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Energy Budgeting and Economics of Rice Based Cropping System under Resource Conservation Technologies in Foothill of Himalayan Region

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Authors' contributions

This work was carried out in collaboration between all authors. Authors AKB and SC designed the study and wrote the experimental protocol. Author TP conducted the field trial and carried out the majority of the data analyses. Authors TP and SC performed the statistical analysis. Author TP wrote the first draft of the manuscript. All authors critically reviewed the results, contributed to the discussions and improved the manuscript.

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ABSTRACT

A field experiment was conducted at Norman E Borlaug Crop Research Center, Pantnagar, India during 2011-12 and 2012-13. The experiment was laid in a factorial split plot design with resource conservation technology practices i.e., Tillage system (conventional and reduced tillage), Mulching (no and straw mulch) and Fertility levels (100 and 75% RDF) were compared in three rice based cropping systems rice-wheat (CS_1); rice-vegetable pea-greengram (CS_2); and rice-potato-maize (CS_3) sequences. The aim of the research was to evaluate the energy use efficiency of different rice based cropping systems under resource conservation technology (RCT) practices. The results revealed that total system productivity (TSP) of cropping system was higher in reduced tillage system (9.8% higher) when compared to conventional tillage. The greatest crop sequence total

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system productivity of 21420 kg ha^{-1} was achieved with paddy straw mulched treatments. Consequently, CS_3 recorded higher total system productivity followed by rice-vegetablepea-greengram system (CS_2). The result further revealed that a combined application of RCT required 6-10% less energy requirement than conventional system while generated 99-143 and 25-52% higher output energy in CS_3 and CS_2, respectively over conventional practices in rice-wheat system (CS_1). RCT practices recorded higher efficiency of energy levels as compared to conventional systems. The economic analysis also revealed that the maximum benefits could be obtained from resource conservation practices.

Keywords: Energy; economics; fertility; mulch; reduced tillage; system productivity.

1. INTRODUCTION

Cropping systems in the Indo-Gangetic Plains (IGP) are primarily irrigated, double cropped and rice based, with wheat grown during the winter season and rice or non-rice (e.g. coarse cereals, legumes, cotton) as the subsequent monsoon crop. The stagnation of productivity growth in these intensive cropping systems has led a strong support for conservation agriculture based technologies to rebuild soil health [1,2]. The conservation agriculture principles are minimal soil disturbance, retention of crop residue mulch and a rational use of crop rotations, along with profitability at the farm level is increasingly recognized as essential for sustainable agriculture in this region.

To date, most momentous progress has been made by addressing the challenge of reducing tillage for arable crops in the IGP's rice-based systems, mainly direct seeded rice (DSR), no-till wheat and reduced tillage for other crops such as maize, legumes, potato, etc., aided by significant cost savings as well as potential crop yield increases [3].

Meanwhile, Energy input–output relationships in cropping systems vary with the crops grown in a succession, type of soils, nature of tillage operations for seedbed preparation, nature and amount of organic manure and chemical fertilizers, plant protection measures, harvesting and threshing operations, yield levels and biomass production [4]. Increasing modernization, in general, involves larger inputs of energy in crop production. It has been observed that in rice cultivation, traditional production practices involve a minimum input of energy [5]. Among the field crops, legumes involve much less energy expenditure than cereals. Consumption of energy has been increasing at a steady rate for improving the productivity in Indian agriculture, but the energy use efficiency is declining consistently [6]. Wheat was found to produce more biomass than maize in the mollisol soil of Uttarakhand, India, but the energy-use efficiency (EUE) of maize was higher than wheat [7]. However, Grain yield and energy-use efficiency of wheat were highest under no-tillage. Thus, this energetic approach in the cropping system focuses on the acceleration of the pace of crop production on one hand and the efficient utilization of farm resources particularly in the intensive cropping system on the other. The crop yield was increased with increasing fertilizer in Pantnagar, India, but reduced the energy-use efficiency. Judicious use of inputs and other agronomic practices of crop production reduced the energy cost total inputs [8].

