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RESEARCH PAPER

Comparative Assessment of Rice Production Practices in Assam

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ABSTRACT

A comprehensive study was made to assess the agronomic, economic, environmental, and energy efficiencies of direct-seeded rice (DSR) under wet (puddled) condition as compared to the conventional farmers' practice (FP) of growing puddled transplanted rice (PTR) across different agroecological zones in Assam during *sali* (*kharif*) and *boro* (*rabi*) seasons. The study revealed that the DSR consistently outperformed the FP-PTR in respect of grain yield, with the highest increase in Barak Valley Zone (BVZ) by 1.65 t/ha and Central Brahmaputra Valley Zone (CBVZ) by 1.35 t/ha while achieving maximum yield in BVZ (5.75 t/ha). Profitability with DSR was also found superior to that of FP-TPR, with the highest record of net profit (₹ 85,000/ha) in Upper Brahmaputra Valley Zone (UBVZ). Agronomic traits, such as effective tillers and grains/panicle were consistently better in DSR, while biomass production ranged from 12.95 to 14.74 t/ha, surpassing that of FP-PTR. Environmental benefits of DSR were evidenced in terms of reduced greenhouse gas (GHG) emissions, with lowering of total emissions by 29.5% as compared to that of FP-PTR. Carbon dioxide (CO_2) emissions dropped by 53.4%, whilst methane (CH_4) and nitrous oxide (N_2O) emissions reduced by 7.7 and 9.6%, respectively, positioning DSR as a climate-smart production practice. Energy analyses highlighted the sustainability of DSR, requiring lower input energy (13.6 GJ/ha) than that of FP-PTR (17.8 GJ/ha) while generating higher output energy (279.2 GJ/ha) as compared to that of FP-PTR (216.7 GJ/ha). Net energy gains (265.5 GJ/ha) and energy use efficiency (20.5) were significantly higher in DSR, showcasing its economic and environmental advantages. However, energy productivity (grain yield per input energy) showed marginal differences with DSR (18.3 kg/MJ), being slightly lower than that of FP-PTR (18.7 kg/MJ). Overall, DSR demonstrated superior performance in terms of productivity, profitability, GHG mitigation, and energy efficiencies, making it a sustainable proposition over conventional rice production system. Further research is needed to optimize zone-specific DSR production practices with moderate yield and economic gains, especially in Lower Brahmaputra Valley Zone (LBVZ) and Hill Zone (HZ) to catalyze widespread adoption across the state of Assam.

HIGHLIGHTS

- Direct-seeded rice (DSR) under wet (puddled) condition outperformed the conventional farmers' practice (FP) of growing puddled transplanted rice (PTR) in terms of productivity and profitability across different agroecological zones of Assam.
- Compared with FP-PTR, DSR could reduce emissions of greenhouse gases, *viz.*, carbon dioxide, methane and nitrous oxide by 53.4, 7.7 and 9.6%, respectively.
- Net energy gains (265.5 GJ/ha) and energy use efficiency (20.5) were significantly higher in DSR, showcasing its economic and environmental benefits.

Keywords: Direct-seeded rice, energetics, grain yield, greenhouse gas emissions, profitability

