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

Kiran Pariyar1*, Lal Prasad Amgain2, Tika Bahadur Karki3, Sambat Ranabhat4

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

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
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-tropical 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 | Category                      |
|------------------------------|-------------------------------------|-------------------------------|
|                              | Rep. I     | Rep. II    | Rep. III   |                          |
| 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 (P2O5 kg ha⁻¹)   | 26.44      | 40.42      | 26.94      | Rep. I- Low; Rep. II- Medium; Rep. III- Low |
| Available K (K2O 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) |
|----------------------|---------------------------------------------|
|                      | Replication I | Replication 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.

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

\[
EUE = \frac{E_o}{E_i} \tag{1}
\]

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.

\[
SE = \frac{E_i}{Y} \tag{2}
\]

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.

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

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.

\[
EI \ (\text{MJ NRs}^{-1}) = \frac{E_i}{CP} \tag{4}
\]

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 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. Contrasting, 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\(_4^+\)) to nitrate (NO\(_3^-\)) 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                            | 60.50c| 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 (\(\times 10^3\) MJ ha\(^{-1}\)) | Output energy (\(\times 10^3\) MJ ha\(^{-1}\)) | Net energy (\(\times 10^3\) 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                                         | 88.98c                                       | 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](image)

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 10^3 MJ ha\(^{-1}\)) which was followed by RT-DSR (11.92 x 10^3 MJ ha\(^{-1}\)) and the lowest was in ZT-DSR (8.97 x 10^3 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 10^3 MJ ha\(^{-1}\) and 124.00 x 10^3 MJ ha\(^{-1}\), respectively) and RT-DSR (128.79 x 10^3 MJ ha\(^{-1}\) and 116.87 x 10^3 MJ ha\(^{-1}\), respectively).
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 10^3 MJ ha\(^{-1}\), 159.18 x 10^3 MJ ha\(^{-1}\) and 144.90 x 10^3 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.

### Acknowledgments

This manuscript has been prepared from the thesis research for the completion of MSc. Agriculture (Agronomy) from IAAS, Post-graduate program, Kirtipur. We would like to acknowledge CNRM, Puranchaur, Kaski for providing their research plots and NARC, Khumaltar for providing their assistance in lab test and reports.

### Conflict of Interest

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

### References

Devasenapathy P, Senthilkumar G, Shanmugam PM. 2009. Energy management in crop production. Indian Journal of Agronomy 54:80–90.

Esk F, Bahrami H, Asakereh A, et al. 2011. Energy survey of mechanized and traditional rice production system in Mazandaran Province of Iran. African Journal of Agricultural Research 6:2565–2570.

Farooq M, Siddique KHM, Rehman H, Aziz T, Lee DJ, Wahid A. 2011. Rice direct seeding: Experiences, challenges and opportunities.
Soil and Tillage Research 111:87–98. doi: 10.1016/j.still.2010.10.008.

Gupta R, Seth A. 2007. A review of resource conserving technologies for sustainable management of the rice–wheat cropping systems of the indo-gangetic plains (IGP). Crop Protection 26:436–447. doi: 10.1016/j.cropro.2006.04.030.

Haque ME, Bell RW, Islam MA, Rahman MA. 2016. Minimum tillage unpuddled transplanting: An alternative crop establishment strategy for rice in conservation agriculture cropping systems. Field Crops Research 185:31–39. doi: 10.1016/j.fcr.2015.10.018.

Ho NK, Romli Z. 2002. Impact of direct seeding on rice cultivation: lessons from the Muda area of Malaysia. In: Direct seeding: research issues and opportunities. Proceedings of the international workshop on direct seeding in Asian rice systems: strategic research issues and opportunities. 25-28 January 2000. Bangkok, Thailand. Los Banos: International Rice Research Institute.

IRRI. 2006. Site-specific nutrient management. http://www.irri.org/irrc/ssnm Accessed 30 December 2020.

Ishii S, Ikeda S, Minamisawa K, Senoo K. 2011. Nitrogen cycling in rice paddy environments: Past achievements and future challenges. Microbes and Environments 26:282–292. doi: 10.1264/jsme2.me11293.