Rice (*Oryza sativa*), based cropping system, is a predominant system in India, which covers 80% of its total area in India [9]. Rice-based crop production systems viz., rice-wheat, rice-vegetable pea- greengram and rice-potato-maize is predominant in ecological niche of IGP of India. Bio-energy utilization pattern, energy efficiency, energy output–input relationship and economics of which has rarely been quantified and analyzed under resource conservation practices for their intrinsic potential and biomass production. Thus, the information on energy input–output pattern of the rice based production systems will bridge the knowledge gap of the farming community, resource researchers and policy makers. An endeavor of this kind will facilitate the development of alternative technologies practices and energy optimal plans to save non-renewable energy inputs like chemical fertilizers, traction power, etc., on the one hand and maximize bio-energy output and sustain the production systems on the other. This paper attempts to analyze the energetics as well as productivity and economics of three predominantly rice-based production systems under resource conservation technology (rice–wheat, rice-vegetable pea- greengram and rice-potato-maize) in Mollisol soil of Uttarakhand region, India.

2. MATERIALS AND METHODS

2.1 Location, Climate and Soil

The experiment was conducted at the Norman E. Borlaug Crop Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India during 2011-12 and 2012-13 under irrigated conditions. The experiment farm is situated at latitude of 29° N and longitude of 79.3° E at an elevation of 243.8 m above mean sea level. The soil was sandy loam in texture having a pH (7.2), EC (0.14), organic carbon (0.70%), available nitrogen (196.4 kg/ha), available phosphorous (21.57 kg/ha) and available potassium (169.2 kg/ha). During the experimental period the average rainfall during 2011-12 and 2012-13 was 2750 and 2518 mm, respectively, was recorded.

2.2 Experimental Design and Treatment Details

The field trial was arranged as factorial split plot design with each plot consisted of 6.0×3.6 m. The treatments included (1) two tillage systems viz. i. Reduced tillage (Direct seeded for rice (DSR), zero tillage (ZT) for wheat and reduced tillage (RT) for vegetable pea, potato, greengram and maize crops) and ii. Conventional tillage, CT. (2) two mulch levels viz. i. No-mulch (M_0) and ii. Paddy straw mulch (M_1) in main plot. Whereas, (3) three different rice base cropping system viz. i. rice-wheat (CS_1), ii. rice-vegetable pea-greengram (CS_2) and iii. rice-potato-maize (CS3) and (4) two fertility levels viz. i. 100 and ii. 75% RDF were laid in sub plot so as totally 24 treatment combinations tested in three replication.

The two different tillage systems were performed as per recommendation of crops. Regards, mulching treatment, sundry rice straw mulch of 4.0t/ha was used as mulching material after chopped into 3-5inches pieces. Rice straw was spread manually over the soil surface to cover at least 80% of the ground area just after sowing to prevent initial soil moisture loss from mulched plots whereas, no-mulch treatment plots left as barren land. The recommended fertilizer was applied through 10-26-26 complex, urea and muriate of potash in all treatments. The weed control for rice accomplished by pre-emergency herbicide butachlor and pendimethalin at 1.0kg a.i/ha TPR and DSR, respectively, while for other crops pendimethalin and atrazin was used to manage crop-weed competition. Crop details and management practices were shown in Table 1. Recommended agronomic management practices were followed as per the local regional specific condition.

2.3 Observations Recorded

2.3.1 Total system productivity (TSP)

TSP of cropping system was calculated by using rice equivalent yield of all crops and minimum supporting prices of farm product as per recommendation of government and reported as kg ha^{-1}.

2.3.2 Energy calculation

In order to calculate input-output ratios and other energy indicators, the data were converted into output and input energy levels using equivalent energy values for each commodity and input. Energy equivalents shown in Table 2 were used for estimation.

