

TILLAGE AND NITROGEN MANAGEMENT EFFECT ON ENERGY EFFICIENCY IN AEROBIC RICE

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Date of Receipt : 01.09.2025

Date of Acceptance : 24.11.2025

ABSTRACT

A field experiment conducted at the Indian Institute of Rice Research, Hyderabad, Telangana, India, during the *rabi* season (November-April) of 2022 and 2023 assessed the impact of tillage practices and nitrogen fertilizer schedules on energy efficiency in aerobic rice. The study employed three tillage treatments (T) and five nitrogen fertilizer schedules (N) in a strip plot design with three replications. Results revealed that Conventional tillage (T₁) showed higher energy input, whereas zero tillage (T₃) showed lower energy input. Higher Gross Energy Output (GEO), Net Energy Output (NEO), Energy Use Efficiency (EUE) and Energy Productivity (EP) obtained under Conventional tillage (T₁) which is statistically comparable with minimum tillage with residue retention (T₂) and significantly higher over zero tillage (T₃). Zero tillage (T₃) resulted in the highest energy intensity in physical terms (EIP). Energy Intensity in Economic terms (EIE) was not significantly influenced by tillage practices. Among nitrogen fertilizer schedules, the treatment 100% RDN + foliar spray of 2.5 ml l⁻¹ nano urea at tillering and before panicle initiation stage (N₂) yielded the highest energy metrics, including GEO and NEO, EUE, EP and EIP which is statistically comparable to 100% RDN (N₁). Conventional tillage (T₁) and 100% RDN (N₁) treatment demonstrated superior performance across various energetics, emphasizing their effectiveness in enhancing the energetic efficiency of aerobic rice cultivation. Overall, conventional tillage and recommended nitrogen management were most effective, while conservation tillage performed on par with conventional tillage in aerobic rice.

Keywords: Aerobic Rice, Energy Efficiency, Tillage Practices, Nitrogen Fertilizer Schedules

INTRODUCTION

Energy optimization in crop production systems is crucial for enhancing sustainability, improving resource-use efficiency, and reducing environmental footprints, especially in the context of increasing energy costs and climate change challenges (Banerjee *et al.*, 2021). Efficient energy use not only lowers input costs but also contributes to long-term agricultural

productivity and ecological balance by minimizing greenhouse gas emissions and non-renewable energy consumption.

Aerobic rice cultivation, which is characterized by growing rice under non-flooded, unsaturated soil conditions, represents a water-saving alternative to traditional puddled rice systems (Mahapatra *et al.*, 2021). However, the success of aerobic rice systems largely

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depends on effective soil and nutrient management strategies. Among these, tillage and nitrogen management are two critical agronomic practices that significantly influence energy inputs, crop growth dynamics, and overall system productivity. Tillage affects soil physical properties, root development (Martins *et al.*, 2021), and controls weeds, while nitrogen management determines nutrient availability, crop biomass accumulation and grain yield.

This study is designed to systematically compare the energy efficiency of different tillage methods such as conventional tillage, minimum tillage and zero tillage alongside varying nitrogen fertilizer schedules, including conventional urea and innovative sources (nano urea and nano DAP). The objective is to identify combinations that not only maintain or improve yield but also optimize energy input-output ratios. Analyzing parameters such as energy

input from fuel, fertilizers, labor, and machinery, and energy output in terms of grain and straw yields, the research aims to determine the most energy-efficient and sustainable management practices for aerobic rice systems.

MATERIAL AND METHODS

The present experiment on aerobic *rabi* rice was laid out in a strip plot design with three vertical plots and five horizontal plots that are allocated randomly and replicated thrice. Vertical plot treatments were conventional tillage (T_1), minimum tillage with residue retention (T_2) and zero tillage (T_3). Horizontal plot treatments were, 100 % RDN (N_1), 100 % RDN + foliar spray of 2.5 ml l⁻¹ nano urea at tillering and before panicle initiation stage (N_2), 100 % RDN + foliar spray of 2.5 ml l⁻¹ nano DAP at tillering and before panicle initiation stage (N_3), 75 % RDN + foliar spray of 2.5 ml l⁻¹ nano urea at tillering and before panicle