Joshi PP, Marahatta S, Sah SK, Amgain LP. 2018. Simulation of growth and yield of rice varieties under varied agronomic management and changing climatic scenario in Chitwan, Nepal. Journal of Pharmacognosy and Phytochemistry SP1:681–688.

Kumar V, Ladha JK. 2011. Direct seeding of rice. In: Advances in Agronomy. Elsevier. p. 297–413. doi: 10.1016/b978-0-12-387689-8.00001-1.

Mandal S, Roy S, Das A, I RG, Lal R, Verma BC, Kumar A, Singh RK, Layek J. 2015. Energy efficiency and economics of rice cultivation systems under subtropical Eastern Himalaya. Energy for Sustainable Development 28:115–121. doi: 10.1016/j.esd.2015.08.002.

MOALD. 2019. Statistical information on Nepalese agriculture. Agri-Business Promotion and Statistics Division. Ministry of Agriculture and Development. Singhadurbar, Kathmandu, Nepal.

Oo NML, Shivay YS, Kumar D. 2007. Effect of nitrogen and sulphur fertilization on yield attributes, productivity and nutrient uptake of aromatic rice (Oryza sativa). Indian Journal of Agricultural Sciences 77:772.

Pampolino MF, Manguiat IJ, Ramanathan S, Gines HC, Tan FS, Chi TTN, Rajendran R, Buresh RJ. 2007. Environmental impact and economic benefits of site-specific nutrient management (SSNM) in irrigated rice systems. Agricultural Systems 93:1–24. doi: 10.1016/j.agsy.2006.04.002.

Fishgar-Komleh SH, Sefeedpari P, Rafiee S. 2011. Energy and economic analysis of rice production under different farm levels in Gilan province of Iran. Energy 36:5824–5831. doi: 10.1016/j.energy.2011.08.044.

Ramesh S, Chandrasekaran B. 2007. Effect of establishment techniques and nitrogen management on the leaf nitrogen concentration (Inc), flowering, nitrogen use efficiency and quality of rice hybrid (Oryza sativa L.) ADTRH1. Agricultural Journal 2:38–45.

Reddy KR, Patrick WH, Broadbent FE. 1984. Nitrogen transformations and loss in flooded soils and sediments. C R C Critical Reviews in Environmental Control 13:273–309. doi: 10.1080/10643388409381709.

Sasakawa H, Yamamoto Y. 1978. Comparison of the uptake of nitrate and ammonium by rice seedlings. Plant Physiology 62:665–669. doi: 10.1104/pp.62.4.665.

Sharma PK, Ladha JK, Bhushan L. 2015. Soil physical effects of puddling in rice-wheat cropping systems. In: Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. p. 97–113. doi: 10.2134/asaspecpub65.e5.

Singh UP, Singh Y, Kumar V, Ladha JK. 2009. Evaluation and promotion of resource conserving tillage and crop establishment technique in the rice-wheat system of eastern India. In: Ladha et al. (Ed.), integrated crop and resource management in rice-wheat system of South Asia. International Rice Research Institute, Los Banos, Philippines.

Thapa K, Shrestha A, Neupane MP, Amgain LP. 2016. Assessing the Economic and Energy Use Efficiencies of Direct Seeded and Transplanted Rice (Oryza sativa L) in Lamjung, Nepal. International Journal of Applied Sciences and Biotechnology 4:172–177. doi: 10.3126/ijasbt.v4i2.14854.
Tripathi RP, Gaur MK, Rawat MS. 2003. Puddling effects on soil physical properties and rice performance under shallow water table conditions of Tarai. Journal of the Indian Society of Soil Science 51:118–124.

Wakil M. 2018. Energy-Use Efficiency of Rice Production Under Irrigation in Jere Bowl Borno State, Nigeria. American Journal of Environmental and Resource Economics 3:6. doi: 10.11648/j.ajere.20180301.12.

Zia MS, Mahmood IA, Aslam M, Yasin M, Khan MA. 2001. Nitrogen dynamics under aerobic and anaerobic soil conditions. International Journal of Agriculture & Biology 3:458–460.