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Resource use efficiencies of rice grown under different crop establishment methods and fertilizer management approaches in Kaski, Nepal

Kiran Pariyar [1*], Lal Prasad Amgain [2], Tika Bahadur Karki [3], Sambat Ranabhat [4]

[1]Institute of Agriculture and Animal Sciences, Kathmandu, Nepal
[2]Faculty of Agriculture, Far-Western University, Mahendranagar, Kanchanpur, Nepal
[3]Nepal Agriculture Research Council, Kathmandu, Nepal
[4]Agriculture and Forestry University, Rampur, Chitwan, Nepal

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Md Moshiul Islam
moshiul@bsmrau.edu.bd

*Corresponding Author
Kiran Pariyar
keyrun1991@gmail.com

ABSTRACT

The conventional transplanting of rice production system and farmers ignorance about proper fertilizer application has been a major problem in rice production and resource conservation in Nepal. To address the problem of resource conservation, an experiment was conducted in Kaski, Nepal during the rainy season of 2019. The experimental set up was in strip plot design consisting of three crop establishment methods- (i) zero-till dry direct-seeded rice (ZT-DSR), (ii) reduced-till dry direct-seeded rice (RT-DSR) and (iii) transplanted rice (TPR) and four site-specific nutrient management (SSNM) options- (i) nutrient expert (NE Model), (ii) leaf color chart (LCC), (iii) chlorophyll content meter-200 (CCM-200) and (iv) farmers fertilizer practice (FFP) with three replications in the fields. Among the establishment methods, TPR performed better in terms of grain yield and nutrient uses, whereas ZT-DSR was superior in terms of profitability and energy use. Among the nutrient management, CCM-200 showed promising performance with significantly higher grain nitrogen uptake (60.5 kg ha^{-1}), straw nitrogen uptake (24.11 kg ha^{-1}) and total nitrogen uptake (84.6 kg ha^{-1}) than other nutrient management practices. The energy input in ZT-DSR and RT-DSR were 41.8% and 32.9% lower than the TPR. The energy use efficiency (EUE) was higher in ZT-DSR (15.79) and FFP (15.07) as compared to other crop establishment methods and fertilizer management approaches. The ZT-DSR with FFP had the highest EUE (20.94) followed by ZT-DSR with LCC (15.0). Whereas, the highest grain yield and B:C ratio was recorded on TPR with CCM-200 and ZT-DSR with CCM-200 respectively. Thus, considering the great importance of yield and profitability at the farmers' level, combination of ZT-DSR and CCM-200 may be recommended to farmers.

Keywords: Direct seeded rice, transplanted, nutrient uptake, energy use, profitability

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1 Introduction

Rice (*Oryzae sativa*) is the most cultivated crop in Nepal in terms of area (56.42% of cultivated land) and productivity (3.51%) (MOALD, 2019). It has a major contribution in the food security of Nepal. However, the rice cultivation and production system in Nepal is threatened by its indulgence in puddling transplantation and farmers are rarely known about the proper fertilizer application. The puddling based rice production system has several challenges like reduced productivity, retrenched profitability due to over use of energy and labor whose cost is ever-increasing and getting scarce, increasing water crisis and the challenge of changing climatic conditions. On the other hand, the fertilizer dose recommended by the government is very general and incompetent in addressing the dynamic soil nutrient condition of soil.

Puddling practice is water, capital, and energy intensive which also deteriorates soil health (Sharma et al., 2015) and creates a poor soil-physical condition for establishment and raising of the succeeding crops (Tripathi et al., 2003). In agriculture, various resource conserving technologies (RCTs) such as zero tillage (ZT), reduced tillage and direct seeded rice (DSR) have been introduced which involve minimum soil disturbance, less energy, labor and water along with their reduced input cost, improved yield and environmental conservation. Such RCTs are supposed to be beneficial in terms of improving soil health, water use, crop productivity and farmers income (Gupta and Seth, 2007; Singh et al., 2009). DSR rice requires only 34% of the total labor and saves 29% of the total cost of the transplanted rice (Ho and Romli, 2002).