Table 1. Agronomical details of selected crops used in experiment

Crops	Variety	Seed rate (kg ha^{-1})	Planting geometry (cm)	Recommended fertilizer dose (kg ha^{-1})
Rice	PR 113	40 kg (TPR) & 60 kg (DSR)	20×10 (TPR) & 20×0.5 (DSR)	150-60-40
Wheat	PBW 550	100 kg (CT) & 125 kg (ZT)	20 × 2.5 cm	150-60-40
Potato	Kufri Chandramukhi	1200-1500 kg	60 x 20 cm	120-80-100
Vegetable pea	Arkel	100 kg	30 ×10 cm	20-40-40
Maize	31Y45 pioneer hybrid	15 kg	60 x 30 cm	120-60-40
Green gram	Pant-5	25 kg	30 x 10 cm	25-50-0

Table 2. Energy co-efficient value of experimental inputs and outputs (MJ)

System input	Energy equivalent (EE)	Unit
1. Farm operation		
Human labour	1.95	MJ h^{-1}
Operator	1.05	MJ h^{-1}
Machinery	62.70	MJ h^{-1}
Diesel fuel	56.31	MJ L^{-1}
Oil	50.23	MJ L^{-1}
Water	1.02	MJ m^{-3}
Transportation	4.50	MJ km^{-1} ton^{-1}
2. Agro chemicals		
Nitrogen	75.46	MJ kg^{-1}
Phosphorus	13.07	MJ kg^{-1}
Potassium	11.15	MJ kg^{-1}
$ZNSO_4$	20.90	MJ kg^{-1}
Pendimethalin	421.00	MJ ai^{-1}
Atrazine	190.00	MJ ai^{-1}
Isoproturan	378.00	MJ ai^{-1}
Butachlor	388.00	MJ ai^{-1}
Other herbicide	85.00	MJ ai^{-1}
Fungicide	160.00	MJ L^{-1}
Insecticide	99.00	MJ L^{-1}
3. Crop outputs		
Paddy	14.70	MJ kg^{-1}
Wheat	14.48	MJ kg^{-1}
Vegetable pea	7.74	MJ kg^{-1}
Potato	4.06	MJ kg^{-1}
Maize	15.10	MJ kg^{-1}
Green gram	14.03	MJ kg^{-1}

Source: Gundogmus (2006)

2.3.2.1 Input and output energy

For computing input energy of various operation and inputs involved in the study the following equation was used [10]:

Input Energy(MJ ha^{-1}) =Input energy of BE + ChE + Field operation FOE (1)

Where, BE is biological energy, ChE is chemical energy, FOE is field operation energy

BE = Labour × Hours of work ha^{-1} × Energy equivalent (MJ ha^{-1}) (1a)

ChE = Fertilizer energy (FE) +Toxin energy (TE) (1b)

FE = [WF (N) × [EM (N) × E (N)] + [WF (P) × [EM (P) × E (P)] (1bi)

Where, WF (N) is recommended dose of fertilizer (kg ha^{-1}); EM (N) is pure fertilizer percent and E (N) is energy required to produce pure fertilizer. Notations of WF (P), EM (P) and E (P) correspond to above notations; P in the parenthesis is phosphorous.

$$TE = \sum(wt \times et \times Em + wt \times nt \times Nm) \quad (1bii)$$

Where, wt is toxin weight (kg); et is pure toxin per cent; Em is energy required for pure production (MJ kg^{-1}). The energy required for pure and gross herbicide material was 20% and 80%, respectively. The gross herbicide material was considered as petroleum with a 41.78 MJ L^{-1}

FOE (MJ L^{-1}) = [FC × Ee] + [MO × Ee] (1C)

Where, FC is Fuel Consumption (L h^{-1}); MO is Machinery operation h^{-1}; Ee is energy equivalent

Output energy (MJ kg^{-1}) = Product yield+ Ee (2)

2.3.2.2 Energy efficiency

The various energy efficiency viz. net energy return, energy ratio, energy profitability, energy productivity and energy specific were calculated according to bottom equations [11,12].

Net energy (MJ ha^{-1}) = Output energy (MJ ha^{-1})- Input energy (MJ ha^{-1}) (3)

Energy ratio = Output energy (MJ ha^{-1})/ Input energy (MJ ha^{-1}) (4)

Energy profitability (MJ ha^{-1}) = Net energy return (MJ ha^{-1})/Input energy (MJ ha^{-1}) (5)

Energy productivity (kg MJ^{-1} ha^{-1}) = TSP (kg ha^{-1}) / Energy input (MJ ha^{-1}) (6)

Specific energy (MJ kg^{-1} ha^{-1}) = Input energy (MJ ha-1) /TSP (kg ha^{-1}) (7)

