric motor	kg	64.8	Kitani, (1999)
(b) Tractor	kg	138	Kitani (1999)
(c) Plow	kg	180	Kitani (1999)
(d) Sprayer	kg	129	Kitani (1999)
(e) Thresher	kg	148	Kitani (1999)
(f) Self-propelled machinery	kg	62.7	Kitani (1999)
7. Chemicals and fertilizers			
(a) Nitrogen	kg	60.6	Kitani (1999)
(b) Phosphorous (P_2O_5)	kg	11.1	Kitani (1999)
(c) Potash (K_2O)	kg	6.7	Kitani (1999)
(d) Zinc sulfate	kg	20.9	
(e) Insecticides	kg	261	West and Marland (2002)
(f) Herbicide	kg	277	West and Marland (2002)
8. Farmyard manure (FYM) (dry)	kg	0.3	West and Marland (2002)
9. Rice Seed	kg	14.7	West and Marland (2002)
B. Outputs			
1. Rice grain/seed (dry)	kg	14.7	Kitani (1999)
2. Straw (dry)	kg	12.5	Kitani (1999)

in SRI and mechanized TRP systems, respectively. In all systems, pesticides (Tricyclazole 75 WP, Monocrotophos 36 SL) were sprayed by knapsack sprayer except in the mechanized TRP where a power sprayer was used. Systemic herbicide roundup (*N*-phosphonomethyl, glycine, active ingredient glyphosate) 41% SL at the rate of 1.0 kg active ingredient (*a.i.*) per ha was used to manage weed in NT-DSR and NT-TRP systems.

In all systems, except in the mechanized TRP, sickle and pedal operated thresher were used for harvesting and threshing, respectively. In mechanized system, vertical conveyor reaper and power operated heavy duty thresher of 600 kg h^{-1} capacity were used.

Energy balance

Energy balance was computed using the different equivalents of agronomic practices and outputs (Table 3). Equivalents of the machines, for those commonly used in the NER, were calculated based on hourly use (Table 4). Conversion factor by Kitani (1999) was used to calculate the hourly energy cost of power tiller and the energy equivalent of tractor. However, the energy equivalent for self-propelled machinery (62.7 MJ kg^{-1}) was used (Mittal and Dhawan, 1988) for transplanter, reaper, and cono weeder. All outputs were considered on dry weight basis. The EUE and specific energy were calculated by using Eqs. (1) and (2) (Burnett, 1982; Mittal and Dhawan, 1988; Singh et al., 1997):

$$\text{EUE} = \text{Energy output}\left(\text{MJ ha}^{-1}\right)/\text{Energy input}\left(\text{MJ ha}^{-1}\right) \quad (1)$$

$$\text{Specific energy} = \text{Energy input}\left(\text{MJ ha}^{-1}\right)/\text{Grain output}\left(\text{t ha}^{-1}\right) \quad (2)$$

Economic analysis

Total input cost of cultivation of rice in different systems was calculated by summing the cost of all inputs (seeds, fertilizers, pesticides, fuel, laborers, etc.) and cost of machinery (Sartori et al., 2005). Costs of seeds, fertilizers, pesticides, and FYM were calculated on the basis of the prevailing market rate in the respective years. The government labor wages (Ministry of Labour and Employment, Government of India, GOI) were used to estimate the labor costs. The operating cost of machinery per hour basis was computed from the cost of machine, machine life, depreciation, and interest rate prevailing in the respective years. Total operating cost was calculated by multiplying the hourly cost with total hours of use per hectare. Fuel rates (petrol and diesel) were obtained from the Ministry of Petroleum and Natural Gas, Government of India (GOI). Price of grain was obtained from the Commission of Agricultural Cost and Prices, Directorate of Economic and Statistics, GOI (CACP, 2010) and the North Eastern Development Finance Corporation Limited (NEDFI). Selling price of rice straw was calculated based on the average price prevalent in different states of northeast India. The following economic parameters were calculated based on input and output costs as shown in Eqs. (3) to (5) :

$$\text{Net return} = (\text{Product cost} + \text{Byproduct cost}) - \text{Input cost} \quad (3)$$

$$\text{Benefit-cost ratio} = \text{Total output cost}/\text{Input cost} \quad (4)$$

$$\text{Energy intensiveness} = \text{Energy input}\left(\text{MJ ha}^{-1}\right)/\text{Cost of cultivation}\left(\text{Rs ha}^{-1}\right) \quad (5)$$

Statistical analysis

The data obtained were statistically analyzed using SPSS software (SPSS Inc. IBM Corporation, USA Ver. 20.0) to compare the differences between means of different cultivation systems at 5% level of significance ($p = 0.05$).