In nutrient management, SSNM is a low-tech, plant need-based approach for applying major nutrients *viz*. N, P, and K in optimal level (IRRI, 2006). SSNM enables farmers to dynamically adjust fertilizer use to fulfill the deficit between the crop nutrient needs and the nutrient supply from natural sources (Pampolino et al., 2007). The requirement of much higher input of energy in rice production is mainly due to its high water and fertilizer requirements in addition to other practices like transplanting, harvesting and threshing (Wakil, 2018). Comparatively, the fertilizer use, fuel in land preparation and seed inputs had the highest energy use. Irrigation and fertilizer are the most energy consumers in rice production (Esk et al., 2011). Pishgar-Komleh et al. (2011) found that the chemical fertilizer was the biggest energy consumer (36% of total energy usage) and followed by gasoline (19%), diesel fuel (11%), natural gas (11%) and seed energy (8%). Thus, the objective of the current study was to evaluate the yield, profitability and resource use efficiencies (nitrogen and energy) of rice grown under different crop establishment methods and SSNM approaches and the best interaction for farmers' situation of Puranchaur, Kaski and similar agro-climatic places of central Nepal.

2 Materials and Methods

A field experiment was performed at the research plots of the College of Natural Resource Management, Puranchaur of Kaski district during the rainy season (May 2019 to October 2019). The area is located at latitude 25°17′23.4″ N and longitude: 83°56′51.8″ E with an elevation of 1200 masl. The soil type is silty loam (Table 1) and climatically sub-temperate with an average annual rainfall of 3400 mm (mainly from July to September).

The experiment was laid out in a strip plot design consisting of three crop establishment methods- (i) zero-till dry direct seeded rice (ZT-DSR), (ii) reduced-till dry direct seeded rice (RT-DSR) and (iii) conventional transplanted rice (TPR); and four site-specific nutrient management (SSNM) options– (i) nutrient expert (NE Model), (ii) leaf colour chart (LCC), (iii) Chlorophyll Content Meter-200 (CCM-200), and (iv) farmers fertilizer practice (FFP) with three replications of the field in which the previous crops were mustard, potato and garlic, respectively so that we could determine the best crop establishment and nutrient management options for rice production based on the average performance. Rice variety was Khumal-4, which is a recommended variety of rice for mid-hill region of Nepal. The spacing was 20 cm × continuous sowing for ZT-DSR and RT-DSR whereas, for TPR the spacing was 20 cm × 20 cm.

The recommended dose of FYM @ 10 t ha^{-1} was applied 20 days before land preparation for direct seeding in ZT, RT and before two primary tillages in TPR plots. Urea, DAP and MOP were used for supplying nitrogen, phosphorus and potash, respectively. The full dose of P and K fertilizers based on NE were applied as basal dose in ZT-DSR and RT-DSR and also in puddling TPR. Ten LCC readings were taken in each plot by randomly selecting top most fully expanded healthy leaves. N @ 23 kg ha^{-1} was applied through urea when 6 leaves out of 10 showed the LCC reading below critical value 4. The LCC reading was taken from 21 DAS for ZT, and RT and for TPR from 14 days after transplanting and every 10 days interval repeated for 4 times. Readings were taken on by placing its middle part on the color strips of the LCC. Similarly, the CCM-200 reading was taken from 30 different points of the leaves on each plot and the average chlorophyll content index (CCI) of each plot below 35 was subjected to fertilizer with nitrogen in the form of urea at the rate of 35 kg ha^{-1} and this reading was repeated every 10 days interval for 4 times. For CCM-200, the reading was taken from 30 DAS. For FFP, the half dose of N fertilizer

Table 1. The result of soil sampling and analysis of initial fertility status of soil from the soil laboratory of Province-4, Pokhara

Particulars	Average content on composite samples			
	Rep. I	Rep. II	Rep. III	Category
Textural class	Silty loam	Silty loam	Silty loam	
PH	6.00	5.90	5.60	Acidic
Organic C (%)	4.44	4.44	4.12	Medium
Available N (%)	0.22	0.22	0.20	High
Available P (P_2O_5 kg ha^{-1})	26.44	40.42	26.94	Rep. I- Low; Rep. II-Medium; Rep. III- Low
Available K (K_2O kg ha^{-1})	169.8	225	292.2	Rep. I- Medium; Rep. II-Medium; Rep. III- High

Rep. I = mustard field, Rep. II = potato field, and Rep. III = garlic field

Table 2. Total amount of N applied for ZT, RT and TPR under different SSNM options at Puranchaur, Kaski, 2019

Fertilization method	Total N applied for ZT, RT and TPR (kg ha^{-1})	
	Replicaiton I	Replicaiton II and III
NE-Model	109	118
LCC	92	92
CCM-200	140	140
FFP	16	16

ZT-DSR= zero-till dry direct seeded rice, RT-DSR= reduced-till dry direct seeded rice, TPR= conventional transplanted rice, NE-Model= nutrient expert model, LCC= leaf colour chart, CCM-200= Chlorophyll Content Meter-200, FFP= farmers fertilizer practice.