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Rice is one of the important food staples worldwide. Around 90% of global rice production comes from Asia, whereas it is around 29% in Southeast Asia. As a resilient crop, rice production needs to be increased globally to ensure food security of expanding population. Global rice production, driven by population growth and economic development in emerging nations, is projected to increase from 510 million tons (mt) in 2023 to about 550 mt by 2030, reaching 590 mt by 2050 (Yuan *et al.* 2021). As compared to Southeast Asia, rice production is estimated to be generally higher in South Asia with major contributions from India (137.83 mt) and China (144.62 mt) in 2023. Endowed with enormous plant-soil-climate diversity, the North-Eastern Region (NER) of India not only serves as a gateway to Southeast Asia, it holds immense potentials for strategic interventions towards optimizing resource use and reducing environmental footprint, which can sustain food security and economic development in the region. Within the NER, Assam occupies the highest area under rice cultivation (~ 2.31 m ha) during three seasons of 2022-23, *viz.*, *sali* (*kharif*) or winter (June-July to November-December), *boro* (*rabi*) or spring/summer (November-December to May-June), and *ahu* (pre-*kharif*) or autumn (February-March to June-July), with annual rice production of 6.05 mt (GoA, 2024). Although rice productivity in the state of Assam was almost comparable with the national average (2.70 t/ha) during 2022-23, it was quite unstable in previous years due to prevalence of biotic and/or abiotic stresses, attributed mainly to the unpredictable and uneven distribution of rainfall. Among rice production practices, direct-seeded rice (DSR) has been gaining attention as a viable alternative to the traditional farmer's practice of puddled transplanted rice (FP-PTR), which requires intensive labour/water/energy/capital, and contributes significant emissions of greenhouse gases (GHGs), especially methane (Liu *et al.* 2015). In particular, DSR under puddled (wet) condition holds potentials in NER as well as eastern India, eliminating the need for nursery preparation and transplanting, and ensuring timely rice establishment with productivity gains (Chaudhary *et al.* 2023; Kumar *et al.* 2022). Amidst challenges posed by growing scarcities of labour and water along with impending climate change, sustainable production practices are highly crucial for ensuring food security and environmental sustainability. Besides, rice farmers face challenges with higher cultivation costs and suboptimal returns, often due to inefficient resource-use and reliance on traditional practices (Das *et al.* 2014). Mechanization offers a promising solution in reducing costs, improving productivity, and ensuring timely agricultural operations as compared to the deployment of manual or animal labour (Mandal *et al.* 2002). With these perspectives in view, a comprehensive study was undertaken to assess conventional and innovative practices of rice farming across different zones of Assam.

MATERIALS AND METHODS

Study area and experimental details

A six-year study was conducted in both wet (*sali* or *kharif)* and dry (*boro* or *rabi*) seasons across six agroecological zones of Assam during the period from 2018-19 to 2023-24. The zones were Barak Valley Zone (BVZ), Central Brahmaputra Valley Zone (CBVZ), Hill Zone (HZ), Lower Brahmaputra Valley Zone (LBVZ), North Bank Plain Zone (NBPZ), and Upper Brahmaputra Valley Zone (UBVZ), representing diverse soil and climatic conditions (Table 1). In general, the state with sub-tropical climate (warm humid summer, cool dry winter) is situated in high rainfall zone with an average annual rainfall of 2,297 mm with major receipts during monsoon months of June-September (65% of total rainfall), followed by summer months of March-May (25%), post-monsoon months of October-December (8%), and winter months of January-February (2%). The study was aimed at comparing the performance of DSR with FP-PTR under varying management practices. High-yielding rice varieties of long duration (140-155 days) group (Bahadur-Sub1, Ranjit-Sub1, Swarna-Sub1), and mid-early duration (120 days) group (BINA Dhan 11) were compared with the farmers' varieties (Lalpan, Lalganga, Baishumati) during *sali* season (n = 2,176). Similarly, in *boro* season (n = 659), medium duration (130-135 days) rice varieties (BINA Dhan11, BINA Dhan17) were compared with the farmers' varieties (Lalganga, Disang). Each zone included multiple field trials to assess different agronomic traits, yield parameters, economic viability, and environmental impact.

Table 1: Agro-climatic conditions for growing rice in different agroecological zones of Assam

Zone	Intervention districts	Soil characteristics	Climatic conditions
BVZ	Cachar	Silty clay loam to silty clay, pH 4.9-5.3, OM 2.65-3.15%, Available N: medium, Available P_2O_5: high, Available K_2O: medium	Rainfall receipt 1,400 mm and maximum temperature around 37°C during crop season; relatively higher temperature and rainfall, leading to enhanced OM decomposition in the soil
CBVZ	Morigaon, Nagaon	Sandy clay loam to clay loam, pH 4.9-5.5, OM 0.94-2.50%, Available N: low to medium, Available P_2O_5: medium, Available K_2O: low to medium	Rainfall receipt 600 mm and maximum temperature around 38°C during crop season
HZ	Karbi Anglong	Sandy loam to clay loam, pH 4.5-7.1 (possibly due to presence of free liming materials as limestone deposits in the hills), OM 1.02-2.69%, Available N: medium, Available P_2O_5: low, Available K_2O: low	Rainfall receipt 872 mm and maximum temperature around 37°C during crop season; annual rainfall as low as 800-1,200 mm; growing water scarcities; lack of effective irrigation systems or water harvesting practices
LBVZ	Barpeta, Bongaigaon, Dhubri, Goalpara, Kamrup (Metropolitan), Kamrup (Rural), Kokrajhar, Nalbari	Sandy clay loam to clay loam, pH 4.9-5.5, OM 0.94-2.50%, Available N: low to medium, Available P_2O_5: low to medium, Available K_2O: low to medium	Rainfall receipt 1,300 mm and maximum temperature around 35°C during crop season
NBPZ	Darrang, Dhemaji, Lakhimpur, Sonitpur	Sandy loam to clay loam, pH 4.5-5.1, OM 0.52-2.20%, Available N: low to medium, Available P_2O_5: low to medium, Available K_2O: low to medium	Rainfall receipt 1,000 mm and maximum temperature around 37°C during crop season
UBVZ	Golaghat, Jorhat, Sivasagar	Sandy loam to clay loam, pH 4.2-5.8, OM 1.50-3.80%, Available N: low to medium, Available P_2O_5: low to medium, Available K_2O: low to medium	Rainfall receipt 1,500 mm and maximum temperature around 37°C during crop season