Results and discussion

Energy input

Energy inputs required for major farm operations in six cultivation systems are presented in Fig. 3. A large share of the energy used was on fertilizer and FYM application, which ranged from 48% to 67% of total energy requirement. Land preparation consumed 19–23% of total energy used in all systems, except the NT systems. Consumption of more energy for fertilizers and manure than that of other cultural practices and inputs in many crops and cropping systems have been widely reported (Verma et al., 1995; Mandal et al., 2002; Salami et al., 2010; Sørensena et al., 2014). While use of chemical fertilizers makes the farming extremely energy-intensive, energy use in rice cultivation can be reduced by supplementing chemical fertilizers with FYM (Billore et al., 1994). The SRI was the most energy-intensive in nutrient supply among all the cultivation systems due to addition of higher amount of FYM along with recommended dose of fertilizers. Practice of MMN also involved more energy input due to high use of manpower for

Table 4
Energy equivalent of machinery employed in different rice cultivation systems.

Machinery	Weight (kg)	Life (h)	Energy equivalent (MJ h^{-1})
Power tiller with rotavator	485	10000	6.693
Transplanter	320	4000	5.02
Cono weeder	6	1500	0.251
Knapsack sprayer	10	5000	0.258
Power sprayer	66	5000	1.703
Reaper	125	4000	1.96
Pedal thresher	34	5000	1.01
Engine operated thresher	550	5000	16.28

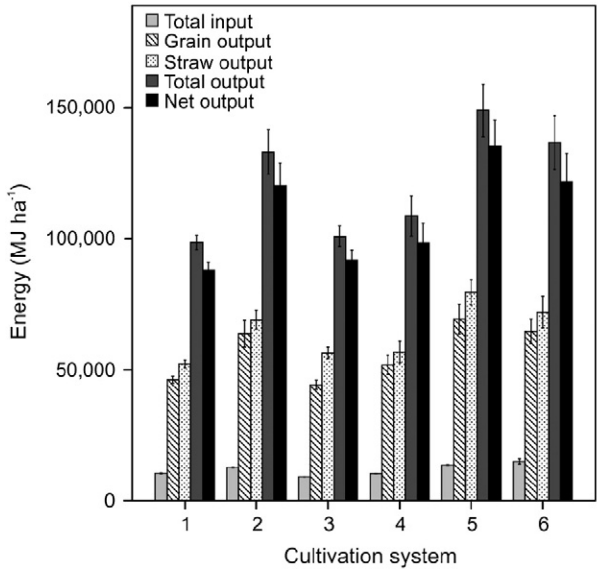

Fig. 3. Energy input, output, and net output in six rice cultivation systems. Cultivation systems: 1—conventional direct seeded (DSR), 2—conventional transplanted (TRP), 3—no-till DSR, 4—no-till TRP, 5—system of rice intensification, and 6—mechanized TRP.

preparing media, tray and nurturing the seedlings. However, the energy requirement was lower in SRI compared to mechanized TRP.

Tillage operations used considerable amount of energy for land preparation. Understandably, the energy requirement for land preparation was negligible in NT systems, which is among its major advantages over the conventional tillage. For seeding and transplanting, mechanized TRP system had higher energy input than all other methods because it used machines for transplanting and higher manpower to establish mat-type nursery. On the other hand, direct seeding reduced the energy input by 22% as compared to TRP because there was no need for nursery. The energy input for seeding was also the lowest for SRI (Das et al., 2014).

