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Energy and Economic Efficiency of Integrated Nutrient Management (INM) under Upland Paddy Cultivation at High Elevations of North-East India

Deity Gracia Kharlukhi[1], Kalidas Upadhyaya[1]
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ABSTRACT

Background: The study looks at integrated nutrient treatments' energy requirements and the link between energy input and output and economic benefits. The experiment was conducted during 2019 to 2020 to compare the energy budget and monetary returns under INM modules in upland paddy.

Methods: A total of 12 organic, inorganic and INM modules were evaluated employing randomised block design. Fertilizers, organic manures, bio-fertilizers *viz*., *Azospirillum lipoferum*, phosphorus solubilizing bacteria, potassium mobilizing bacteria, *Glomus* and zinc solubilizing bacteria were used.

Result: Energy output and net energy were highest with INM treatments (T_{10} - 100% recommended doses of fertilizers (RDF) + Farm Yard Manure + *Azospirillum lipoferum* + PSB + KMB + *Glomus* + ZnSB), while energy use efficiency, energy productivity and energy efficiency ratio were highest in control (T_1) in 2019 and in 2020 recorded the highest in T_{11} (*Azospirillum lipoferum* + PSB + KMB + *Glomus* + ZnSB). Other treatments, except T_{11} and T_{12} - FYM + *Azospirillum lipoferum* + PSB + KMB + *Glomus* + ZnSB, were at par. Although in T_{10} benefit cost ratio was lower than T_9 (100% of RDF + *Azospirillum lipoferum* + PSB + KMB + *Glomus* + ZnSB), T_{10} produced maximum returns than other treatments. Due to its high returns, despite the need for non-renewable resources and low energy use efficiency, integration of various soil amendments were significant for maintaining production sustainability. However, long term experimentation needed to ascertain the overall benefit of INM practices in upland paddy in hilly regions of North East India.

Key words: Bio-fertilizers, Chemical fertilizers, Economics, Energy efficiency, Organic fertilizers.

INTRODUCTION

The production of upland paddy necessitates numerous energy-intensive processes, including slashing, burning, land preparation, seeding, weeding, harvesting, threshing and winnowing. Since efficient energy usage gives the highest cost savings, resource preservation and reduction in the environment falsification, it is essential to maintain agricultural output (Demircan *et al*., 2006). Before implementing any policies on energy use and conservation during the current energy calamity, it is crucial to assess the outline of energy consumption for agricultural output (Mohanty *et al*., 2014).

When energy utilization is expressed as a unit of land, integrated nutrient farming outperforms conventional farming for nearly all crop kinds. Integrated fertilization, with its emphasis on sustainable production practices, can be a more energy efficient alternative. Making optimum use of fertilizers and other nutrition sources is a significant way for producers to save energy. As part of a soil fertility strategy, it helps to optimize fertilizer use by fertilizer placement and application, as well as the use of farm manures, bio-fertilizers and cover crops. Farmers will save money and energy by judiciously employing these management strategies. As a result, this proactive strategy in integrated nutrient systems concentrates on increasing the rate of crop production on the one hand and on the effective use of agricultural resources in particular on the other (Mandal *et al*., 2002).

[1]Department of Forestry, Mizoram University, Aizawl-796 004, Mizoram, India.

Corresponding Author: Deity Gracia Kharlukhi, Department of Forestry, Mizoram University, Aizawl-796 004, Mizoram, India.
Email: deitygracia4@gmail.com

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INM found to be sustainable from both an economic and environmental standpoint (Srinivasarao *et al*., 2020). Maximum yields and economics are achieved when organic manures, bio-fertilizers and a reduced dosage of chemical fertilizers are used to minimize pollution, boost yield and quality and preserve the health of the soil (Mounika *et al*., 2020). Nutritional integration resulted in greater profits (Mohapatra *et al*., 2013). However, the integrated treatments with the greatest cost of production had the highest benefit, gross and net returns in terms of economic viability since they increased returns by increasing the yield of the rice crop.

In light of this, a field experiment was done to assess the energetics and economic returns of upland paddy under various nutrient management techniques.

MATERIALS AND METHODS

Randomised block design with 12 treatments were executed for the study, during the year 2019 and 2020 at Lai-Lad, Jirang Block of Ri-Bhoi District, Meghalaya, India under the affiliation of Mizoram University, Aizawl, Mizoram. The area lies within 25°56′61″N latitude and 91°45′90.3″ E longitude with an elevation of 226 m above MSL and a slope of 40°.