BVZ: Barak Valley Zone, CBVZ: Central Brahmaputra Valley Zone, HZ: Hill Zone, LBVZ: Lower Brahmaputra Valley Zone, NBVZ: North Bank Plain Zone, OM: Organic matter, UBVZ: Upper Brahmaputra Valley Zone.

Soil and crop management

DSR method employed direct sowing of sprouted seeds on puddled (wet) soil with a drum seeder (Jat *et al.* 2022), whereas FP-PTR included nursery raising, followed by conventional puddling and manual transplantation. In DSR, the recommended doses of fertilizer nutrients ($N-P_2O_5-K_2O$ at 60-20-40 kg/ha in *sali* and 60-30-30 kg/ha in *boro*) were applied whilst farmers applied higher doses of nitrogen in the FP-PTR. Weed management involved use of pre- and post-emergence herbicides in DSR, whereas farmers generally avoided timely weeding and that too with manual weeding (15-20 labour/ha). The *sali* crop was grown as rainfed, while *boro* crop was grown under assured irrigation.

Yield estimation and production economics

Major growth and yield contributing traits were recorded under different crop establishment (CE) methods. Grain yield was determined by harvesting a representative area of each plot, followed by threshing, cleaning, and weighing to calculate the yield (t/ha). Biomass yield (grain and straw together) and harvest index (HI) were also recorded to determine the crop efficiency in converting biomass into economic yield. Economic analyses included calculating net profit based on input costs and market grain prices.

Measurement of GHG emissions

Emissions of GHGs, *viz.*, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) were measured using static chamber techniques. Samples were collected periodically and analyzed using gas chromatography. Emission data were converted into CO_2-equivalent (CO_2eq) values (kg/ha) to compare the total GHG footprint under two different CE methods.

Energy analyses

Energy analyses were made on the basis of direct (*e.g.*, labour, water, fuel) and indirect (*e.g.*, seeds, fertilizers, pesticides) energy inputs, considering every stage of farm operations, starting from land preparation to post-harvest activities (Devasenapathy *et al.* 2009). These inputs were from both renewable (e.g., human labour, water) and nonrenewable (e.g., diesel, machinery) energy sources (Singh, 2000; CAEEDAC, 2000). Human labour, machinery, diesel oil, fertilizer, pesticides and seed requirements for rice production systems were used to estimate the input energy. To study the input and output energy with regard to both the CE methods, a complete inventory of all inputs (fertilizers, seeds, plant protection chemicals, fuels, human labour, and machinery power) and outputs (both main and by-products) was prepared. Net energy was calculated as the difference between output and input energy. Energy use efficiency was calculated as the ratio between output energy and input energy. Energy productivity was expressed as the grain yield per unit of input energy, whereas energy profitability was expressed as the net energy per unit of input energy. The study compared key energy indicators (input energy, output energy, net energy, energy use efficiency, energy productivity, and energy profitability) in respect of DSR and FP-PTR systems.