Table 1. Energy equivalents for various inputs

Human labour	Input	Unit	Ec (MJ h ⁻¹)
	Adult men	Man-hour	1.96
	Women	Women-hour	1.57
Machinery and implements	Sickle	MJ kg ⁻¹	0.031
	Sprayer	MJ kg ⁻¹	0.502
	Cultivator	MJ kg ⁻¹	3.135
	Rotavator	MJ kg ⁻¹	10.283
	Tractor (>45 hp)	MJ kg ⁻¹	16.416
Irrigation	Electricity	KWh	11.93
	Electric motor 35 hp	KW h ha ⁻¹	0.343
	Diesel	Litre	56.31
	Water	m ³	1.02
Chemicals	N	Kg	60.6
	P	Kg	11.1
	K	Kg	6.7
	Herbicide	kg	230
	Insecticide	kg	120
Seeds	Rice	kg	14.7

initiation stage (N_4) and 75 % RDN + foliar spray of 2.5 ml l⁻¹ nano DAP at tillering and before panicle initiation stage (N_5). The succeeding experiment was continued on succeeding cowpea in strip plot design to find out the residual effect of the treatments imposed to *rabi* aerobic rice. Energy parameters were calculated for rice with their respective energy equivalent values (Table 1).

The field experiment data were statistically analyzed using ANOVA for a strip plot design in R Studio with the *agricolae* package. Significance of treatment effects was determined at the 5% level ($p < 0.05$). Post-hoc comparisons were made using the LSD test, with letter groupings indicating non-significant differences among treatment means.

RESULTS AND DISCUSSION

Energy Input (MJ ha⁻¹)

The total energy input was significantly influenced by both tillage practices and nitrogen fertilizer schedules (Table 2 and Fig. 1). Among tillage practices, Conventional tillage (T_1) recorded the highest energy input, followed by minimum tillage with residue retention (T_2), while zero tillage (T_3) recorded the lowest energy input across both years and pooled data. This was attributed to greater fuel consumption, labor, and machinery requirements in conventional tillage operations. Regarding nitrogen schedules, the highest energy input was observed in 100% RDN + foliar nano urea spray (N_2), closely followed by 100% RDN + foliar nano DAP spray (N_3). The lowest energy input was associated with 75% RDN + foliar nano DAP spray (N_5). Increased fertilizer rates and the use of nano formulations contributed to the variation in energy input levels.

Gross Energy Output (MJ ha⁻¹)

Gross energy output was significantly affected by tillage and nitrogen fertilizer schedules, while their interaction remained

non-significant. Among tillage treatments, Conventional tillage (T_1) consistently produced the highest gross energy output, significantly outperforming zero tillage (T_3), and being statistically at par with minimum tillage with residue retention (T_2) in 2023–24 and pooled data. In terms of nitrogen management, 100% RDN (N_1), 100% RDN + foliar nano urea spray (N_2), and N_3 yielded significantly higher gross energy output than N_4 and N_5 , suggesting that full-dose nitrogen application (with or without nano foliar supplements) enhanced crop biomass and yield, thereby increasing energy output. Despite their higher input energy, N_1 – N_3 treatments translated more of the input into productive energy due to higher yields. Similar findings have been reported by Kumar *et al.* (2017) and Sinha *et al.* (2018).

Net Energy Output (MJ ha⁻¹)

Net energy output followed a trend similar to gross output. Among tillage practices, T_1 and T_2 were statistically comparable and significantly superior to T_3 in both years and pooled data. The enhanced physical properties of the soil under T_1 and the soil health benefits of residue retention under T_2 contributed to greater biomass production, thus improving net energy output. Among nitrogen schedules, N_1 , N_2 , and N_3 had significantly higher net energy output compared to N_4 and N_5 , underscoring the role of adequate nitrogen availability in enhancing yield and energy returns. These results reaffirm that reduced nitrogen rates (N_4 and N_5) could not compensate for lower input with foliar sprays alone. Similar results were corroborated by Pratap *et al.* (2022) Jin *et al.* (2024).

