



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(2): 245-248
Received: 15-12-2025
Accepted: 10-01-2026

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Effect of integrated weed and nutrient management strategies for enhancing the growth and yield of transplanted rice under reduced input management approach

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i2d.4861>

Abstract

Recent years have highlighted the need to overcome inefficient input responsiveness and expanding environmental concerns. Nano urea and fresh *Azolla* are currently considered as the best alternative to chemical inputs for sustainable and cost saving strategies in agriculture. Hence, a field trial was carried out at Experimental farm, Annamalai University, Tamil Nadu, India during *Kharif*, 2024 season to evaluate the effect of integrated application of nano urea, urea, fresh *Azolla* and weed management practices in transplanted rice. The field trial was laid out in Split Plot Design (SPD) with twenty combination treatments and replicated thrice. Regarding the integrated nutrient management treatments, the integration of 50% N as urea + foliar application of 50% N as nano urea (2 spray at active tillering and panicle initiation stage) + fresh *Azolla* 500 kg ha⁻¹ registered the higher plant height of 95.5 cm, dry matter yield of 10769 kg ha⁻¹, grain yield of 5183 kg ha⁻¹ and straw yield of 7241 kg ha⁻¹. Among the integrated weed management practices, twice hand weeding on 20 & 40 DAT registered maximum plant height of 94.9 cm, dry matter yield of 10885 kg ha⁻¹, grain yield of 5482 kg ha⁻¹ and straw yield of 7522 kg ha⁻¹. With regards to interaction effect, application of 50% N as urea + foliar application of 50% N as nano urea (2 spray at active tillering and panicle initiation stage) + fresh *Azolla* 500 kg ha⁻¹ followed by twice hand weeding on 20 & 40 DAT resulted maximum plant height of 103.6 cm, dry matter yield of 12280 kg ha⁻¹, grain yield of 6192 kg ha⁻¹ and straw yield of 8549 kg ha⁻¹ (M₃S₂). However, it was statistically on par with the application 50% N as urea + foliar application of 50% N as nano urea (2 spray at active tillering and panicle initiation stage) + fresh *Azolla* 500 kg ha⁻¹ followed by Pre-emergence application of Penoxsulam 0.97% + Butachlor 38.7% SE@ 2 lit ha⁻¹ at 3 DAT *fb* Post emergence application of Bispyribac sodium 10% SC @ 0.25 lit ha⁻¹ at 21 DAT with a plant height of 103.4 cm, dry matter yield of 12259 kg ha⁻¹, grain yield of 6186 kg ha⁻¹ and straw yield of 8544 kg ha⁻¹ (M₃S₃).

Keywords: Nano urea, fresh *Azolla*, transplanted rice, growth characters, yield

Introduction

Rice (*Oryza sativa* L.) is a staple crop for about half of Asia's population and an essential source of calories. India is the world's fourth-largest exporter of paddy. For the vast majority of India's rural population, paddy production is also a key source of employment (Singh *et al.*, 2020) [19]. Around the world, 165.67 million hectares of rice are grown, yielding 520 million metric tonnes of output and 4.69 tonnes of productivity per hectare. In India, 47.60 million hectares of rice are grown, yielding 137.00 million metric tonnes of total production and 4.32 tonnes of productivity per hectare (USDA, 2024). According to the Directorate of Economics and Statistics (2021), rice is farmed on 2.03 million hectares in Tamil Nadu, yielding 6.88 million tonnes of output and a productivity rate of 3.38 tonnes per hectare. Nitrogen (N) is one of the essential macro-nutrients for plants, serving as a key element for chlorophylls, amino acids (constitute plant proteins) and other organic compounds. N is crucial in promoting crop growth, tiller development and increasing yields in rice like any other crop, particularly the cereals (Gawdiya *et al.*, 2023) [9]. Nanotechnology, which utilizes nanomaterials of less than 100 nm size, has emerged as an innovative science to develop concentrated sources of plant nutrients having higher absorption

rate, utilization efficiency, and minimum losses. This primarily pertains to nitrogen, which accounts for approximately 82% of total fertilizer consumption in India, predominantly in the form of urea (Subramani, 2023) ^[20].