RESULTS AND DISCUSSION

Growth and yield contributing traits

The results revealed that the DSR crop exhibited higher number of effective tillers/m^2 as compared to that of FP-PTR across all the agroecological zones (Table 2). Maximum number of effective tillers/m^2 in DSR was observed in BVZ (281/m^2), whereas FP-PTR recorded a lower value (241/m^2) in the same zone. Similarly, DSR outperformed FP-PTR in terms of effective tiller production in CBVZ (252/m^2 in DSR *vs*. 225/m^2 in FP-TPR) and UBVZ (235/m^2 in DSR *vs*. 222/m^2 in FP-TPR). Plant height under DSR was marginally higher across most of the zones, ranging from 106 cm (HZ) to 114 cm (BVZ). In contrast, FP-PTR recorded lower plant stature, with the tallest plants in BVZ (109 cm) and the shortest in HZ (101 cm). Total number of grains/panicle was higher under DSR in all the zones (Table 2), with the highest count in NBPZ (217), followed by HZ (212) and CBVZ (206), whereas FP-PTR exhibited lower number of grains/panicle, with its maximum record in CBVZ (198). But the number of grains/panicle was consistently higher in DSR, with the highest count in NBPZ (217), while FP-PTR registered comparatively lower values in all the zones. Notably, DSR in UBVZ recorded higher number of grains/panicle (189), significantly surpassing that of FP-PTR (152).

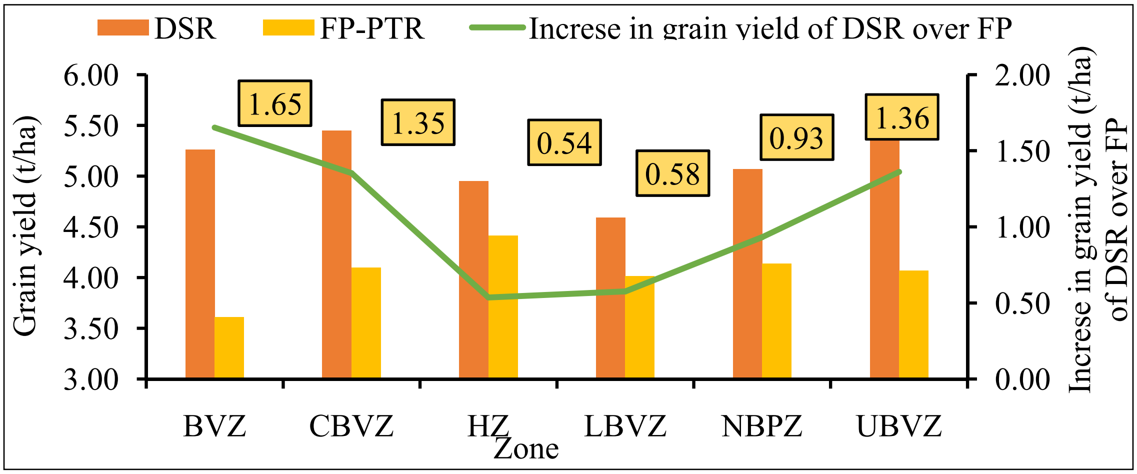
Grain yield and yield gains

Grain yield was substantially higher in DSR across all zones (Fig. 1). The highest grain yield with DSR was recorded in CBVZ (5.52 t/ha), followed by UBVZ (5.39 t/ha) and NBPZ (5.10 t/ha), whereas the FP-PTR yielded significantly lower, with the highest being 4.38 t/ha in HZ. The highest absolute yield for DSR was recorded in BVZ (~5.75 t/ha), while the FP-PTR crop performed better in UBVZ

Table 2: Growth and yield contributing traits as influenced by DSR and FP-PTR in different agroecological zones of Assam during *kharif* and *rabi* seasons (pooled data of six years)

Zone	DSR			FP-PTR		
	Plant height (cm)	Effective tillers/m^2	Grains/ panicle	Plant height (cm)	Effective tillers/m^2	Grains/ panicle
BVZ	114	281	188	109	241	178
CBVZ	110	252	206	103	225	198
HZ	104	226	212	101	223	165
LBVZ	109	245	187	104	226	186
NBPZ	111	242	217	106	227	188
UBVZ	106	235	189	108	222	152

BVZ: Barak Valley Zone, CBVZ: Central Brahmaputra Valley Zone, HZ: Hill Zone, LBVZ: Lower Brahmaputra Valley Zone, NBVZ: North Bank Plain Zone, UBVZ: Upper Brahmaputra Valley Zone.