Land preparation, seeding or transplanting, fertilizer, and FYM applications together accounted for most of the energy input ranging from 79% to 90% of total energy need. With the chemical fertilizer application involving a major part of the energy requirement, it can be supplemented by the use of FYM. Intensive weed growth under NT-DSR system caused the highest energy demand in weeding than that in other methods. In comparison with other farming operations, energy input was low for harvesting and threshing in all systems. However, energy by a high capacity power operated thresher was also high in mechanized TRP than in other cultivation systems.

Total energy requirement per hectare was significantly higher ($p < 0.05$) in mechanized TRP system than that in other cultivation systems. The energy input was the lowest in NT-DSR system. Energy input in the mechanized TRP rice system was 17% more than that in the conventional TRP rice because all operations were carried completely mechanized. Energy in put in conventional DSR and TRP systems was 13% and 19% more than those for the NT-DSR and NT-TRP, respectively. Indeed, the use of non-renewable source of energy was the highest in mechanized TRP system (80%), while it accounted for 61–72% of the total energy use in other systems. Energy input for the chemical fertilizers accounted for the major share of non-renewable energy ranging from 40% to 58%. Input of the non-renewable energy was low in manually-used farm operations and cultural practices. As is discussed in another section, manual labor is rather expensive.

Energy input–output relationship

Both grain and plant biomass yields were the highest under SRI system among all rice cultivation systems (Table 1). Consequently, SRI had the highest energy output followed by that for the mechanized TRP, conventional TRP, and NT-TRP (Fig. 3). The SRI system yielded the highest energy output because it produced the highest grain and plant biomass compared with the other systems. Higher rice productivity under SRI than those under conventional cultivation (by 32%, Sinha and Talati, 2007, and by 9.6%, Das et al., 2014) have been reported in other studies. The yield advantage in SRI can be attributed to the adoption of different principles such as young seedlings, single seedling per hill, wider spacing, and cono-weeding (Sridevi and Chellamuthu, 2007). Grain output was also significantly higher in mechanized TRP than in DSR and NT systems. Both the DSR methods produced the lowest total energy output because of poor crop establishment and poor productivity. The net energy output was significantly lower in mechanized than that in the SRI system due to lower productivity and higher input energy. Less productivity in mechanized TRP may be due to missing hills of the seedlings while transplanting with the machine. Further, productivity of straw or biomass was more in SRI leading to a higher biomass energy production than that in the mechanized TRP system. Net energy output in mechanized system was higher than that in the DSR and NT systems. The net energy output was significantly more in the conventional TRP than that of the conventional DSR; however, it was not more in the NT-TRP than that of the NT-DSR system.

The EUE of the rice cultivation systems were in the order of: NT-DSR (11.00) > SRI (10.91) > NT-TRP (10.45) > conventional TRP (10.43) > conventional DSR (9.39) > mechanized TRP (8.58) cultivation (8.6) (Fig. 4). The energy input in NT-DSR was negligible for tillage operation, which accounted for as much as 20% of the total energy in other cultivation practices. However, the total energy output of NT-TRP was also low because of lower crop productivity than that of the other TRP systems. The SRI was more energy efficient than other systems because of more grain and biomass production. The EUE of NT-DSR was significantly ($p < 0.05$) more than that of the conventional DSR system because of lesser energy input. Conventional DSR and NT DSR were energy-intensive than all other systems because of low productivity and higher input of chemicals.

The NT-TRP (2956 MJ kg^{-1}) system was significantly lesser energy-intensive rice production system than conventional and mechanized systems because it produced higher yield and consumed lesser energy than those of other systems (Fig. 5a). The specific energy of mechanized TRP (3645 MJ kg^{-1}) system was higher ($p < 0.05$) than that of all systems except the conventional DSR system because of higher input of mechanical power and the seed material. Although total energy input was