2.3.3 Economic analysis

In order to analysis the economic condition of both conservation and conventional agriculture systems the amount of payments as labor wages or purchasing fertilizer, chemical and seed were asked from local farmers and calculated as the total cost of production. The respective crop yield was multiplied by its price as fixed by the Government of India for rice (US$ 21.13 q^{-1}), wheat (US$ 21.77 q^{-1}), vegetable pea (US$

24.19 q^{-1}), potato (US\$ 11.29 q^{-1}), maize (US\$ 21.13 q^{-1}) and greengram (US\$ 72.58 q^{-1}) crops and considered as gross income. Afterwards, the benefit-cost ratio [13] was used by dividing the gross value of production by the total cost of production per hectare to determine the best total system from benefit-cost ratio point of view. System profitability is meant net income per days.

2.4 Statistical Analysis

The data obtained in respect of various observations were statistically analyzed by the method described by Cochran and Cox [14]. The significance of "F" and "t" was tested at 5% level of significance.

3. RESULTS AND DISCUSSION

3.1 Total System Productivity

Total system productivity (TSP) in all the three cropping systems was significantly affected by different tillage, mulching and fertility (Table 4). The highest average TSP (20350 kg ha^{-1}) was recorded with RT which proved significantly superior to CT treatments (18530 kg ha^{-1}). Between mulching treatments, paddy straw mulched treatment significantly improved TSP (21420 kg ha^{-1}) than no mulch treatments (17460 kg ha^{-1}). The CS3 (26850 kg ha^{-1}) recorded higher TSP followed by CS2 (20960 kg ha^{-1}) while existing cropping systems (CS1) gave lower TSP (10500 kg ha^{-1}). Similarly, fertility levels had a significant effect on TSP and higher with F_1 (19210 kg ha^{-1}) over F_2 (17380 kg ha^{-1}) treatment.

3.2 Energetics of System

3.2.1 Energy input requirement

Energy consumption for one kilogram of different crops in cropping systems was compared as shown in Fig. 1. The total inputs of different energy level of CT had higher energy consumed, i.e., 58.49 ×103 MJ ha^{-1} and RT had the lowest i.e. 53.27 ×103 MJ ha^{-1}. Of mulching practices, application of mulch had the highest energy consumed as compared to no mulch system. An introduction of one more crop in a diversified cropping system (CS_2 and CS_3), that cropping system consumed higher energy than existing rice-wheat cropping system (CS_I). However, CS_2 registered less energy utilization as compared to CS_I due to of less energy consumption in biological and chemical energy utilization pattern by 100% RDF.