Treatment modules were: T_1 [Control], T_2 [100 % recommended doses of fertilizers (RDF)], T_3 [100% RDF + farm yard manure (FYM)], T_4 [100% RDF + *Azospirillum lipoferum*], T_5 [100% RDF + *Glomus*], T_6 [100% RDF + zinc solubilizing bacteria (ZnSB)], T_7 [100% RDF + phosphorus solubilizing bacteria (PSB)], T_8 [100% RDF + potassium mobilising bacteria (KMB)], T_9 [100% RDF + *Azospirillum lipoferum* + PSB + KMB + *Glomus* +ZnSB] , T_{10} [100% RDF + FYM + *Azospirillum lipoferum* + PSB + KMB + *Glomus* + ZnSB], T_{11} [*Azospirillum lipoferum* + PSB + KMB + *Glomus* + ZnSB] and T_{12} [FYM + *Azospirillum lipoferum* + PSB + KMB + *Glomus* + ZnSB].

Energy

Energy efficiency of all treatments were calculated according to energy value incurred from all the input and the outputs. Using the appropriate energy conversion factors, all units of agricultural inputs were converted to energy units (Table 1).

Rupees per hectare per year (` ha^{-1} yr^{-1}) was used as a measure of financial flow. The entire amount invested served as the input component and the proceeds from sales provided the output for each treatment. All agricultural inputs were calculated using the current market price in order to analyse the monetary input (Table 2).

Energy indices

Energy indices for upland paddy have been calculated by using the following equations (Soni and Soe, 2016).

$$\text{Energy use efficiency} = \frac{\text{Total output energy (MJ ha}^{-1}\text{)}}{\text{Total input energy (MJ ha}^{-1}\text{)}}$$

$$\text{Energy productivity} = \frac{\text{Paddy yield (kg ha}^{-1}\text{)}}{\text{Total input energy (MJ ha}^{-1}\text{)}}$$

$$\text{Specific energy} = \frac{\text{Total input energy (MJ ha}^{-1}\text{)}}{\text{Paddy yield (kg ha}^{-1}\text{)}}$$

$$\text{Net energy} = \text{Total output energy (MJ ha}^{-1}\text{)} - \text{Total input energy (MJ ha}^{-1}\text{)}$$

$$\text{Energy efficiency ratio} = \frac{\text{Total output energy in main product (MJ ha}^{-1}\text{)}}{\text{Total input energy (MJ ha}^{-1}\text{)}}$$

Economics

The costs incurred from the preparation of the land through crop harvest were used to determine the economics of each treatment. The following formulae were used to determine cultivation cost as well as gross and net returns and B:C ratio.

$$\text{Gross return (Seed)} = \text{Seed yield ha}^{-1} \times \text{Price kg}^{-1}$$

$$\text{Gross return (Straw)} = \text{Straw yield ha}^{-1} \times \text{Price kg}^{-1}$$

$$\text{Total gross return} = \text{Gross return (Seed)} + \text{Gross return (Straw)}$$

$$\text{Net return} = \text{Total gross return} - \text{Total cost of cultivation}$$

$$\text{BCR} = \frac{\text{Gross returns (`)}}{\text{Cost of cultivation (`)}}$$

RESULTS AND DISCUSSION

Energy efficiency

Operational and non-operational energy requirement (crop energy requirement) and energy input-output

Both operational and non-operational energy were included in the energy inputs. In contrast to non-operational (indirect) energy, which included seed, manure, bio-fertilizers and chemical fertilizer (NPK), whereas operational (direct) energy consisted of slashing, burning, land preparation, sowing, weeding, harvesting, threshing and winnowing. Table 3 summarises the overall energy input through various

Table 1: Energy equivalents of major inputs for integrated nutrient management in upland paddy production.

Energy source		Unit	Energy equivalent (MJ unit^{-1})	Reference
1.	Direct energy input			(Upadhyaya *et al.*, 2015;
a.	Human labour-Mandays	ha	0.679	Toky and Ramakrishnan, 1982
2.	Indirect energy input			
a.	Chemical fertilizers			
i.	N	Kg	60.60	(Soni and Soe, 2016; Alipour
ii.	P	Kg	11.10	*et al.*, 2012; Ghosh *et al.*, 2021)
iii.	K	Kg	6.70	
b.	FYM	Kg	0.30	(Mandal *et al.*, 2015; Ghosh *et al.*, 2021).
c.	Bio-fertilizers	Kg	10.00	(Ram and Verma, 2015)
d.	Seeds	Kg	14.80	(Soni and Soe, 2016)
3.	Energy output			
a.	Paddy grains	Kg	14.80	(Soni and Soe, 2016)
b.	Straw	Kg	12.50	

operations, soil amendments and seed and illustrates the plots with the highest levels of integrated nutrients that produced the highest levels of energy input. Compared to alternative fertility treatments and unfertilized plots, integrated plots produced more energy output overall (Table 4).