BVZ: Barak Valley Zone, CBVZ: Central Brahmaputra Valley Zone, HZ: Hill Zone, LBVZ: Lower Brahmaputra Valley Zone, NBVZ: North Bank Plain Zone, UBVZ: Upper Brahmaputra Valley Zone

Fig. 1: Grain yield under DSR and FP-PTR in different agroecological zones of Assam during *kharif* and *rabi* seasons (pooled data of six years)

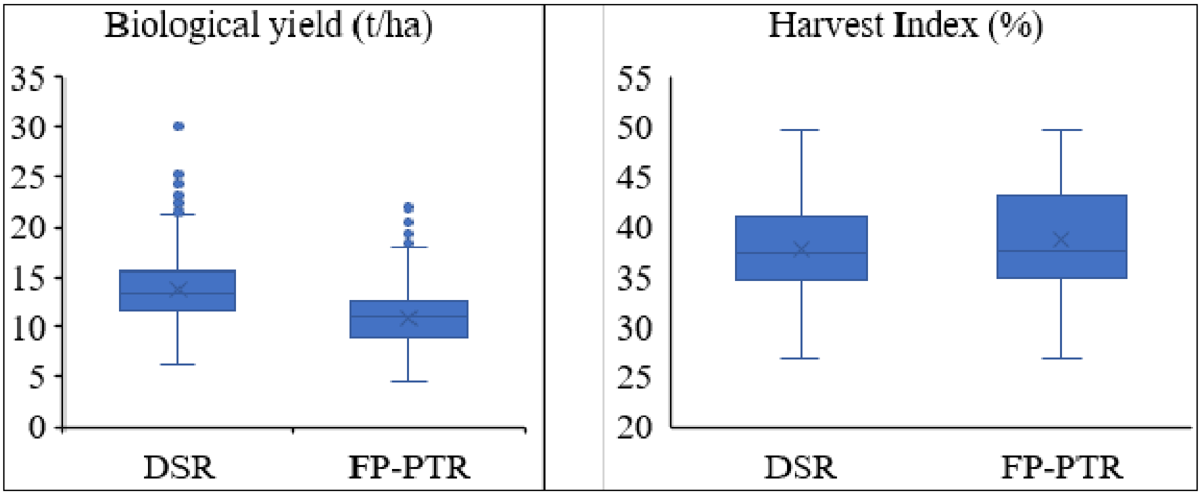


Fig. 2: Comparative assessment of biological yield and harvest index under DSR and FP-PTR in Assam during *kharif* and *rabi* seasons (pooled data of six years)

(~4.50 t/ha). The DSR crop exhibited the largest yield gain in BVZ (1.65 t/ha), followed by CBVZ (1.35 t/ha), and UBVZ (1.36 t/ha) (Fig. 1). Moderate yield gains were noted in NBPZ (0.93 t/ha), LBVZ (0.58 t/ha) and HZ (0.54 t/ha). Total crop biomass in DSR ranged from 12.95 t/ha in LBVZ to 14.74 t/ha in CBVZ, consistently exceeding that of FP-PTR, which produced a maximum of 11.68 t/ha in HZ (Fig. 2). Harvest index (HI) was comparable between the two methods, hovering around 38-39% across all zones (Fig. 2). These results strongly support the transition from FP-PTR to DSR in terms of improved agronomic efficiency and productivity, particularly in the regions like CBVZ and UBVZ. Further adaptation and localized studies might be necessary to fine-tune the newly introduced production practices for the specific conditions in the zones like LBVZ and HZ.

Production economics

The net profit of DSR and FP-PTR, along with the increase in income achieved with DSR over FP-PTR, were compared across all six zones (Fig. 3). The results revealed that DSR consistently recorded higher profits across all zones. The highest profit under DSR was observed in UBVZ (₹ 85,000/ha), followed by CBVZ and BVZ (₹ 80,000/ha each). Conversely, the FP-PTR recorded lower profits in all zones, with the highest being in UBVZ (~₹ 55,000/ha). The increase in income with DSR over FP-PTR was most prominent in UBVZ and CBVZ, with