was used at the time of seed sowing (for ZT-DSR and RT-DSR) and transplantation (for TPR) as basal dose and the remaining half dose was side-dressed during the tillering stage. The time and amount of applied N fertilizer are as shown in Table 2. Similarly, for the calculation of energy use efficiency various energy equivalents were taken from Devasenapathy et al. (2009) and Wakil (2018). The formulas for energy equivalents were used as:

Energy use efficiency (EUE)/ Energy use ratio (EUR) EUE shows the efficiency of per unit use of energy for production of output.

$$EUE = \frac{E_o}{E_i} \quad (1)$$

where E_o and E_i denote energy output and energy input in MJ, respectively.

Specific energy (SE) It is the amount of energy required for production of a unit economical yield or grain yield.

$$SE = \frac{E_i}{Y} \quad (2)$$

where SE = specific energy (MJ kg^{-1} grain), E_i = energy input, and Y = grain yield (kg).

Energy productivity (EP) = It shows the amount of output gained by a unit energy input.

$$\text{EP (kg MJ}^{-1}) = \frac{\text{Output (grain + by-product)}}{E_i} \quad (3)$$

where, E_i = energy input. Enumeration: Higher the EP ratio= Higher the efficiency of energy resource .

Energy intensity in economic terms (EI) It is the ratio of energy input to the cost of production.

$$\text{EI (MJ NRs}^{-1}) = \frac{E_i}{\text{CP}} \quad (4)$$

where E_i = energy input, and CP = cost of production (NRs ha^{-1})

3 Results and Discussion

3.1 Nitrogen uptake

The grain and straw nitrogen uptake (GNU and SNU), and total nitrogen uptake (TNU) were unaffected by the crop establishment practices (Table 3) but significantly influenced by the nutrient management approaches. Further, the interaction between crop establishment and SSNM approaches significantly influenced the SNU. The experiment revealed comparatively higher GNU and TNU under TPR (51.05 kg ha^{-1} and 66.4 kg ha^{-1} respectively) which was lower in ZT-DSR (46.63 kg ha^{-1} and 63.8 kg ha^{-1} respectively). Similarly, SNU was comparatively higher under ZT-DSR (17.12 kg ha^{-1}) which was the lowest on TPR (15.36 kg ha^{-1}). These higher nutrient uptakes in TPR may be due to the adequate availability of soil moisture and the flooded water controls the growth of weeds making it easier for more nitrogen uptake by rice. Farooq et al. (2011) reported the different nutrient dynamics in dry DSR than in TPR, as DSR follows an aerobic environment in the soil-sphere which creates a challenge for high yield and increased NUE. Previously, according to Reddy et al. (1984) the ammonium N accumulated in puddled field conditions (i.e. anaerobic condition) contributed to 60% of rice nitrogen need and higher uptake under that condition (i.e. under transplanted condition).

Furthermore, the GNU, SNU and TNU were significantly highest under CCM-200 (60.5 kg ha^{-1}, 24.11 kg ha^{-1} and 84.6 kg ha^{-1}, respectively) which may be due to need based application of nitrogen and the use of higher dose of nitrogen (120 kg ha^{-1}) than in other approaches. Contrastingly, the lowest GNU, SNU and TNU were recorded in FFP (29.06 kg ha^{-1}, 9.64 kg ha^{-1} and 38.5 kg ha^{-1}, respectively) which might be due to the lower use of nitrogen (16 kg ha^{-1}) and its blanket use. Based on the amount of N applied, there was 58.44%, 86.23% and 119.7% increase in N uptake with the application of N fertilizer from LCC, NE Model and CCM-200 respectively. Increasing the level of N application significantly increased the N uptake by rice grain and straw, resulting in the increased total N uptake. Oo et al. (2007) also found significantly higher nitrogen uptake by grain, straw and also total N uptake in 100 kg N ha^{-1} than in 50 kg N ha^{-1}.

3.2 Nitrogen economy and grain yield

Among establishment methods, TPR had comparatively higher GNU and TNU which was at par with ZT-DSR. SNU was significantly highest under ZT-DSR. Similarly, under the nutrient management, CCM-200 reported significantly highest GNU (60.50 kg ha^{-1}), SNU (24.11 kg ha^{-1}) and TNU (84.6 kg ha^{-1}), which used the total nitrogen at the rate of 140 kg ha^{-1}. Those uptakes from CCM-200 were followed by NE Model and then by LCC which used the nitrogen at an average rate of 113.5 kg ha^{-1} and 92 kg ha^{-1}, respectively. This could explain that the higher the nitrogen use higher would be the nitrogen uptake by the plants. TPR had higher uptakes because of the availability of sufficient soil moisture in the silty loam soil due to irrigation. The relationship between grain yield with GNU, SNU, TNU and total nitrogen applied were linear in nature and significant (Fig. 1A, B, C and D). Joshi et al. (2018) also reported a significant relationship of grain yield with grain nitrogen uptake, straw nitrogen uptake and total nitrogen uptake.