The study's findings show that each operations under scrutiny relies mostly on human labour. It has been calculated that the larger energy intake also includes the energy consumed by human labour to carry out the processes. Upadhyaya *et al*. (2015) also reported related findings. Additionally, the integrated plots with the highest energy input are those that have applied different soil amendments. The study also demonstrated that, while energy use efficiency was constantly declining, energy consumption was rising steadily to enhance agricultural output. Pal *et al*. (1985) and Sharma and Thakur (1989) also illustrated the same findings. Hence, manures, bio-fertilizers and chemical fertilizers accounted for the majority of the energy used in the inputs for the various activities that were used on crops (Mandal *et al*., 2002). The use of integrated nutrients in the cultivation of upland paddy results in higher material and energy requirements for bio-products, chemical and manure fertilizers and labour as also reported by (Khan *et al*., 2009). However, integrated nutrient management help to significantly boost the energy production with the yield (Mihov and Tringovska, 2010). In contrast to other treatments under the research, fertility management had the highest grain energy output at the maximum energy input, most likely due to the high grain productivity (Mandal *et al*., 2002).

Table 2: Monetary input in a variety of integrated nutrient management initiatives for upland rice.

A. Operations	Monetary input (` ha^{-1} $year^{-1}$)
1. Slashing	26710.53
2. Burning	26710.53
3. Land preparation	17807.02
4. Sowing	17807.02
5. Weeding	17807.02
6. Harvesting	17807.02
7. Threshing	17807.02
8. Winnowing	17807.02
B. Seeds	1650.00
C. Fertilizers	
1. Chemical fertilizers	
a. Urea	781.20
b. SSP	1875.00
c. MOP	1032.00
2. Organic fertilizers	
a. FYM	37500.00
3. Bio-fertilizers	
a. Azospirillum lipoferum	1125.00
b. PSB	1175.00
c. KMB	1175.00
d. *Glomus* (AMF)	3150.00
e. Zinc solubilizing bacteria	1150.00

Energetics

For systematizing the various nutrient control modules, the energy budgeting have been gauged (Table 5). Highest energy use efficiency is recorded in T_1 during both the cropping years and energy ratio recorded the highest in the organically treated plot T_{11} after the second year cropping. Highest energy productivity in first year cropping was recorded in T_1 and in the second year cropping it was recorded in T_{11}. Whereas, the maximum specific energy in the first year cropping was estimated in T_2 and in the second year cropping it was found in T_3. Net energy was recorded the highest in $T_{10.}$

Energy use efficiency was shown to be significantly greater in the plots with no fertilizers, but efficiency varied significantly owing to nutrient management systems. Increasing fertilizer intensity for increased productivity is proportional to the energy consumed in production, but it

Table 3: Total input energy consumed (MJ ha^{-1}).

Treatments	Energy input through operations	Energy input through seeds	Energy input through soil amendments	Total input energy consumed
T_1	4288.42	740.00	-	5028.42
T_2	4429.88	740.00	10317.09	15486.97
T_3	4712.80	740.00	14817.09	20269.89
T_4	4514.75	740.00	10342.09	15596.84
T_5	4514.75	740.00	10504.59	15759.34
T_6	4514.75	740.00	10342.09	15596.84
T_7	4514.75	740.00	10342.09	15596.84
T_8	4514.75	740.00	10342.09	15596.84
T_9	4571.34	740.00	10604.59	15915.93
T_{10}	4854.25	740.00	15104.59	20698.84
T_{11}	4429.88	740.00	287.50	5457.38
T_{12}	4712.80	740.00	4787.50	10240.30