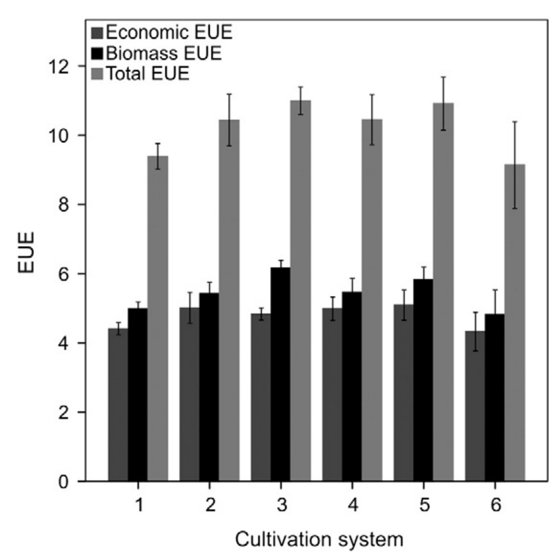

Fig. 4. Energy use efficiency (EUE) of six rice cultivation systems. Cultivation systems: 1—conventional direct seeded (DSR), 2—conventional transplanted (TRP), 3—no-till DSR, 4—no-till TRP, 5—system of rice intensification, and 6—mechanized TRP.

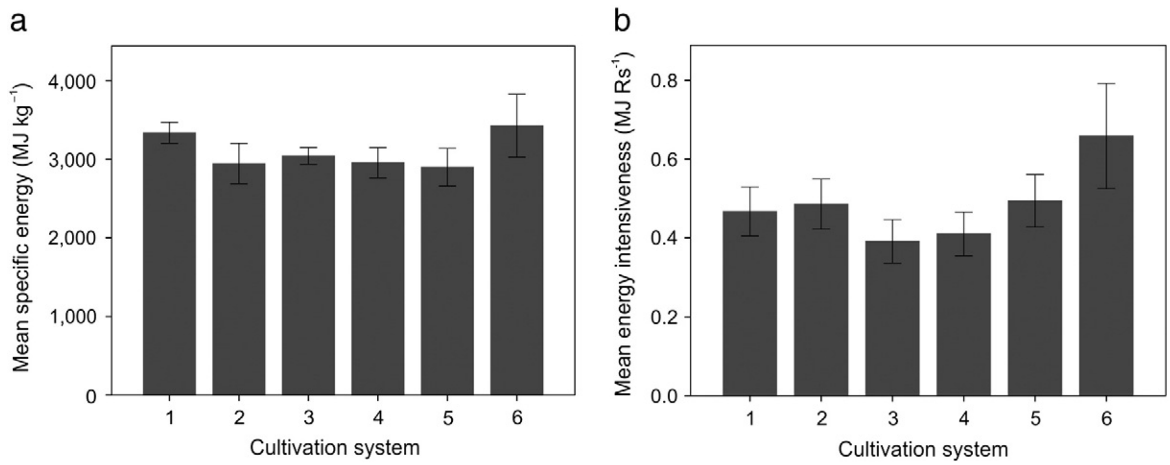

Fig. 5. Mean specific energy (a) and mean energy intensiveness (b) of six rice cultivation systems. Cultivation systems: 1—conventional direct seeded (DSR), 2—conventional transplanted (TRP), 3—no-till DSR, 4—no-till TRP, 5—system of rice intensification, and 6—Mechanized TRP.

relatively lower in the conventional DSR system, the energy use per unit of grain productivity was high. The specific energy was similar in the conventional TRP and both NT methods (NT-DSR and NT-TRP). In terms of the energy input per unit money spent, mechanized TRP was superior to all other systems because of its lower input cost and higher input energy. All other systems were statistically at par in terms of energy intensiveness (Fig. 5b).

Economics

Mechanized TRP was the most cost-effective rice cultivation system (Fig. 6). Input cost in the mechanized system (INR. 21,445) was significantly lower than that for the SRI system (INR. 27,880), while the total output cost was at par with each other. In the mechanized TRP system, input and output costs were 23.4% and 2.6% lower than that of the conventional TRP, respectively. This trend signifies the requirements for mechanization of rice production in the NER. The mechanized system had low labor requirements, which reduced the cost of cultivation as wages were high for manual labors in comparison to the cost of machine operations. Despite the higher total output in the SRI system, the input cost was also higher in comparison to all other cultivation systems. High input costs were attributed to higher labor requirements in transplanting and higher rates of application of FYM. The cost of production of FYM at the farm level, using weed biomass and crop residues, could reduce the cost of FYM. In addition, adapting transplanter to suit to younger seedlings can also significantly reduce the cost of transplanting, both of which can make SRI energy and cost-efficient rice cultivation system (Das et al., 2014; Islam et al., 2013).