3.3 Nitrogen use efficiencies (NUE)

The analysis of variance elucidated the significant effect of crop establishment, nutrient management and their interaction on partial factor productivity (PFP). Internal use efficiency (IUE) was significantly affected only by nutrient management approaches (Table 3). TPR revealed significantly highest PFP (80.47) and comparatively higher IUE (71.33) which were statistically at par with RT-DSR (75.60 and 67.94, respectively). Contrastingly ZT-DSR showed the lowest PFP (70.69) and IE (66.9). Kumar and Ladha (2011) mentioned lower nitrogen use efficiency under DSR as compared to puddle TPR, which confirms with our finding. Besides, Ishii et al. (2011) described that the rice prefers ammonium (NH_4^+ –N) to nitrate (NO_3–N) as a source of N, and in the presence of those nitrogen species, rice seedlings uptake NH_4^+–N form faster than NO_3–N form (Sasakawa and Yamamoto, 1978). Further, Reddy et al. (1984) mentioned that NH_4^+–N accumulated in anaerobic conditions (Puddled TPR condition) contributed to 60% of rice nitrogen needed. The other reason for lower NH_4^+–N under anaerobic conditions might be due to nitrification of ammonium and subsequent denitrification (Zia et al., 2001) which leads to lower uptake and lower use efficiencies of applied nitrogen under DSR.

Due to nutrient management, both PFP and IUE were recorded significantly higher on FFP (175.29 and 73.37, respectively) and IUE was statistically similar with that of LCC (73.72) and contrastingly lower in CCM-200 (60.4). The result shows that the NUE decreases with an increase in fertilizer application. Ramesh and Chandrasekaran (2007) found that the PFP which indicates the efficiency of absorption of applied nitrogen decreases at a higher level of fertilizer. Also, Haque et al. (2016) observed significantly higher nitrogen use efficiency in the plots applied with 60 kg N ha^{-1} as compared to 100 kg N ha^{-1}.

Table 3. Influence of crop establishment and nutrient management practices on nitrogen uptakes of rice during monsoon season at Puranchaur, Kaski, Nepal 2019

Treatments	N uptake (kg ha^{-1})			PFP	IUE
	Grain	Straw	Total		
Crop establishment options					
ZT-DSR	46.63	17.12	63.8	70.69b	66.9
RT-DSR	46.23	15.48	61.7	75.60ab	67.94
TPR	51.05	15.36	66.4	80.47a	71.33
SEm (±)	1.78	0.611	1.98	1.299	1.034
LSD(0.05)	ns	ns	ns	5.1	ns
Nutrient management options					
NE Model	54.79b	16.91b	71.70b	41.95b	67.39b
LCC	47.53c	13.48c	61.00c	48.62b	73.72a
CCM-200	60.50a	24.11a	84.60a	36.48b	60.40c
FFP	29.06d	9.46d	38.50d	175.29a	73.37a
SEm (±)	1.218	0.843	1.25	4.042	1.285
LSD(0.05)	4.214	2.916	4.32	13.988	4.146
Interaction					
SEm (±)	3.078	1.732	3.42	4.419	2.638
LSD(0.05)	ns	5.091	ns	14.293	ns
CV (%)	12.3	23.2	10.5	4.4	8
Grand Mean	47.97	15.99	64	75.58	68.72

PFP = Partial factor productivity, IUE = Internal use efficiency

Table 4. Influence of crop establishment and nutrient management options on the energy use of rice during monsoon season at Puranchaur, Kaski, Nepal 2019