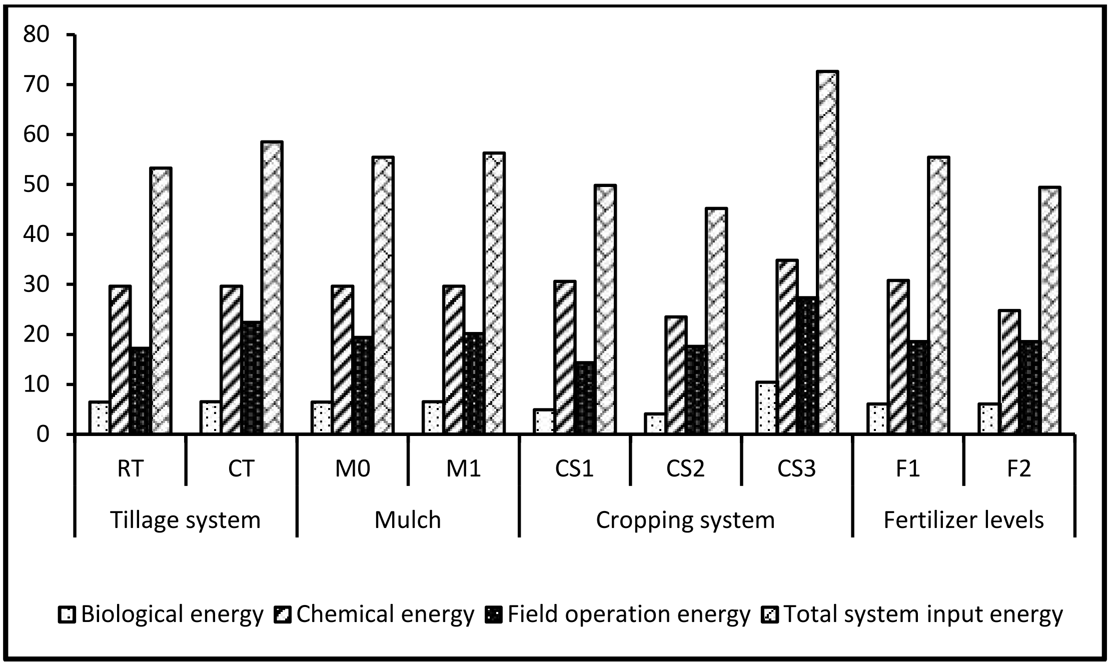

Fig. 1. Energy utilization (×10^3 MJ ha^{-1}) of rice based cropping systems under different resource conservation management practices (two year pooled data)

3.2.2 Energy input-output relationship

Results revealed that the energy output of cropping system per hectare under RT and CT was 210.3 and 190.3 x 10^3 MJ ha^{-1}, respectively (Table 3 This shows an increase of 10.5 per cent over the energy output from the RT system. Application of paddy straw mulch in the cropping system recorded higher total energy output as compared to no-mulch system. Further, experimental results showed that mulched plot increased 12.7 per cent higher output energy than no- mulched plots. The cropping system followed the rice - potato-maize (CS_3) had resulted 89.6 and 75.6 per cent higher total output energy over CS_l and CS_2, respectively. While, F_1 treatment has resulted in significantly higher total energy output as compared to F_2 treatment.

Consequently, an energy efficiency relationship, such as net energy, energy ratio, energy profitability, energy productivity, specific energy were also highest in RCT practices, i.e. RT, paddy straw mulched, diversified cropping system (CS_3 and CS_2) and 100% RDF as in comparison with conventional practices.

3.3 Economics of System

Overall, conventional method of agronomic practices was found to be the most expensive systems. As a consequence, the cost of cultivation for conventional practices, i.e. conventional tillage without mulch along with 100% RDF followed in rice-potato-maize (CS_3) was higher than resource conservation practices. These resource conservation practices showed higher gross and net return, benefit-cost ratio and system profitability (Table 4). Though the CS_3 sequence was found to be the most remunerative to the farmers with a net return of US$ 4250 ha^{-1} as compared to CS_2 (US$ 3429 ha^{-1}), the B:C ratio was higher in CS_2 (4.01) followed by CS3 (3.73). The CS_1 had lower return, B: C ratio and system profitability. Similarly, application of full fertilizer recommended dose (F_1 treatment) significantly produced a higher system return and system profitability.

3.4 Discussion

4.1.1 Total system productivity

Results from this study, tillage methods significantly affected the productivity of cropping system and total system productivity. In the rice - wheat system of the IGP, rice is grown traditionally by transplanting seedlings into puddled soil which requires large amounts of water and labor and often delays planting of the succeeding wheat crop [15]. In recent years, numerous experimental results show RCT practices on soil with no tillage, which saves on water and labor and allows timely planting of succeeding crops. The DSR is a RCT as it uses less water with high efficiency, incurs low labor expenses and is conducive to mechanization [16]. Our results indicate that an increase in rice grain yield of DSR in all three cropping systems. The difference of rice grain yield obtained under DSR from 11 to 19% over TPR. The yield attributing characters, i.e. effective tillers per square meter, panicle length, grains per panicle were higher in the DSR, which were responsible for the increased grain yield. This finding of present experimental result was also reported by Sanjeewane et al. [17] that substantially higher grain yield was recorded in DSR (3 t ha^{-1}) than TPR (2 t ha^{-1}), which was attributed to an increased panicle number, higher 1000 kernel weight and lower sterility percentage. Further observed that in DSR, there was a longer period of growth from flowering to harvest stage in the paddy field and taking more days to filling grain; an absence of transplantation shock might be a higher yield than TPR. Similar results were also reported by Hayashi et al. [18].