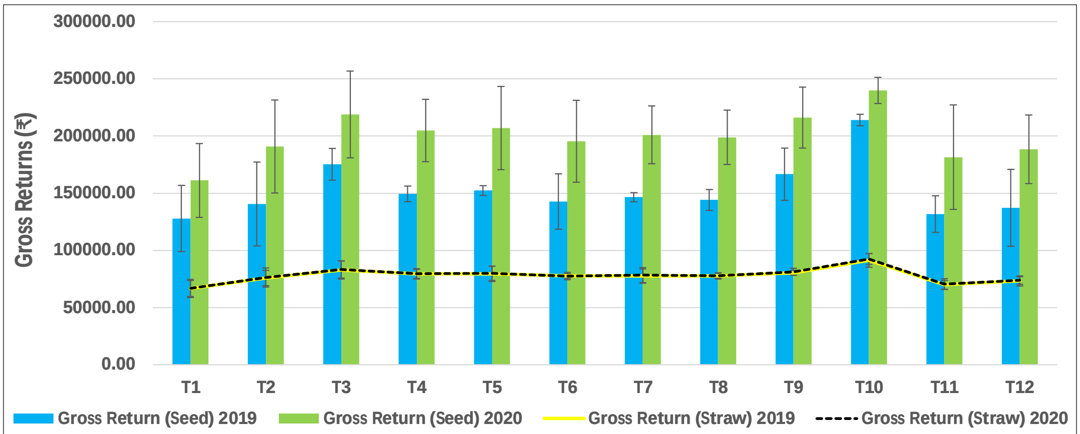
also decreases the EUE (Sharma and Thakur, 1989). The study also demonstrates that the higher energy usage efficiency in terms of output-input produced was connected to economics and is inversely proportional to the cost of cultivation.

Because of the higher system productivity, the INM module had higher net energy. The study illustrated that the net energy was considerably influenced by the various treatments, with INM application producing higher net energy and no fertilizer application producing lower net energy. This is a result of an increase in gross output relative to input energy. These conclusions are relevant to the findings by (Harika *et al*., 2020). Furthermore, the lower energy usage in the system is primarily responsible for the greater energy efficiency ratio in the no fertilizer plot. Similar results were also reported by (Lewandowska-Czarnecka *et al*., 2019).

Table 4: Total output energy consumed in cropping years (MJ ha^{-1}).

Treatments	Energy output through grain yield		Energy output through straw yield		Total output energy	
	2019	2020	2019	2020	2019	2020
T_1	57350.00	72273.33	166666.67	166666.67	224016.67	238940.00
T_2	63023.33	85593.33	189583.33	190625.00	252606.67	276218.33
T_3	78686.67	98173.33	207291.67	208333.33	285978.33	306506.67
T_4	66970.00	91883.33	198958.33	198958.33	265928.33	290841.67
T_5	68326.67	92870.00	198958.33	200000.00	267285.00	292870.00
T_6	64010.00	87690.00	193750.00	193750.00	257760.00	281440.00
T_7	65736.67	90156.67	193750.00	195833.33	259486.67	285990.00
T_8	64626.67	89170.00	193750.00	194791.67	258376.67	283961.67
T_9	74740.00	96940.00	201041.67	203125.00	275781.67	300065.00
T_{10}	95953.33	107546.67	228125.00	231250.00	324078.33	338796.67
T_{11}	59076.67	81400.00	175000.00	176041.67	234076.67	257441.67
T_{12}	61543.33	84483.33	183333.33	184375.00	244876.67	268858.33
	CD	**SE(m) ±**	**CD**	**SE(m) ±**	**CD**	**SE(m) ±**
Treatments (A)	NS	8,420.27	28,118.35*	9,845.90	41,739.30*	14,615.40
Cropping season (B)	9,817.14*	3,437.56	NS	4,019.57	17,040.00*	5,966.71
A × B	NS	11,908.06	NS	13,924.20	NS	20,669.30

*(P<0.05) significant at 0.05 level of probability.



	Gross Return (Seed) 2019-2020		**Gross Return (Straw) 2019-2020**	
	CD	**SE(m) ±**	**CD**	**SE(m) ±**
Treatments (A)	**NS**	**18,774.93**	**11,247.34***	**3,938.36**
Cropping season (B)	**21,889.56***	**7,664.83**	**NS**	**1,607.83**
A x B	**NS**	**26,551.76**	**NS**	**5,569.68**

Fig 1: INM effect on seed and straw gross return (`) for the cropping years.

Table 5: Energy use efficiency (EUE), energy productivity (Kg MJ^{-1}), specific energy (MJ Kg^{-1}), net energy (MJ ha^{-1}) and energy efficiency ratio (EER) for cropping years.