Energy Use Efficiency (%)

Energy use efficiency (EUE) was significantly influenced by tillage and nitrogen fertilizer treatments. T_1 recorded the highest EUE, followed closely by T_2 , with both being statistically superior to T_3 . In 2022–23, T_2 was

Table 2. Energetics of aerobic rice as influenced by tillage practices and nitrogen fertilizer schedules

Treatments	Gross energy output (MJ ha ⁻¹)			Net energy output (MJ ha ⁻¹)			Energy use efficiency (%)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
Tillage practices (T)									
T ₁	140759a	143126a	141943a	86952a	89185a	88069a	2.61a	2.64a	2.63a
T ₂	131295b	134863a	133079a	78757a	82159a	80458a	2.49a	2.55ab	2.52ab
T ₃	117859c	119848b	118853b	66208b	67937b	67073b	2.27b	2.3b	2.29b
SEm±	3056	2846	2747	3056	2846	2747	0.05	0.05	0.05
CD (p=0.05)	12001	11176	10786	12001	11176	10786	0.22	0.21	0.20
P-value	0.02	0.01	0.01	0.02	0.01	0.01	0.04	0.03	0.02
Nitrogen fertilizer schedules (N)									
N ₁	139100a	142057a	140578a	85817a	88588a	87203a	2.6a	2.65a	2.63a
N ₂	141367a	143214a	142291a	87936a	89596a	88766a	2.64a	2.66a	2.65a
N ₃	137599a	139612a	138606a	84191a	86017a	85104a	2.57a	2.6a	2.58a
N ₄	118553b	120595b	119574b	66940b	68795b	67868b	2.29b	2.32b	2.31b
N ₅	113235b	117583b	115409b	61645b	65806b	63725b	2.19b	2.26b	2.23b
SEm±	3096	3283	2995	3096	3283	2995	0.05	0.06	0.05
CD (p=0.05)	10099	10709	9768	10099	10709	9768	0.19	0.20	0.18
P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEm±	4179	3898	3663	4179	3898	3663	0.08	0.07	0.07
P-value	0.40	0.20	0.23	0.40	0.20	0.23	0.49	0.27	0.33

T₁: Conventional tillage, T₂: Minimum tillage with residue retention, T₃: Zero tillage. N₁: 100% RDN, N₂: 100% RDN + Foliar spray of 2.5 ml l⁻¹ nano urea at tillering and before panicle initiation stage, N₃: 100% RDN + Foliar spray of 2.5 ml l⁻¹ nano DAP at tillering and before panicle initiation stage, N₄: 75% RDN + Foliar spray of 2.5 ml l⁻¹ nano urea at tillering and before panicle initiation stage, N₅: 75% RDN + Foliar spray of 2.5 ml l⁻¹ nano DAP at tillering and before panicle initiation stage.

Table 2 (Cont.).

Treatments	Energy productivity (kg MJ ⁻¹)			Energy intensity in physical terms (MJ kg ⁻¹)			Energy intensity in economic terms (MJ □ ⁻¹)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
Tillage practices (T)									
T ₁	0.0834a	0.0844a	0.0839a	5.17b	5.08b	5.12b	3.33	3.40	3.37
T ₂	0.0782a	0.0811a	0.0796a	5.46ab	5.33ab	5.4ab	3.24	3.33	3.28
T ₃	0.0699b	0.0709b	0.0704b	5.92a	5.86a	5.89a	3.05	3.09	3.07
SEm±	0.0020	0.0019	0.0018	0.13	0.14	0.13	0.07	0.08	0.07
CD (p=0.05)	0.008	0.007	0.007	0.49	0.54	0.50	NS	NS	NS
P-value	0.02	0.01	0.01	0.03	0.03	0.03	0.11	0.10	0.09
Nitrogen fertilizer schedules (N)									
N ₁	0.0820a	0.0838a	0.0829a	5.18b	5.08b	5.13b	3.51a	3.58a	3.55a
N ₂	0.0831a	0.0845a	0.0838a	5.11b	5.08b	5.09b	3.50a	3.54a	3.52a
N ₃	0.0811a	0.0823a	0.0817a	5.25b	5.13b	5.19b	3.33a	3.41a	3.37a
N ₄	0.0715b	0.0728b	0.0721b	5.89a	5.80a	5.84a	2.94b	3.00b	2.97b
N ₅	0.0682b	0.0706b	0.0694b	6.17a	6.02a	6.09a	2.75b	2.83b	2.79b
SEm±	0.0024	0.0023	0.0021	0.13	0.14	0.13	0.08	0.08	0.07
CD (p=0.05)	0.0079	0.0075	0.0067	0.41	0.45	0.40	0.25	0.27	0.24
P-value	0.0071	0.0063	0.0029	0.00	0.01	0.00	0.00	0.00	0.00
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEm±	0.003	0.004	0.002	0.18	0.17	0.16	0.11	0.10	0.09
P-value	0.52	0.86	0.31	0.81	0.57	0.71	0.57	0.34	0.41