The net economic return strongly depended on the grain yield of rice in different cultivation systems. In SRI and mechanized systems, net return was significantly higher than those in the conventional DSR and NT systems. Higher productivity in TRP systems made them superior in terms of net returns in comparison with the DSR systems. Among the conventional rice cultivation systems, the net return of conventional TRP was 43.2% higher than that of the conventional DSR system. Net returns from the SRI and mechanized TRP systems were statistically similar. The benefit–cost (B:C) ratio of the mechanized system was significantly higher than those of all other cultivation systems (Fig. 7). Furthermore, the B:C ration of the SRI was statistically not superior to that of the conventional TRP system. The B:C ratios of NT systems were significantly higher than that of the conventional TRP system.

Conclusion

The data support the following conclusions:

1. As much as 80% to 90% of the energy input is accounted for by the use of chemical fertilizers and manure, land preparation, and seeding or transplanting operations in rice cultivation systems practiced in the NER of India.
2. The mechanized TRP system is the most energy-intensive rice cultivation system. In comparison, the NT-DSR system is the most

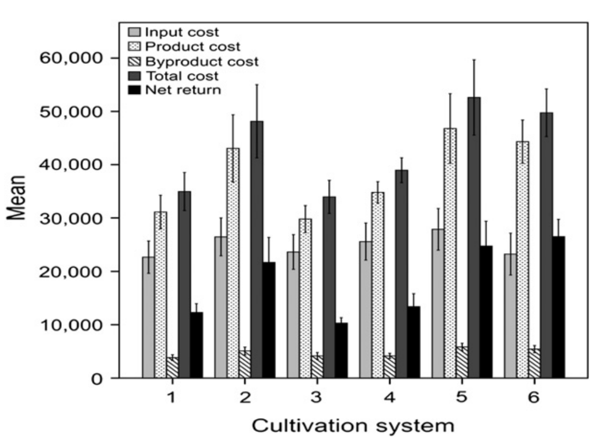

Fig. 6. Input, output cost, and net return of six rice cultivation systems. Cultivation systems: 1—conventional direct seeded (DSR), 2—conventional transplanted (TRP), 3—no-till DSR, 4—no-till TRP, 5—system of rice intensification, and 6—mechanized TRP.

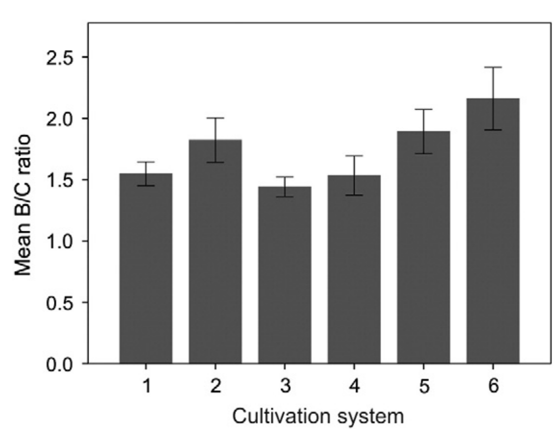

Fig. 7. Mean benefit/cost (B/C) ratio of six rice cultivation systems. Cultivation systems: 1—conventional direct seeded (DSR), 2—conventional transplanted (TRP), 3—no-till DSR, 4—no-till TRP, 5—system of rice intensification, and 6—mechanized TRP.

energy-efficient rice cultivation system, and it has the lowest energy input per unit of grain production and the highest energy productivity.

3. The NT system, with low energy input and high energy productivity, can be a viable option for the rice grower of the NER. However, SRI has a high productivity, low inputs of non-renewable energy, and the seed.
4. The SRI is an expensive rice cultivation system because of high labor input. On the contrary, the mechanized system is energy intensive but has low cost.
5. There is a strong need to combine SRI and the mechanized TRP systems. Costs can be reduced by mechanized transplanting and other operations (such as harvesting and threshing) and by farm level FYM production.

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