

Original Research Article

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

ABSTRACT

A field experiment was conducted at Norman E Borlaug Crop Research Center, Pantnagar, India. The experiment was laid in a factorial split plot design with resource conservation technology practices viz. 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 (CS₁); rice-vegetable pea-greengram (CS₂); and rice-potato-maize (CS₃) 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 system productivity of 214.2 q/ha was achieved with paddy straw mulched treatments. Consequently, CS₃ recorded higher total system productivity followed by rice-vegetablepea-greengram system (CS₂). The further result 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 CS₃ and CS₂, respectively over conventional practices in rice-wheat system (CS₁). 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

17 crop rotations, along with profitability at the farm level is increasingly recognized as essential
18 for sustainable agriculture in this region.

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

23 Meanwhile, Energy input–output relationships in cropping systems vary with the crops grown
24 in a succession, type of soils, nature of tillage operations for seedbed preparation, nature
25 and amount of organic manure and chemical fertilizers, plant protection measures,
26 harvesting and threshing operations, yield levels and biomass production [4]. Increasing
27 modernization, in general, involves larger inputs of energy in crop production. It has been
28 observed that in rice cultivation, traditional production practices involve a minimum input of
29 energy [5]. Among the field crops, legumes involve much less energy expenditure than
30 cereals. Consumption of energy has been increasing at a steady rate for improving the
31 productivity in Indian agriculture, but the energy use efficiency is declining consistently [6].

32 Wheat was found to produce more biomass than maize in the mollisol soil of Uttarakhand,
33 India, but the energy-use efficiency (EUE) of maize was higher than wheat [7]. However,
34 Grain yield and energy-use efficiency of wheat were highest under no-tillage. Thus, this
35 energetic approach in the cropping system focuses on the acceleration of the pace of crop
36 production on one hand and the efficient utilization of farm resources particularly in the
37 intensive cropping system on the other. An increase fertilizer increased the crop yield in
38 Pantnagar, India, but reduced the energy-use efficiency. Judicious use of inputs and other
39 agronomic practices of crop production reduced the energy cost total inputs [8].

40 Rice (*Oryza sativa*), based cropping system, is a predominant system in India, which covers
41 80% of its total area in India [9]. Rice-based crop production systems viz., rice-wheat, rice-
42 vegetable pea- greengram and rice-potato-maize is predominant in ecological niche of IGP
43 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. MATERIAL 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

71 base cropping system viz. i. rice-wheat (CS₁), ii. rice-vegetable pea-greengram (CS₂) and iii.
 72 rice-potato-maize (CS₃) and (4) two fertility levels viz. i. 100 and ii. 75% RDF were laid in
 73 sub plot so as totally 24 treatment combinations tested in three replication.

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

85 **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)
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
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86 **2.3 Observations Recorded**

87 **2.3.1 Total system productivity (TSP)**

88 TSP of cropping system was calculated by using rice equivalent yield of all crops and
 89 minimum supporting prices of farm product as per recommendation of government and
 90 reported as q/ha.

91 **2.3.2 Energy calculation**

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

95 **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

96 Source: Gundogmus (2006)

97 2.3.2.1 Input and output energy

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

$$100 \text{ Input Energy}(\text{MJ ha}^{-1}) = \text{Input energy of BE} + \text{ChE} + \text{Field operation FOE} \quad (1)$$

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

$$102 \text{ BE} = \text{Labour} \times \text{Hours of work ha}^{-1} \times \text{Energy equivalent (MJ ha}^{-1}) \quad (1a)$$

$$103 \text{ ChE} = \text{Fertilizer energy (FE)} + \text{Toxin energy (TE)} \quad (1b)$$

$$104 \text{ FE} = [\text{WF (N)} \times [\text{EM (N)} \times \text{E (N)}] + \text{WF (P)} \times [\text{EM (P)} \times \text{E (P)}] \quad (1bi)$$

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

$$108 \text{ TE} = \sum(wt \times et \times Em + wt \times nt \times Nm) \quad (1bii)$$

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

$$FOE (MJ L^{-1}) = [FC \times Ee] + [MO \times Ee] \quad (1C)$$

Where, FC is Fuel Consumption (L h⁻¹); MO is Machinery operation h⁻¹; Ee is energy equivalent

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

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].

$$\text{Net energy (MJ ha}^{-1}\text{)} = \text{Output energy (MJ ha}^{-1}\text{)} - \text{Input energy (MJ ha}^{-1}\text{)} \quad (3)$$

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

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

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

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

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, seed and so on 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.