T₁: Conventional tillage, T₂: Minimum tillage with residue retention, T₃: Zero tillage. N₁: 100% RDN, N₂: 100% RDN + Foliar spray of 2.5 ml l⁻¹ nano urea at tillering and before panicle initiation stage, N₃: 100% RDN + Foliar spray of 2.5 ml l⁻¹ nano DAP at tillering and before panicle initiation stage, N₄: 75% RDN + Foliar spray of 2.5 ml l⁻¹ nano urea at tillering and before panicle initiation stage, N₅: 75% RDN + Foliar spray of 2.5 ml l⁻¹ nano DAP at tillering and before panicle initiation stage.

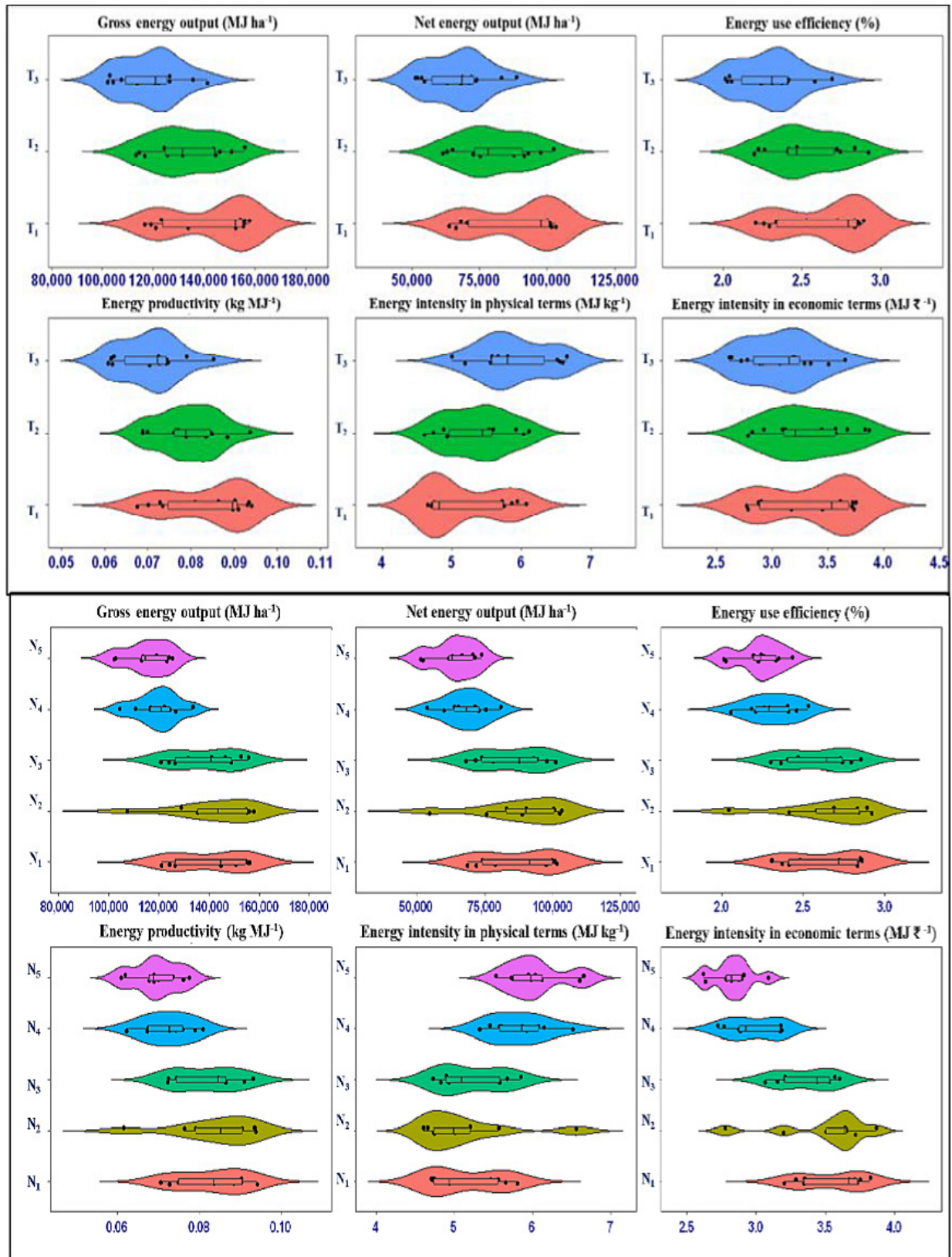


Fig. 1 Energetics of aerobic rice as influenced by tillage practices and nitrogen fertilizer schedules (pooled mean).

significantly better than T₃, but in 2023–24 and the pooled mean, their differences narrowed. Nitrogen schedules N₁, N₂, and N₃ exhibited significantly higher EUE than N₄ and N₅. While foliar application of nano fertilizers improved nitrogen use efficiency, it did not fully offset the effects of reduced basal nitrogen. Therefore, full-dose nitrogen treatments remained more efficient in energy utilization. Similar findings were reported by Tiwari *et al.* (2023) and Kundu *et al.* (2024).

Energy Productivity (kg MJ⁻¹)

Energy productivity, representing grain yield per unit of energy input, showed significant variation across treatments. Among tillage treatments, T₁ exhibited the highest energy productivity, followed by T₂, both statistically superior to T₃. The improved soil conditions and nutrient availability under conventional tillage likely promoted better energy conversion into yield. For nitrogen treatments, N₁, N₂, and N₃ were again significantly more productive compared to N₄ and N₅, demonstrating that sufficient nitrogen supply remains essential for maximizing energy use in crop production. The reduced productivity under N₄ and N₅ reflects the adverse effects of nitrogen deficiency despite foliar supplementation. These results were substantiating with Prakash *et al.* (2023) and Pedireddy *et al.* (2024).

Energy Intensity in Physical Terms (MJ kg⁻¹)