Treatments	Input energy ($\times10^3$ MJ ha^{-1})	Output energy ($\times10^3$ MJ ha^{-1})	Net energy ($\times10^3$ MJ ha^{-1})	EUE
Crop establishment options				
ZT-DSR	8.97c	132.97	124	15.79a
RT-DSR	11.92b	128.79	116.87	11.03b
TPR	12.72a	139.91	127.19	11.09b
SEm (±)	0.4043	4370.5	4370.9	0.429
LSD(0.05)	1.5875	ns	ns	1.683
Nutrient Management options				
NE Model	12.76b	149.11ab	136.34ab	11.84bc
LCC	11.37c	137.39b	126.02b	12.34b
CCM-200	14.28a	159.18a	144.90a	11.30c
FFP	6.41d	89.88c	83.48c	15.07a
SEm (±)	97.044	3982.1	3952.8	0.279
LSD(0.05)	355.814	13779.9	13678.6	0.966
Interaction				
SEm (±)	97.044	7241.7	7225.9	0.631
LSD(0.05)	355.814	ns	ns	1.909
CV (%)	0	8.4	9.1	7.8
Grand Mean	11.21	133.89	122.68	12.64

EUE = energy use efficiency

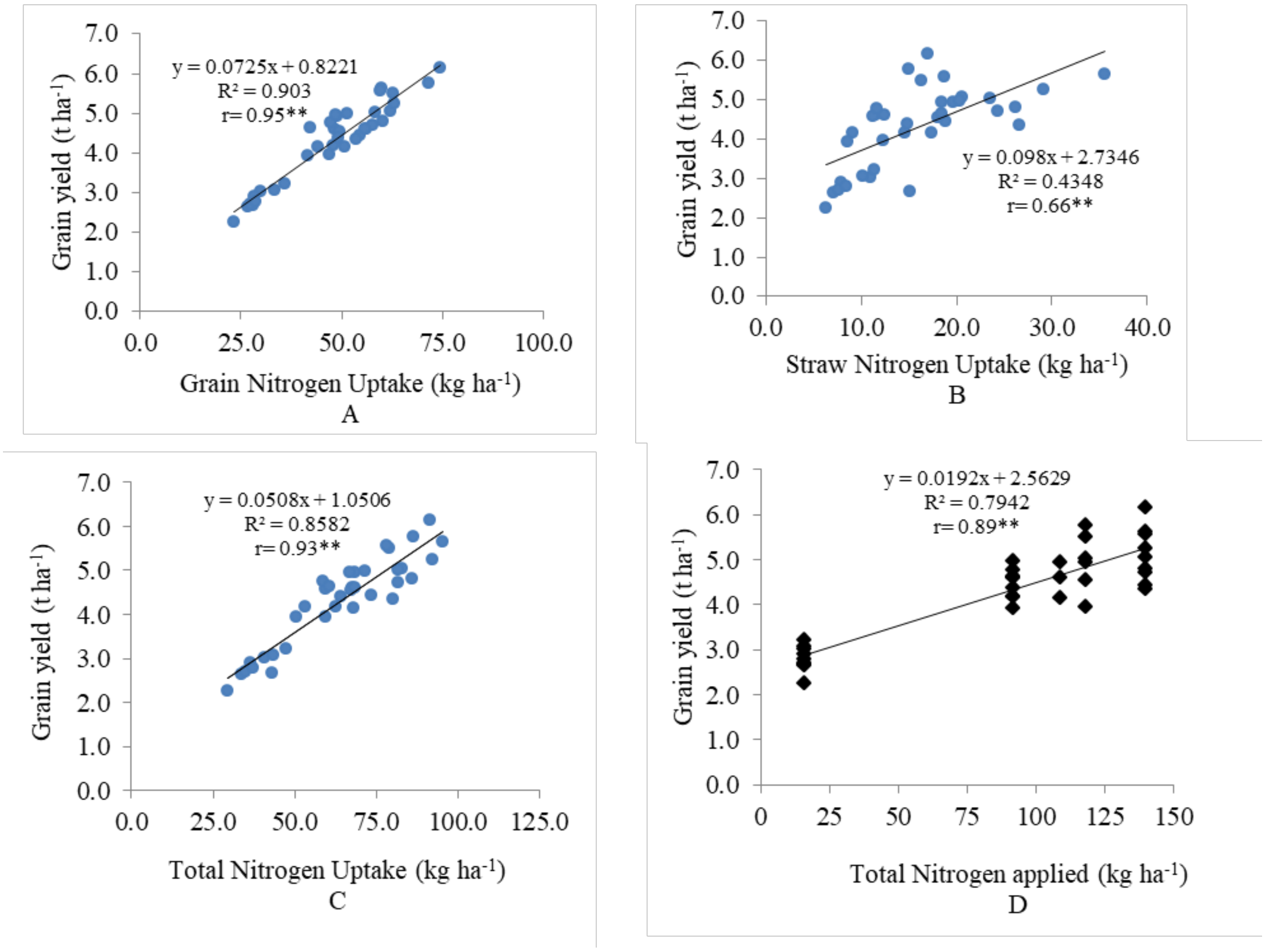

Figure 1. Relationship between the grain nitrogen uptake and grain yield of rice (A), straw nitrogen uptake and grain yield (B), total nitrogen uptake and grain yield of rice (C) and grain yield and total nitrogen applied (D) grown under different establishment methods and SSNM options in 2019 at Puranchaur, Kaski, Nepal