Treatments	EUE		Energy productivity		Specific energy		Net energy		EER	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
T_1	44.55	47.52	0.77	0.97	1.49	1.14	218988.25	233911.58	11.41	14.37
T_2	16.31	17.84	0.27	0.37	4.29	3.02	237119.70	260731.36	4.07	5.53
T_3	14.11	15.12	0.26	0.33	3.86	3.22	265708.44	286236.78	3.88	4.84
T_4	17.05	18.65	0.29	0.40	3.46	2.61	250331.49	275244.83	4.29	5.89
T_5	16.96	18.58	0.29	0.40	3.42	2.69	251525.66	277110.66	4.34	5.89
T_6	16.53	18.04	0.28	0.38	3.80	2.82	242163.16	265843.16	4.10	5.62
T_7	16.64	18.34	0.28	0.39	3.52	2.65	243889.83	270393.16	4.21	5.78
T_8	16.57	18.21	0.28	0.39	3.60	2.67	242779.83	268364.83	4.14	5.72
T_9	17.33	18.85	0.32	0.41	3.26	2.52	259865.74	284149.07	4.70	6.09
T_{10}	15.66	16.37	0.31	0.35	3.20	2.86	303379.49	318097.83	4.64	5.20
T_{11}	42.89	47.17	0.73	1.01	1.41	1.19	228619.29	251984.29	10.83	14.92
T_{12}	23.91	26.25	0.41	0.56	2.90	1.89	234636.37	258618.03	6.01	8.25
	CD	SE(m) ±	CD	SE(m) ±	CD	SE(m) ±	CD	SE(m) ±	CD	SE(m) ±
Treatments (A)	4.446*	1.557	0.175*	0.061	0.971*	0.340	41,738.28*	14,615.05	2.589*	0.907
Cropping season (B)	1.815*	0.635	0.071*	0.025	0.397*	0.139	17,039.58*	5,966.57	1.057*	0.370
A × B	NS	2.201	NS	0.087	NS	0.481	NS	20,668.80	NS	1.282

*(P<0.05) Significant at 0.05 level of probability.

Table 6: Total cost of cultivation (in ` ha^{-1}).

Treatments	Total input (Operational*) costs	Total input (Seeds + Fertilizers**) costs	Total (`)
T_1	1,60,263.16	1,650.00	1,61,913.16
T_2	1,60,263.16	5,338.20	1,65,601.36
T_3	1,60,263.16	42,838.20	2,03,101.36
T_4	1,60,263.16	6,463.20	1,66,726.36
T_5	1,60,263.16	8,488.20	1,68,751.36
T_6	1,60,263.16	6,488.20	1,66,751.36
T_7	1,60,263.16	6,513.20	1,66,776.36
T_8	1,60,263.16	6,513.20	1,66,776.36
T_9	1,60,263.16	13,113.20	1,73,376.36
T_{10}	1,60,263.16	50,613.20	2,10,876.36
T_{11}	1,60,263.16	9,425.00	1,69,688.16
T_{12}	1,60,263.16	46,925.00	2,07,188.16

*Operational: Slashing, burning, land preparation, sowing, weeding, harvesting, threshing, winnowing.

**Fertilizers: Urea, SSP, MOP, FYM, *Azospirillum lipoferum*, PSB, KMB, *Glomus*, ZnSB.

Additionally, the energy efficiency ratio tends to be low for larger energy input and high for lower energy input.

Economics

Cost of cultivation, net return and gross return and benefit cost ratio

Costs of the various materials utilised and the cost of their preparation per hectare were compared. Due to the greater cost of organic manures and bio-fertilizers, cultivation costs were higher with INM treatments (Table 6).

The study depicted that the cost of cultivation climbed steadily as the rate of integrated nutrient application increased and the use of chemical, organic and bio-fertilizers were linked with the greatest cost, surpassing that of all other fertility treatments. According to Baishya *et al*. (2013), the cost of cultivation also increases in direct proportion to the usage of large quantities of fertilizer modules. However, INM offered greater returns (Fig 1 and Fig 2) as compared to organic nutrient supply conforming the findings of (Hanson and Musser, 2003 and Russo and Taylor, 2006). Baishya *et al*. (2010) and Kumar *et al*. (2013) discovered that crops with integrated nutrients produced a much higher return on investment per rupee. The crop that received just organic fertilization produced a poorer return.