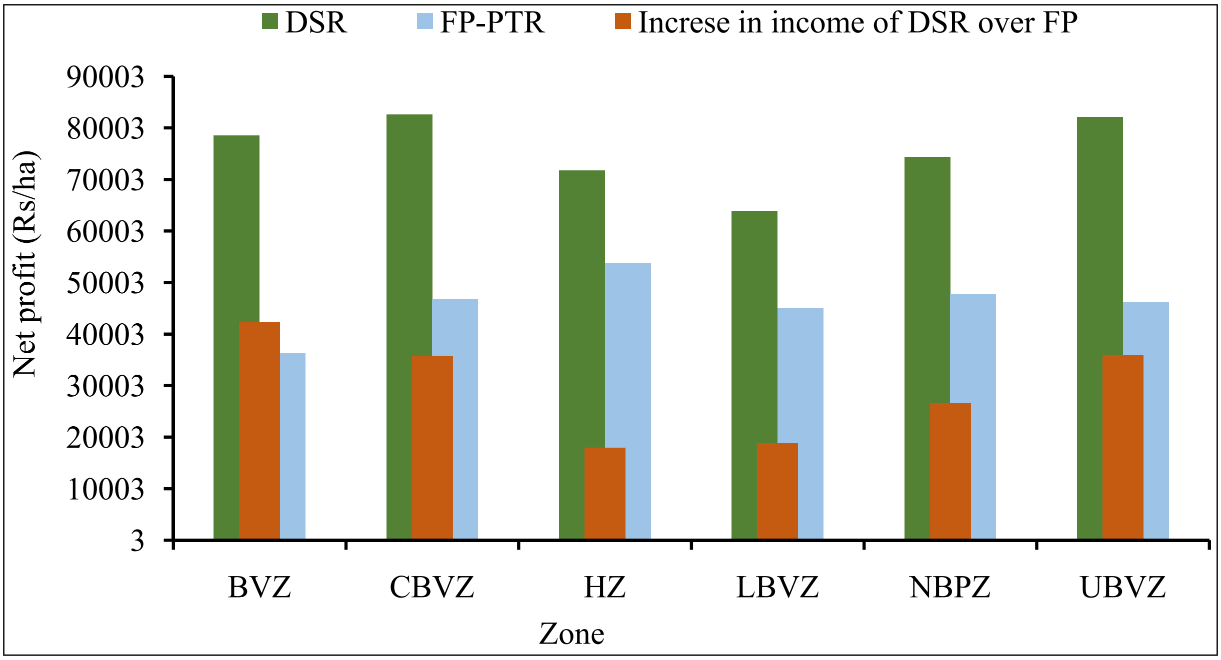


Fig. 3: Net profit under DSR and FP-PTR in different agroecological zones of Assam during *kharif* and *rabi* seasons (pooled data of six years)

substantial increases in BVZ and NBPZ. The lowest income gain from DSR was observed in LBVZ and HZ although it outperformed FP-PTR. The results revealed that the DSR not only could enhance grain yield, but also significantly improve the profitability across different agroecological zones, with the highest record of economic benefit in UBVZ.

GHG emissions

GHG emission reduction potentials of DSR were discernible as compared to that of FP-PTR. DSR significantly reduced CO_2 emissions by 53.4%, with emissions of around 2,000 kg CO_2eq/ha as compared to over 4,000 kg CO_2eq/ha for FP-PTR (Fig. 4). Similarly, DSR lowered CH_4 emissions by 7.7% and N_2O emissions by 9.6%. Overall, the total GHG emissions were reduced by 29.5% with DSR as compared to FP-PTR. These results indicated the environmental benefits of DSR, proving it as a climate-smart proposition for mitigating GHG emissions in rice production system while supporting sustainable farming practices (Srivastava *et al.* 2024).

Energetics in rice production

The study indicated significant differences in energetics (energy inputs, outputs, and efficiencies) under two different CE methods (Table 3). DSR required a lower input energy of 13.6 GJ/ha as compared to that of FP-PTR (17.8 GJ/ha), demonstrating a more energy-efficient input management in DSR. Besides, DSR exhibited a higher output energy (279.2 GJ/ha) in comparison to that of FP-PTR (216.7 GJ/ha), showcasing the superiority of DSR in terms of energy productivity. Thus, the net energy was significantly higher in DSR (265.5 GJ/ha) than that of FP-PTR (198.9 GJ/ha), indicating a better energy return on investment. Even DSR recorded higher energy use efficiency (20.5) than FP-PTR (12.2), reflecting its potential to generate more output energy per unit of input energy. Efficient energy use could not only optimize cultivation practices and reduce costs, but also could contribute in enhancing productivity and sustainability (Hatirli *et al.* 2006). The energy productivity was slightly lower in DSR (18.3 kg/MJ) as compared to that in FP-PTR (18.7 kg/MJ), suggesting marginal differences in grain production efficiency relative to input energy. However, DSR achieved a higher energy profitability (20.5), being 68% higher of FP-PTR (12.2), underlining its economic and energy-efficient advantages. These results collectively indicated that the DSR system could outperform the FP-PTR in terms of energy savings and efficiency, making it a more sustainable