Many researchers have reported that rice yield could perform high when the inclusion of legumes in rice based cropping system than the sole cereal cropping system [19,20]. In both the years, wheat yield was higher in no-till than conventional practice. Also, it was higher in plots which were not puddled during previous rice crop than those puddled. Studies have shown that shallow hard pan caused by repeated puddling generally reduces root growth [21] resulting in lower tillering and ultimately grain yield. Zero tillage (ZT) management can increase both water use efficiency and wheat grain yield under IGP [22]. As a result, TSP of RT system in our experiment had significantly increased over CT system. Covering of the soil surface with straw mulch is another agronomic input with the potential to alleviate stress by both reducing water evaporation and increasing infiltration [23]. With conformity of this fact, present experimental results have shown that ZT wheat with paddy straw mulching plots increased yield by 16 per cent than CT plots. Compared to conventional ploughing systems, Nurbekov [24] argues that the lower evaporation loss of soil moisture and consequently lower salt accumulation in surface layers as the main reasons for higher yield of wheat under ZT system with a mulched field in Uzbekistan.

Mulch management, in general, and straw mulch, in particular, helped in the conservation of soil moisture in the root zone, which ultimately influenced grain yield. Higher moisture status increased root proliferation and thus enhanced availability of nutrients to crop roots [25]. This was well reflected in terms of grain yield. Similar effects have been observed in vegetable pea, greengram, potato and maize crops with mulch practices under RT. Present studies reported that RT with residue retention treatment generally had the highest yields, about 5–20% higher than the CT without residue retention treatment. These results are in agreement of Liu et al. [26] who concluded that crop residue on the soil increased soil temperature and soil water contents, improved the ecological environment of the field and increased the grain yield of maize[27]. In addition, the lower yield of all crops with 25% less fertilizer application, i.e. 75% RDF in both RT and CT. As the amount of chemical fertilizers applied with additional nutrients supplied through paddy straw might have contributed to the increase in TSP in RT plots. Calegari et al. [28] also reported that maximum grain yield had been recorded with additional nutrient source in conservation tillage practices. Hence, with these total effects, higher total system productivity was obtained in RT with paddy straw mulch and 100% RDF in rice-potato- maize (CS3) cropping system than in any other practices of the cropping system.

3.4.2 Energetics of system

The minimum energy input was occurred in RCT practices as compared to conventional practices in CS_2. There is a significant difference between conservation (RT, M_1, diversified cropping system and F_1 treatments) and conventional systems (CT, M_0, CS_1 and F2 RDF) in most of energy items, i.e. machinery, fuel, human power, seed and chemicals. Conventional tillage systems consumed 10% higher energy for the most part on biological and field operation energy due to more number of man days is required in field operation. Similarly, mulching practices also varied significantly with energy input level. Paddy straw mulched plot incurred more energy input level than no-mulched plot. This might be due to excess man days used to cover mulch material in the soil surface. However, the input energy of this system is not considerably different. An introduction of one more crop in a diversified cropping system (CS_2 and CS_3), that cropping system consumed higher energy than existing rice-wheat cropping system (CCS_I). However, CS_2 registered less energy utilization as compared to CS_I due to less energy consumption in biological and chemical energy utilization pattern by 100% RDF. The higher input energy required in CS_3 is primarily caused by seed materials of potato and maize crops. Three main energy consumers are fertilizer, diesel fuel and seed in all the systems which use near to 90% of total energy input. The low energy requirement under RCT treatments due to it reduces time, fuel as well as labor requirements. Therefore, this resource conservation practices can be adopted in regions where the resource is constraints. This conclusion is in close agreement with the findings of Kosutic et al. [29] who pointed out that soil tillage systems differ greatly with respect to energy requirements. They reported that a conservation tillage system with 192.38 MJ Mg^{-1} enabled savings of 39%, while a ZT system with only 47.14 MJ Mg^{-1} saved 85.1% in comparison to a CT system. These results supported the conclusion of several earlier investigations that the energy input requirement can be reduced with following resource conservation practices [30].