135 **2.4 Statistical analysis**

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

139 **3. RESULTS AND DISCUSSION**

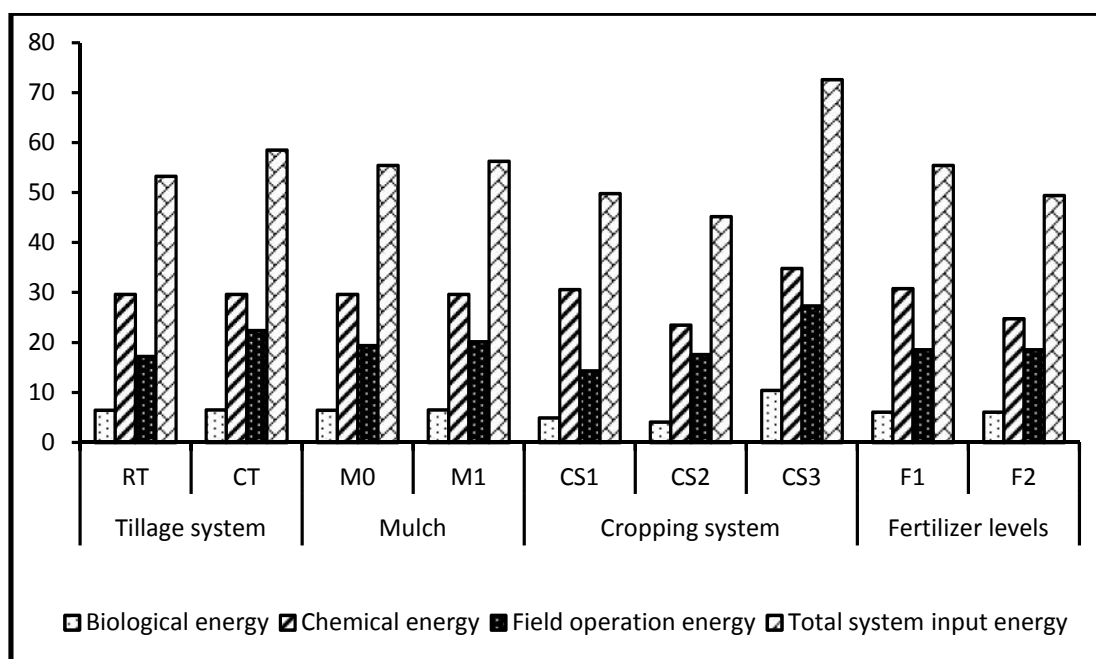
140 **3.1 Total System Productivity**

141 Total system productivity (TSP) in all the three cropping systems was significantly affected
142 by different tillage, mulching and fertility (Table 4). The highest average TSP (203.5 q ha^{-1})
143 was recorded with RT which proved significantly superior to CT treatments (185.3 q ha^{-1}).
144 Between mulching treatments, paddy straw mulched treatment significantly improved TSP
145 (214.2 q ha^{-1}) than no mulch treatments (174.6 q ha^{-1}). The CS3 (268.5 q/ha) recorded
146 higher TSP followed by CS2 (209.6 q/ha) while existing cropping systems (CS1) gave lower
147 TSP (105.0 q/ha). Similarly, fertility levels had a significant effect on TSP and higher with F_1
148 (192.1 q/ha) over F_2 (173.8 q/ha) treatment.

149 **3.2 Energetics of System**

150 **3.2.1 Energy input requirement**

151 Energy consumption for one kilogram of different crops in cropping systems was compared
152 as shown in Fig 1. The total inputs of different energy level of CT had higher energy
153 consumed, i.e., $58.49 \times 10^3 \text{ MJ ha}^{-1}$ and RT had the lowest i.e. $53.27 \times 10^3 \text{ MJ ha}^{-1}$. Of
154 mulching practices, application of mulch had the highest energy consumed as compared to
155 no mulch system. An introduction of one more crop in a diversified cropping system (CS₂
156 and CS₃), that cropping system consumed higher energy than existing rice-wheat cropping
157 system (CS₁). However, CS₂ registered less energy utilization as compared to CS₁ due to of
158 less energy consumption in biological and chemical energy utilization pattern by 100% RDF.



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

161 **3.2.2 Energy input-output relationship**

162 Results revealed that the energy output of cropping system per hectare under RT and CT
 163 was 210.3 and 190.3 $\times 10^3$ MJ ha $^{-1}$, respectively (Table 3 This shows an increase of 10.5 per
 164 cent over the energy output from the RT system. Application of paddy straw mulch in the
 165 cropping system recorded higher total energy output as compared to no-mulch system.
 166 Further, experimental results showed that mulched plot increased 12.7 per cent higher
 167 output energy than no- mulched plots. The cropping system followed the rice - potato-maize
 168 (CS₃) had resulted 89.6 and 75.6 per cent higher total output energy over CS₁ and CS₂,
 169 respectively. While, F₁ treatment has resulted in significantly higher total energy output as
 170 compared to F₂ treatment.