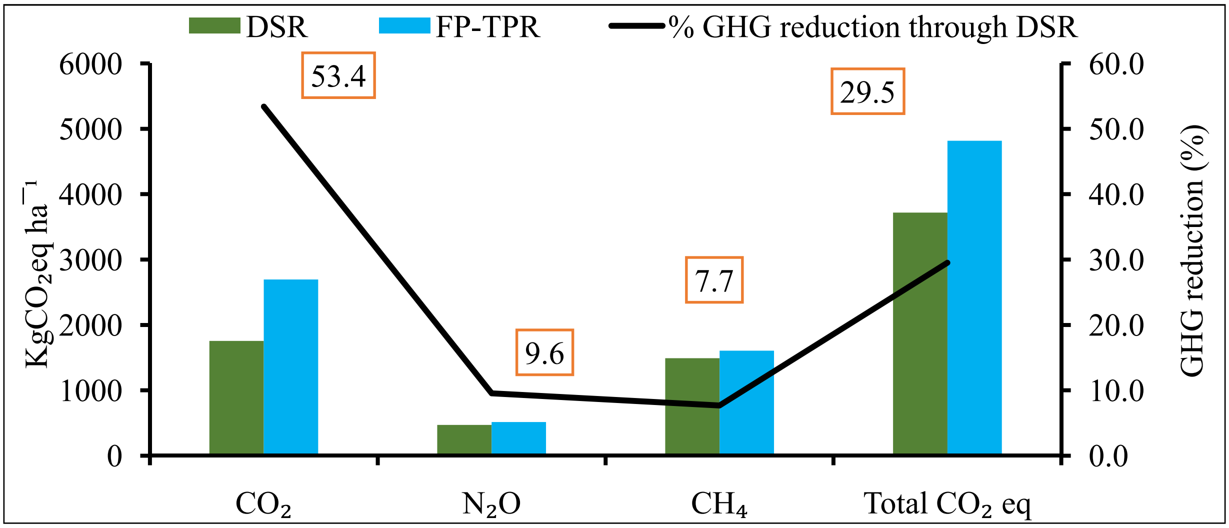


Fig. 4: Emissions of GHGs as influenced by DSR and FP-TPR in Assam during *kharif* and *rabi* seasons (pooled data of six years)

Table 3: Comparison of energy indicators under DSR and FP-PTR methods in Assam during *kharif* and *rabi* seasons (pooled data of six years)

Energy indicators	*DSR*	*FP-PTR*	*Potential gains*
Input energy (GJ/ha)	13.6	17.8	30.6% input energy addition in FP-PTR
Output energy (GJ/ha)	279.2	216.7	22.4% output energy gain in DSR due to higher biological productivity and low input use
Net energy (GJ/ha)	265.5	198.9	25.1% gain in net energy due to higher grain yield in DSR
Energy use efficiency	20.5	12.2	40.6% more energy use efficiency in DSR
Energy productivity (kg/MJ)	18.3	18.7	2.4% more energy productivity in DSR
Energy profitability	20.5	12.2	40.6% more energy profitability in DSR

option in rice production system. According to the Intergovernmental Panel on Climate Change (IPCC), DSR adoption could contribute towards ecological and economic benefits (IPCC, 2007; Sulaiman *et al.* 2018).

CONCLUSION

DSR consistently delivered higher grain yields, with notable improvements in certain zones, *viz.*, BVZ, CBVZ, and UBVZ, while achieving superior net profits, particularly in UBVZ and CBVZ. Agronomic traits such as plant height, effective tillers/m^2, number of grains/panicle, biological yield and economic yield could further underscore the agronomic efficacy of DSR. Although the HI showed similar values for both the CE methods, DSR clearly outperformed FP-PTR in terms of yield and economic benefits. Environmental analyses revealed that DSR could significantly reduce GHG emissions, particularly CO_2 (53.4% reduction) and CH_4 (7.7% reduction), making it a climate-smart alternative to the traditional practice. Additionally, the energy efficiency metrics of DSR could further reinforce its sustainability. With lower input energy requirements, higher output energy, and superior net energy gains, DSR could present a more energy-efficient and sustainable model for rice production. The remarkable energy use efficiency (20.5) and energy profitability (20.5) of DSR could further underline its economic and environmental advantages over PTR.

In conclusion, DSR could emerge as a transformative practice for sustainable rice production, offering significant agronomic, economic, and environmental benefits. While its performance proved to be robust across most of the agroecological zones, further local adaptations and studies in certain zones like LBVZ and HZ might enhance its further potentials. Thus, DSR proved to be a viable solution for sustainable intensification of rice production system, balancing productivity with environmental conservation and energy efficiency.