Average energy output calculated from converting crop yield of one hectare in different cropping system to Mega Joule. Although we found no detailed study regarding the effect of this RCT on the soil properties and yield in this region, this system conserves soil humidity by only disturbing on soil surface and saving residue on the soil and lead to better seed germination. Accordingly, the better yield comes from this system. Total bioenergy output (energy output of economic product) of RCT practice followed in diversified cropping system, i.e. CS_3 followed by CS_2 was higher compared to conventional practice in CS_1 system. Again, CS_3 with the highest energy input gave higher energy productivity compared to other cropping system under study probably because of high economic yield productivity of potato and maize. Consequently, RT and mulched plot gave higher energy productivity because of lesser energy input. Similarly, F_1 treatment generated higher energy productivity than F_2 treatment.

Table 3. Total system productivity and energy efficiency relationship of various rice based cropping systems under different resource conservation management practices (two year pooled data)

Treatments	TSP (kg ha^{-1})	Energy outputs ($\times 10^3$ MJ ha^{-1})	Net energy returns ($\times 10^3$ MJ ha^{-1})	Energy ratio	Energy profitability (MJ ha^{-1})	Energy productivity (kg MJ^{-1} ha^{-1})	Specific energy (MJ kg^{-1} ha^{-1})
Tillage system (T)							
Reduced tillage (RT)	20350	210.3	157.1	3.92	2.92	0.39	2.92
Conventional tillage (CT)	18530	190.3	131.8	3.19	2.19	0.31	3.58
SEm.±	52	0.65	0.65	0.01	0.01	0.01	0.01
LSD (P=0.05)	197	1.85	2.47	0.04	0.04	0.004	0.05
Mulch (M)							
No- mulch (M_0)	17460	188.4	132.9	3.35	2.35	0.32	3.51
Straw mulch (M_1)	21420	212.3	156.0	3.76	2.76	0.39	2.99
SEm.±	52	0.65	0.65	0.01	0.01	0.001	0.018
LSD (P=0.05)	197	1.85	2.47	0.04	0.04	0.004	0.05
Cropping system (CS)							
Rice-wheat (CS_1)	10500	151.2	101.4	3.06	2.06	0.21	4.80
Rice-Veg. pea- Greengram (CS_2)	20960	163.2	118.0	3.65	2.65	0.47	2.22
Rice-Potato-Maize (CS_3)	26850	286.6	214.1	3.95	2.95	0.37	2.74
SEm.±	63	0.79	0.79	0.01	0.01	0.001	0.02
LSD (P=0.05)	242	2.26	3.02	0.05	0.05	0.005	0.06
Fertilizer levels (F)							
100% RDF (F_1)	19210	197.5	142.0	3.56	2.37	0.33	3.08
75% RDF (F_2)	17380	178.2	128.4	3.58	2.40	0.34	3.03
SEm.±	52	0.65	0.65	0.01	0.01	0.01	0.01
LSD (P=0.05)	197	1.85	2.47	0.04	0.04	0.004	0.05

Table 4. Cost effective profits (US$ ha-1) of rice based cropping system under different RCT, s practices (two year pooled data)

Treatments	Cost of cultivation	Gross return	Net return	B:C ratio	System profitability ($ha^{-1}day^{-1}$)
Tillage system (T)					
Reduced tillage (RT)	1165	4446	3282	3.74	8.99
Conventional tillage (CT)	1290	4036	2746	3.03	7.52
SEm.±	-	10.97	10.99	0.01	0.03
LSD (P=0.05)	-	41.78	41.77	0.03	0.11
Mulch (M)					
No- mulch (M_0)	1162	3821	2659	3.24	7.29
Straw mulch (M_1)	1293	4661	3368	3.53	9.23
SEm.±	-	10.97	10.99	0.01	0.03
LSD (P=0.05)	-	41.78	41.77	0.03	0.11
Cropping system (CS)					
Rice-wheat (CS_1)	980	2342	1362	2.41	3.73
Rice-Veg. pea- Greengram (CS_2)	1145	4574	3429	4.01	9.39
Rice-Potato-Maize (CS_3)	1557	5807	4250	3.73	11.64
SEm.±	-	13.43	13.46	0.01	0.04
LSD (P=0.05)	-	51.17	51.15	0.04	0.14
Fertilizer levels (F)					
100% RDF (F_1)	1191	4186	2995	3.23	8.21
75% RDF (F_2)	1128	3794	2666	3.09	7.30
SEm.±	-	10.97	10.99	0.01	0.03
LSD (P=0.05)	-	41.78	41.77	0.03	0.11