Energy intensity in physical terms was significantly affected by treatments. Among tillage methods, T₃ recorded the highest energy intensity, indicating lower yield per unit of energy input, while T₁ and T₂ had significantly lower and comparable values.

For nitrogen fertilizer schedules, N₅ exhibited the highest energy intensity, followed by N₄, whereas N₁, N₂, and N₃ had significantly lower and statistically similar values. This

suggests that inadequate nitrogen supply in N₄ and N₅ led to inefficient energy conversion, resulting in higher energy requirements per unit of yield.

Energy Intensity in Economic Terms (MJ ⁻¹)

Energy intensity in economic terms was significantly influenced by nitrogen management but not by tillage or their interaction. Among tillage practices, T₁ showed the highest economic energy intensity, while T₃ recorded the lowest. However, due to lower production costs, T₃'s energy intensity in economic terms was statistically comparable with T₁ and T₂.

Among nitrogen treatments, N₁, N₂, and N₃ showed significantly higher energy intensity per rupee of output compared to N₄ and N₅. This trend reflects the stronger energy returns from full-dose nitrogen treatments, even though the input costs for N₄ and N₅ were relatively lower.

CONCLUSION

The study highlights the energetic advantages of conventional tillage and nitrogen schedule 100 % RDN + foliar spray of 2.5 ml l⁻¹ nano urea at tillering and before panicle initiation stage in aerobic rice cultivation. However, minimum tillage with residue retention exhibited comparable performance to conventional tillage, indicating its potential as a sustainable and energy-efficient alternative. Among nitrogen strategies, 100 % RDN + foliar spray of 2.5 ml l⁻¹ nano urea at tillering and before panicle initiation stage optimized energy productivity and efficiency, while 100% RDN alone produced statistically comparable results and emerged as the more economical option for energy-conscious rice farming.

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