171 Consequently, an energy efficiency relationship, such as net energy, energy ratio, energy
 172 profitability, energy productivity, specific energy were also highest in RCT practices, i.e. RT,
 173 paddy straw mulched, diversified cropping system (CS₃ and CS₂) and 100% RDF as in
 174 comparison with conventional practices.

175 **3.3 Economics of System**

176 Overall, conventional method of agronomic practices was found to be the most expensive
177 systems. As a consequence, the cost of cultivation for conventional practices, i.e.
178 conventional tillage without mulch along with 100% RDF followed in rice-potato-maize (CS₃)
179 was higher than resource conservation practices. These resource conservation practices
180 showed higher gross and net return, benefit-cost ratio and system profitability (Table 4).
181 Though the CS₃ sequence was found to be the most remunerative to the farmers with a net
182 return of US\$ 4250 ha⁻¹ as compared to CS₂ (US\$ 3429 ha⁻¹), the B:C ratio was higher in
183 CS₂ (4.01) followed by CS₃ (3.73). The CS₁ had lower return, B: C ratio and system
184 profitability. Similarly, application of full fertilizer recommended dose (F₁ treatment)
185 significantly produced a higher system return and system profitability.

186 **4 DISCUSSIONS**

187 **4.1 Total System Productivity**

188 Results from this study, tillage methods significantly affected the productivity of cropping
189 system and total system productivity. In the rice - wheat system of the IGP, rice is grown
190 traditionally by transplanting seedlings into puddled soil which requires large amounts of
191 water and labor and often delays planting of the succeeding wheat crop [15]. In recent years,
192 numerous experimental results show RCT practices on soil with no tillage, which saves on
193 water and labor and allows timely planting of succeeding crops. The DSR is a RCT as it
194 uses less water with high efficiency, incurs low labor expenses and is conducive to
195 mechanization [16]. Our results indicate that an increase in rice grain yield of DSR in all

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

Treatments	TSP (q/ha)	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)	203.5	210.3	157.1	3.92	2.92	0.39	2.92
Conventional tillage (CT)	185.3	190.3	131.8	3.19	2.19	0.31	3.58
SEm.±	0.52	0.65	0.65	0.01	0.01	0.01	0.01
LSD (P=0.05)	1.97	1.85	2.47	0.04	0.04	0.004	0.05
Mulch (M)							
No- mulch (M ₀)	174.6	188.4	132.9	3.35	2.35	0.32	3.51
Straw mulch (M ₁)	214.2	212.3	156.0	3.76	2.76	0.39	2.99
SEm.±	0.52	0.65	0.65	0.01	0.01	0.001	0.018
LSD (P=0.05)	1.97	1.85	2.47	0.04	0.04	0.004	0.05
Cropping system (CS)							
Rice-wheat (CS ₁)	105.0	151.2	101.4	3.06	2.06	0.21	4.80
Rice-Veg. pea- Greengram (CS ₂)	209.6	163.2	118.0	3.65	2.65	0.47	2.22
Rice-Potato-Maize (CS ₃)	268.5	286.6	214.1	3.95	2.95	0.37	2.74
SEm.±	0.63	0.79	0.79	0.01	0.01	0.001	0.02
LSD (P=0.05)	2.42	2.26	3.02	0.05	0.05	0.005	0.06
Fertilizer levels (F)							
100% RDF (F ₁)	192.1	197.5	142.0	3.56	2.37	0.33	3.08
75% RDF (F ₂)	173.8	178.2	128.4	3.58	2.40	0.34	3.03
SEm.±	0.52	0.65	0.65	0.01	0.01	0.01	0.01
LSD (P=0.05)	1.97	1.85	2.47	0.04	0.04	0.004	0.05

198 **Table 4 Cost effective profits (US\$ ha⁻¹) of rice based cropping system under different RCT,**
 199 **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

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.