Note: B:C is Benefit: Cost ratio (return per unit cost invested)

The energy use efficiency, in terms of total output energy/input energy (energy ratio), was highest in RCT practices (RT, M_1, diversified cropping system, i.e., CS_3 followed by CS_2) than conventional practices (CT, M_0, CS1). The higher energy ratio in CS_3 is attributed to the fact that although CS_3 requires higher energy inputs, potato and maize yielded much more than any other crops in cropping systems. Even though higher output energy generated by 100% RDF application, it recorded less energy use efficiency. This is attributed to the fact that F_1 application invested more input energy in terms of chemical energy was related to lesser use efficiency and F_2 recorded higher use efficiency. Further observed that F_2 gave higher energy efficiency in RCT practices than conventional practices. This result showed that one fourth of chemical input energy could be saved if follows RT as compared to CT. The same findings reported by Bockari et al. [31].

Similarly, energy profitability, energy productivity and specific energy were highest in RCT practices. Consequently, energy productivity and specific energy were great in CS_2 followed by CS_3 systems. Regarding this efficiency of the three crop sequences the results were contrary to energy use efficiency. The results confirmed the findings of Baishya and Sharma [32] in rice-wheat, Billore et al. [33] in sorghum-wheat sequence.

3.4.3 Economics of system

The maximum net return (19.51% higher) and B: C ratio (8.8% higher) was recorded in RT as compared to the CT. Bonciarelli and Archetti [34] concluded that reducing soil tillage always resulted in notable savings of fuel consumption and working time, while concerning the crop yield, very considerable differences between tillage systems were observed on crops. Verch et al. [35] in four year trial observed that RT proved to be more profitable than CT. Management practices used within the crop production system affect the energy balance of that system. The use of RT management practices for crop production is increasing because it reduces time, fuel as well as labor requirements and also reduces soil erosion on slopes. Chaudhary et al. [36] compared CT system to ZT and concluded that higher moisture retention and 13% more income was obtained in the case of ZT. Singh et al. [37] observed that that operational energy and B:C ratio were higher in CT than RT system in production of maize and wheat. While application of paddy straw mulch improved the productivity of crops. Therefore, higher net return (26.7% higher) and B: C ratio (8.9% higher) was observed with this treatment. Though, the CS_3 sequence was found to be highest net return, the B: C ratio was higher in CS_2 followed by CS_3 due to lesser cost of cultivation involved. Similar results were also obtained by Pramilarani et al. [38]. Moreover, F_1 treatment observed 12.3%, 4.5% and 12.5% higher returns, B:C ratio and total system profitability than F_2 treatment. With these monetary advantages of RCT, it was higher total system productivity.

4. CONCLUSION

The study concludes that with respect to the total system productivity, energy requirement and economics, the best results were achieved with RCT practices such that conservation tillage with mulch and 100% RDF application in the diversified cropping system. The results of the study show that the yield, energy requirement and economics of crop sequences respond to management strategies. RCT practices consumed 6-10% less energy while generated 99-143 and 25-52% higher output energy in CS_3 and CS_2, respectively, over conventional practices in the rice - wheat system (CS_1). Higher system returns, B: C ratio and profitability were earned in a combined application of RCT practices and this was 2.5 and 3 times higher when followed in CS_2 and CS_3, respectively as compared to CS_1 system under conventional practices. RT in combination with straw mulch with 75% RDF and/or no mulch with 100% RDF is advantageous in point of view of the economically (cost reduction), ecologically (less emission of pollutants and greenhouse gases). Practice of resource conservation practices in CS_2 not only improved energy efficiency, but also ecological benefit in terms of restoring soil health. So using of RCT could help farmers in resource scare regions to increase the natural resource efficiency and to decrease production cost and energy in the crop production. Thus, these holistic approaches of combined RCT practices are technically sound, agronomically efficient, economically attractive, practically feasible and ecologically safe and maybe a *win-win* technology when are adopted for long-term and are advocated for the tarai regions of the Indo-Gangetic plains of India.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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