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REFERENCES

CAEEDAC. 2000. A descriptive analysis of energy consumption in agriculture and food sector in Canada. *Final Report*. The Canadian Agricultural Energy End-Use Data and Analysis Centre. Available at: http://www.usask.ca/agriculture/caedac/main/tpage.html.

Chaudhary, A., Venkatramanan, V., Kumar Mishra, A. and Sharma, S. 2023. Agronomic and environmental determinants of direct seeded rice in South Asia. *Circ. Econ. Sustain.*, **3**(1): 253-290.

Das, A., Patel, D.P., Munda, G.C., Ramkrushna, G.I., Kumar, M. and Ngachan, S.V. 2014. Improving productivity, water and energy use efficiency in lowland rice (*Oryza sativa*) through appropriate establishment methods and nutrient management practices in the mid-altitude of North-East India. *Exp. Agric*., **50**: 353-357.

Devasenapathy, P., Senthilkumar, G. and Shanmugam, P.M. 2009. Energy management in crop production. *Indian J. Agron*., **54**: 80-90.

GoA, 2024. *Economic Survey, Assam, 2023-24*. Government of Assam (GoA), Transformation and Development Department, Directorate of Economics & Statistics, Guwahati, Assam, India, pp. 399.

Hatirli, S.A., Ozkan, B. and Fert, C. 2006. Energy inputs and crop yield relationship in greenhouse tomato production. *Renewable Energy*, **31**(4): 427-438.

IPCC. 2007. Summary for Policymakers. *In*: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University, Cambridge, United Kingdom.

Jat, R.K., Meena, V.S., Kumar, M., Jakkula, V.S., Reddy, I.R. and Pandey, A.C. 2022. Direct seeded rice: Strategies to improve crop resilience and food security under adverse climatic conditions. *Land*, **11**(3): 382.

Kumar, N., Chhokar, R.S., Meena, R.P., Kharub, A.S., Gill, S.C., Tripathi, S.C., Gupta, O.P., Mangrauthia, S.K., Sundaram, R.M., Sawant, C.P., Gupta, A., Naorem, A., Kumar, M. and Singh, G.P. 2022. Challenges and opportunities in productivity and sustainability of rice cultivation system: A critical review in Indian perspective. *Cereal Res. Commun.*, **50**(4): 573-601.

Liu, H.Y., Hussain, S., Zheng, M.M., Peng, S.B., Huang, J.L., Cui, K.H. and Nie, L.X. 2015. Dry direct-seeded rice as an alternative to transplanted-flooded rice in Central China. *Agron. Sustain. Dev*., **35**(1): 285-294.

Mandal, K.G., Saha, K.P., Ghosh, P.K., Hati, K.M. and Bandyopalbyay, K.K. 2002. Bioenergy and economic analysis of soybean-based crop production systems in central India. *Biomass Bioenergy*, **23**: 337-345.

Singh, J.M. 2000. On farm energy use pattern in different cropping systems in Haryana, India. MSc. Thesis. University of Flensburg, Flensburg.

Srivastava, A.K., Fulford, A., Khandai, S., Kumar, V., Bhowmick, M.K., Peramaiyan, P. and Singh, S. 2024. Greenhouse gas emissions from paddy fields: Causes and mitigation strategies. (in) *Sustainable Technologies for Rice-Based Cropping System in Assam* (Singh Sudhanshu and Borgohain R, Chief Editors). Assam Agribusiness and Rural Transformation Project (APART), Assam Rural Infrastructure and Agricultural Services (ARIAS) Society, Assam Agricultural University (AAU), International Rice Research Institute (IRRI), Jorhat, Assam, India, pp. 410-446.

Sulaiman, R.V., Chuluunbaatar, D. and Vishnu, S. 2018. Upscaling Climate Smart Agriculture: Lessons for Extension and Advisory Services. FAO, Rome, Italy.

Yuan, S., Linquist, B.A., Wilson, L.T., Cassman, K.G., Stuart, A.M., Pede, V., Miro, B., Saito, K., Agustiani, N., Aristya, V.E., Krisnadi, L.Y., Zanon, A., Heinemann, A.B., Carracelas, G., Subash, N., Brahmanand, P.S., Li, T., Peng, S.B. and Grassini, P. 2021. Sustainable intensification for a larger global rice bowl. *Nat. Commun*., **12**: 7163.