4.2 Energetics of System

The minimum energy input was occurred in RCT practices as compared to conventional practices in CS₂. There is a significant difference between conservation (RT, M₁, diversified cropping system and F₁ treatments) and conventional systems (CT, M₀, CS₁ 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 (CS₂ and CS₃), that cropping system consumed higher energy than existing

254 rice-wheat cropping system (CCS₁). However, CS₂ registered less energy utilization as
 255 compared to CS₁ due to less energy consumption in biological and chemical energy
 256 utilization pattern by 100% RDF. The higher input energy required in CS₃ is primarily caused
 257 by seed materials of potato and maize crops. Three main energy consumers are fertilizer,
 258 diesel fuel and seed in all the systems which use near to 90% of total energy input. The low
 259 energy requirement under RCT treatments due to it reduces time, fuel as well as labor
 260 requirements. Therefore, this resource conservation practices can be adopted in regions
 261 where the resource is constraints. This conclusion is in close agreement with the findings of
 262 Kosutic *et al.*, [29] who pointed out that soil tillage systems differ greatly with respect to
 263 energy requirements. They reported that a conservation tillage system with 192.38 MJ Mg⁻¹
 264 enabled savings of 39%, while a ZT system with only 47.14 MJ Mg⁻¹ saved 85.1% in
 265 comparison to a CT system. These results supported the conclusion of several earlier
 266 investigations that the energy input requirement can be reduced with following resource
 267 conservation practices [30].

268 Average energy output calculated from converting crop yield of one hectare in different
 269 cropping system to Mega Joule. Although we found no detailed study regarding the effect of
 270 this RCT on the soil properties and yield in this region, this system conserves soil humidity
 271 by only disturbing on soil surface and saving residue on the soil and lead to better seed
 272 germination. Accordingly, the better yield comes from this system. Total bioenergy output
 273 (energy output of economic product) of RCT practice followed in diversified cropping system,
 274 i.e. CS₃ followed by CS₂ was higher compared to conventional practice in CS₁ system.
 275 Again, CS₃ with the highest energy input gave higher energy productivity compared to other
 276 cropping system under study probably because of high economic yield productivity of potato
 277 and maize. Consequently, RT and mulched plot gave higher energy productivity because of
 278 lesser energy input. Similarly, F₁ treatment generated higher energy productivity than F₂
 279 treatment.

The energy use efficiency, in terms of total output energy/input energy (energy ratio), was highest in RCT practices (RT, M₁, diversified cropping system, i.e., CS₃ followed by CS₂) than conventional practices (CT, M₀, CS₁). The higher energy ratio in CS₃ is attributed to the fact that although CS₃ 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 F₁ application invested more input energy in terms of chemical energy was related to lesser use efficiency and F₂ recorded higher use efficiency. Further observed that F₂ 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 CS₂ followed by CS₃ 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.

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*

307 *al.*, [37] observed that that operational energy and B:C ratio were higher in CT than RT
 308 system in production of maize and wheat. While application of paddy straw mulch improved
 309 the productivity of crops. Therefore, higher net return (26.7% higher) and B: C ratio (8.9%
 310 higher) was observed with this treatment. Though, the CS₃ sequence was found to be
 311 highest net return, the B: C ratio was higher in CS₂ followed by CS₃ due to lesser cost of
 312 cultivation involved. Similar results were also obtained by Pramilarani *et al.*, [38]. Moreover,
 313 F₁ treatment observed 12.3%, 4.5% and 12.5% higher returns, B:C ratio and total system
 314 profitability than F₂ treatment. With these monetary advantages of RCT, it was higher total
 315 system productivity.

316 **4. CONCLUSION**

317
 318 The study concludes that with respect to the total system productivity, energy requirement
 319 and economics, the best results were achieved with RCT practices such that conservation
 320 tillage with mulch and 100% RDF application in the diversified cropping system. The results
 321 of the study show that the yield, energy requirement and economics of crop sequences
 322 respond to management strategies. RCT practices consumed 6-10% less energy while
 323 generated 99-143 and 25-52% higher output energy in CS₃ and CS₂, respectively, over
 324 conventional practices in the rice - wheat system (CS₁). Higher system returns, B: C ratio
 325 and profitability were earned in a combined application of RCT practices and this was 2.5
 326 and 3 times higher when followed in CS₂ and CS₃, respectively as compared to CS₁ system
 327 under conventional practices. RT in combination with straw mulch with 75% RDF and/or no
 328 mulch with 100% RDF is advantageous in point of view of the economically (cost reduction),
 329 ecologically (less emission of pollutants and greenhouse gases). Practice of resource
 330 conservation practices in CS₂ not only improved energy efficiency, but also ecological
 331 benefit in terms of restoring soil health. So using of RCT could help farmers in resource
 332 scarce regions to increase the natural resource efficiency and to decrease production cost
 333 and energy in the crop production. Thus, these holistic approaches of combined RCT
 334 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.

337

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339

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