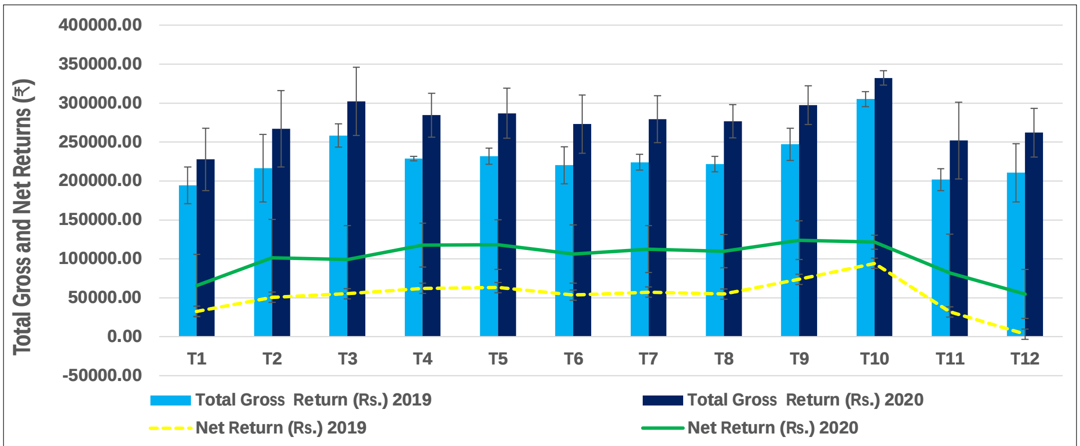
The B:C ratio in INM was superior to that of organic treatments. Furthermore, the cost-benefit analysis of this study revealed that T_{10} and T_9 (Table 7) under better nutrition control produced the greater BCR as also recorded by (Desai *et al*., 2015 and Srinivasarao *et al*., 2020).

Despite having a greater cultivation cost because of the additional nutrients, fertility treatments had considerably higher gross and net returns than the control plots. Additionally, the nutrient management had an effect on the

Table 7: B/C analysis of the INM (Pooled for 2019 and 2020).

Treatments	Gross return (Seed)	Gross return (Straw)	Total gross benefit (`)	Total net benefit (`)	B/C ratio
T_1	144512.50	66666.67	211179.17	39330.59	1.30
T_2	165687.50	76041.67	241729.17	65929.89	1.46
T_3	197175.00	83125.00	280300.00	94223.64	1.38
T_4	177100.00	79583.33	256683.33	103454.89	1.54
T_5	179712.50	79791.67	259504.17	74917.39	1.54
T_6	169125.00	77500.00	246625.00	71623.64	1.48
T_7	173800.00	77916.67	251716.67	74367.39	1.51
T_8	171462.50	77708.33	249170.83	74479.89	1.49
T_9	191400.00	80833.33	272233.33	96911.14	1.57
T_{10}	226875.00	91875.00	318750.00	107229.89	1.51
T_{11}	156612.50	70208.33	226820.83	36343.09	1.34
T_{12}	162800.00	73541.67	236341.67	15555.59	1.14
SE(m) ±	21,605.44	3,399.22	23,564.95	20,709.44	0.133
CD	NS	10,033.90*	NS	NS	NS

*(P<0.05) significant at 0.05 level of probability.



	Total Gross Return 2019-2020		Net Return 2019-2020	
	CD	SE(m) ±	CD	SE(m) ±
Treatments (A)	NS	20,219.41	NS	20,219.50
Cropping season (B)	23,573.67*	8,254.54	23,573.78*	8,254.58
A x B	NS	28,594.56	NS	28,594.69

Fig 2: INM effect on total gross and net return (`) for the cropping years.

B:C ratio of upland paddy. The highest BCR value was seen in T_9 (100% RDF + *Azospirillum lipoferum* + PSB + KMB + *Glomus* + ZnSB).

CONCLUSION

The findings revealed that integrated use of various soil amendments under INM farming produced higher energy input, energy output and cost of cultivation with a higher net return in investment but lower energy indices. This suggests that, compared to other farming systems, INM farming has a far higher dependence on non-renewable energy sources, mostly for fertilizers. Furthermore, it emphasised how crucial nutritional integration is profitable. Besides, INM also helps in maintaining sustainable production as indicated by the increased production and improved energy indices in second year cropping. However, long term study is essential to ascertain the overall production and energy consumption benefits of INM practices in upland paddy in hilly regions of North East India.

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Conflict of interest

On behalf of all authors, as the corresponding author of the manuscript, I warrant that the manuscript submitted is our own original work. All authors participated in the work in a substantive way and are prepared to take public responsibility for the work. The manuscript has not been published and is not being submitted or considered for publication elsewhere. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare there are no conflicts of interest.

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