Table 5. Energy use efficiency as influenced by the interaction effect between the crop establishment and nutrient management during monsoon season at Puranchaur, Kaski, Nepal 2019

Nutrient Management options	Crop Establishment options		
	ZT-DSR	RT-DSR	TPR
NE Model	13.88bc	10.66f	10.99ef
LCC	15.00b	10.94ef	11.08ef
CCM-200	13.36bcd	9.97f	10.56f
FFP	20.94a	12.54cde	11.73def
SEm (±)		0.631	
LSD(0.05)		1.764	

Treatments means followed by a common letter (s) in column are not significantly different among each other based on DMRT at 5% level of significance.

Table 6. Influence of crop establishment and nutrient management practices on energy use efficiencies of rice during monsoon season at Puranchaur, Kaski, Nepal 2019

Treatments	Specific energy (MJ kg^{-1} grain)	Energy productivity (kg MJ^{-1})	Energy intensity in economic term (MJ NRs^{-1})
Crop establishment options			
ZT-DSR	2.13b	1.18a	0.13c
RT-DSR	2.86a	0.82b	0.17a
TPR	2.73a	0.82b	0.15b
SEm (±)	0.0731	0.0326	0.000102
LSD(0.05)	0.2871	0.1281	0.0004
Nutrient Management options			
NE Model	2.66ab	0.88bc	0.17b
LCC	2.55b	0.92b	0.15c
CCM-200	2.82a	0.84c	0.18a
FFP	2.27c	1.12a	0.09d
SEm (±)	0.0565	0.021	0.001243
LSD(0.05)	0.1955	0.0726	0.0043
Interaction			
SEm (±)	0.1122	0.0481	0.001252
LSD(0.05)	0.3373	0.1455	0.004302
CV (%)	6.6	8.1	0.2
Grand Mean	2.57	0.94	0.15

Treatments means followed by a common letter (s) in column are not significantly different among each other based on DMRT at 5% level of significance.

3.4 Effect of interaction on PFP

The interaction showed a significant impact on PFP with the highest value under TPR with FFP (183.51), statistically at par with RT-DSR with FFP (182.29) and contrastingly lowest on RT-DSR with CCM-200 (34.29) (Fig. 2).

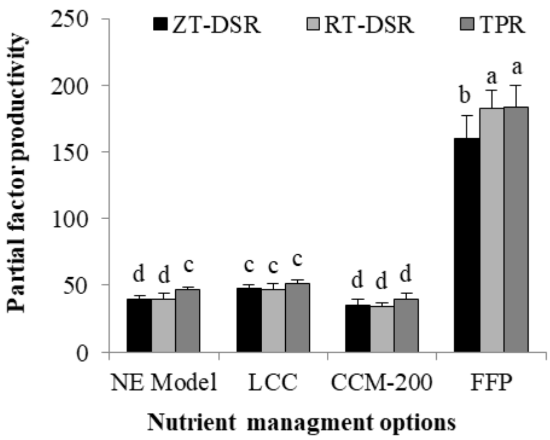

Figure 2. Partial Factor Productivity as influenced by the interaction between crop establishment and nutrient management options in 2019 at Puranchaur, Kaski

The result elucidates that PFP is higher under FFP when combined with any of the crop establishment methods and similar is the trend when TPR is combined with any SSNM approaches. The result shows that the lesser the nitrogen fertilizer applied higher will be the PFP and vice-versa. Further, the transplanted rice shows higher PFP than the zero tilled direct seeded rice.

3.5 Energy use efficiencies (EUE)

The highest input energy was recorded under TPR (12.72 x 103 MJ ha^{-1}) which was followed by RT-DSR (11.92 x 103 MJ ha^{-1}) and the lowest was in ZT-DSR (8.97 x 103 MJ ha^{-1}) (Table 4). These results indicate that crop establishment methods *viz.* ZT-DSR and RT-DSR are less energy consuming technologies than the TPR due to less energy incurred as intensive plowing, planking, nursery bed establishment, seedling uprooting and transplanting which are not required in DSR. Also, the energy input in ZT-DSR and RT-DSR is 41.8 % and 32.9% lower, respectively in comparison to TPR.

Further, a significant impact on input energy, output energy, net energy and energy efficiency was found due to nutrient management. However, the interaction effect was significant only in input energy and energy efficiency. ZT-DSR (132.97 x 103 MJ ha^{-1} and 124.00 x 103 MJ ha^{-1}, respectively) and RT-DSR (128.79 x 103 MJ ha^{-1} and 116.87 x 103 MJ ha^{-1},

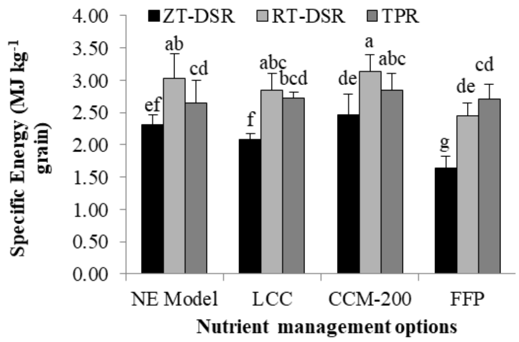

Figure 3. Specific energy as influenced by the interaction between crop establishment and nutrient management in 2019 at Puranchaur, Kaski

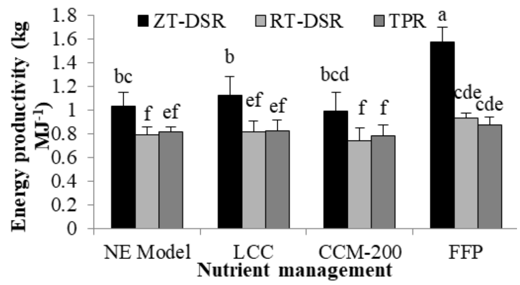

Figure 4. Energy productivity as influenced by interaction between crop establishment and nutrient management in 2019 at Puranchaur, Kaski

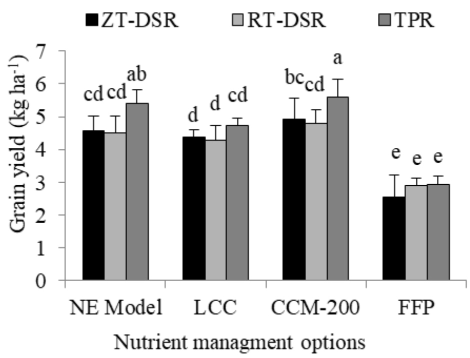

Figure 5. Effect of interaction of crop establishment and SSNM options on grain yield of rice at Puranchaur, Kaski, 2019

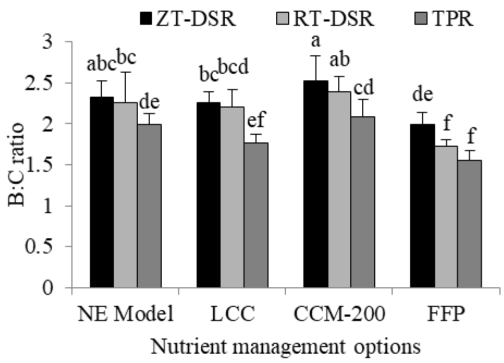

Figure 6. Effect of interaction of crop establishment and SSNM options on B:C ratio of rice at Puranchaur, Kaski, 2019

respectively) have the lowest output and net energy because of the problems of poor crop establishment and poor productivity in DSR. Similar findings were reported by Mandal et al. (2015). Despite higher output and net energy in TPR, the highest energy efficiency was found in ZT-DSR (15.79). Results from the previous studies also reported that ZT-DSR is more energy-efficient than TPR (Mandal et al., 2015; Thapa et al., 2016). Similarly, CCM-200 showed the highest input, output and net energy (14.28 x 103 MJ ha^{-1}, 159.18 x 103 MJ ha^{-1} and 144.90 x 103 MJ ha^{-1}, respectively) which was statistically at par with NE Model. The result showed that energy efficiency is significantly higher in FFP (15.07) and lower in CCM-200 (11.30). These results indicate that despite higher output energy and net energy, the SSNM techniques (CCM-200, NE Model and LCC) had the lowest energy use efficiency because of the higher input energy incurred due to fertilizers used and labors involved in fertilizer. This reveals that the more energy is applied with the higher dose of fertilizer application in rice production system.

3.6 Effect of interaction on EUE

ZT-DSR with FFP has the highest EUE (20.94) followed by ZT-DSR with LCC (15.0). This is because of significantly lesser energy input in ZT-DSR and FFP in comparison to TPR and CCM-200. The higher energy input in TPR during seedling raising, field preparation and transplanting along with higher fertilizer application energy recorded significantly lowest EUE under TPR with CCM-200. ZT-DSR with SSNM methods has the highest EUE than the other crop establishment options (Table 5). The lowest EUE was, however, recorded under RT-DSR with CCM-200 (9.97).

Specific energy indicates the energy required for the production of the unit main output. That is the measure of energy required for the production of the unit kg of rice grain. The statistical analysis revealed that RT-DSR had the highest specific energy (2.86 MJ kg^{-1} grain) and energy intensity (0.17 MJ kg^{-1}) (Table 6) whereas, the lowest was found in ZT-DSR (2.13 MJ kg^{-1} and 0.13 MJ NRs^{-1}). The result showed that for the production of one kg of rice, energy input is required in the following order RT-DSR > TPR > ZT-DSR (Table 6). Similarly, ZT-DSR had the highest energy productivity (1.18 kg MJ^{-1}) and TPR recorded the lowest (0.82 kg MJ^{-1}). These results indicated that higher output per unit energy input could be produced from ZT-DSR which was followed by RT-DSR and TPR, respectively.

Moreover, the significant nutrient management effect was found in each energy use efficiency viz. specific energy and energy intensities under CCM-200 (2.82 MJ kg^{-1} grain and 0.18 MJ NRs^{-1}, respectively). The specific energy under CCM-200 was statistically at par with NE Model. The highest energy productivity was found under FFP (1.12 kg MJ^{-1}) and the lowest under CCM-200 (0.84 kg MJ^{-1}). Here, the result showed that the higher output per unit energy input is produced from FFP as compared to other SSNM which may be due to the less energy input induced by less use of N fertilizer in FFP.

3.7 Effect of interaction on SE and EP

The highest specific energy was revealed from under RT-DSR combined with CCM-200 (3.14 MJ kg^{-1} grain), followed by NE Model and LCC (Fig. 3). However, the least specific energy was recorded from ZT-DSR when combined with SSNM practices *viz.* ZT-DSR+LCC (2.08 MJ kg^{-1} grain), ZT-DSR+NE Model (2.31 MJ kg^{-1} grain) and ZT-DSR+CCM-200 (2.47 MJ kg^{-1} grain) respectively. These findings suggest that ZT-DSR requires less energy input for the production of per unit main output. Energy productivity is the estimate of the amount of energy required to produce per unit product. The analysis showed that ZT-DSR has the highest energy productivity when combined with FFP (1.57 kg MJ^{-1}, LCC (1.12 kg MJ^{-1}), NE Model (1.03 kg MJ^{-1}) and CCM-200 (0.99 kg MJ^{-1}), respectively. The RT-DSR and TPR produce less output per unit energy input in comparison to ZT-DSR when combined with the SSNM practices (Fig. 4).

3.8 Effect of interaction on yield and BCR

The comparative analysis showed a higher yield under TPR with CCM-200 (5.59 t ha^{-1}), followed by TPR with NE Model (5.40 t ha^{-1}) (Fig. 5). The lowest grain yield was recorded from the FFP with any crop establishment approaches. Contrastingly, the ZT-DSR with CCM-200 showed the highest B:C ratio (2.52) (Fig. 6). DSR with NE Model, LCC and CCM-200 showed the B:C ratio greater than 2.0. The B:C ratio in ZT-DSR with CCM-200 is 61.54% higher than in TPR with FFP. The lowest B:C ratio was recorded in TPR with FFP (1.56).

4 Conclusion

The experiment has shown the existing linear and significant effect of GNU, SNU, TNU and total nitrogen applied on the grain yield of rice. TPR reported greater nitrogen uptakes due to enough moisture availability and also CCM-200 due to a higher rate of nitrogen application. The partial factor productivity decreases at a higher level of fertilizer application. TPR with FFP showed higher PFP due to the lower use of N fertilizer. Furthermore, TPR uses more energy due to the utilization of more fuel and labor. Similarly, CCM-200 needed more energy utilized for more nitrogen fertilizer and labor required for application. ZT-DSR and FFP respectively have the highest EUE along with their combination because of significantly least energy input. However, their combination (ZT-DSR+FFP) gave the least grain yield and B:C ratio among all. Thus, we could conclude that it is not always the nutrient and energy use efficiencies, but at farmers' level, yield and profitability take a greater priority which is found higher under ZT-DSR and CCM-200, and their combination according to our experiment. Further field experimentation could be performed for the validation of this research outcome.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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