The losses coupled with low NUE of rice misconceived the farmer to take up more quantity than required to meet out the losses than phosphorus and potassium which is high to moderate in Indian soils (Al-Khuzai and Al-Juthery, 2020) ^[1]. Nano-urea could cope up the requirement of the rice crop; it gets absorbed by plants more effectively than conventional granular urea molecules. It is crucial to reduce conventional fertilizer usage without compromising yield. Also, the application of nano-urea liquid at critical crop growth stages of a plant is expected to fulfil its nitrogen requirement and may leads to higher crop productivity and quality and thus increases the income by reducing the cost involved to purchase reduced quantity of nano urea than the conventional one (Subramani, 2023) ^[20]. In response to these challenges, there is a growing need for innovative solutions that promote sustainable and eco-friendly rice farming systems. One promising solution is the use of *Azolla* spp., a small floating aquatic fern renowned for its ecological and agricultural benefits. *Azolla* forms a symbiotic relationship with the cyanobacterium *Anabaena Azollae*, which resides in its leaves and enables atmospheric nitrogen (N_2) fixation. This symbiosis enriches the fern with nitrogen, making it an excellent natural biofertilizer. When incorporated into rice farming systems, *Azolla* not only enhances soil fertility but also reduces dependence on synthetic fertilizers, thereby supporting more sustainable and cost-effective agricultural practices (Chandrababu *et al.*, 2024) ^[3]. Furthermore, a study by Nyein and Iwai (Nyein *et al.*, 2025) ^[15].

Comparably, effective weed management is crucial to agricultural production because weeds compete with crops for resources like water, nutrients, light, and space. Weed interference alone is estimated to reduce rice yields by around 28% (Patel *et al.*, 2023) ^[16] to 80% (Yadav *et al.*, 2018) ^[23] in transplanted rice eco-systems. Due to workforce shortages and increased labour expenses, rice growing increasingly depends more on herbicides. Herbicidal weed treatment has become a vital technique for weed management due to its speed, effectiveness, affordability, and practicality. Carefully selecting herbicides and considering the right time, dosage, and application methods are essential for effective weed control and higher crop yields. Low dose high efficacy (LDHE) herbicides, another name for new generation herbicides, reduced application costs, minimize herbicidal phytotoxicity to crops, and effectively limit residual build-up (Keerthi *et al.*, 2025) ^[10]. In this context, a field experiment was carried out to examine the impact of conjoint application of nano urea, fresh *Azolla* and weed management practices for enhancing the growth and productivity of transplanted rice.

Materials and Methods

Field trial was conducted during *Khariif* season, 2024 at Experimental farm, Annamalai University, Annamalai Nagar, Tamil Nadu, India to evaluate the effect of integrated application of nano urea, urea, fresh *Azolla* and weed management practices in transplanted rice. The experimental farm is geographically situated at 11°24' N latitude, 79°44' E longitude and at an altitude of + 5.79 m above the mean sea level. The fertility status of the soil was categorised as low in available N, medium in available P_2O_5 and high in available K_2O with a clay loam texture. The short duration rice variety, ADT 43 was used as test crop and transplanted with a spacing of 15 x 10 cm. Twenty-one days old seedlings were transplanted at 2 seedlings hill⁻¹. The

experiment was laid out in split plot design with three replications. The treatment comprised of main plot M_1 - 100% RDF, M_2 - 100% nano urea (2 spray at active tillering and panicle initiation stage) + fresh *Azolla* 500 kg ha⁻¹, M_3 - 50% N as urea + foliar application of 50% N as nano urea (2 spray at active tillering and panicle initiation stage) + fresh *Azolla* 500 kg ha⁻¹, M_4 - 75% N as urea + foliar application of 25% N as nano urea (2 spray at active tillering and panicle initiation stage) + fresh *Azolla* 500 kg ha⁻¹ and M_5 - 25% N as urea + foliar application of 75% N as nano urea (2 spray at active tillering and panicle initiation stage) + fresh *Azolla* 500 kg ha⁻¹. In Sub plots, S_1 - Unweeded control, S_2 - Twice hand weeding on 20 & 40 DAT, S_3 - Pre-emergence application of Penoxsulam 0.97% + Butachlor 38.7% SE@ 2 lit ha⁻¹ at 3 DAT *fb* Post emergence application of Bispyribac sodium 10% SC @ 0.25 lit ha⁻¹ at 21 DAT and S_4 - Pre-emergence application of Pyrazosulfuron ethyl 0.75% + Pretilachlor 30% GR @ 2000g ha⁻¹ at 3 DAT *fb* Post emergence application of Bispyribac sodium 10% SC @ 0.25 lit ha⁻¹ at 21 DAT. The recommended nitrogen dose of 150 kg ha⁻¹ was applied according to the treatment schedule the conventional urea (46% N) distributed in three equal splits at the basal stage, active tillering, and at panicle initiation, while the necessary amounts of nano urea (4% N) were calculated based on the treatment schedule and applied as foliar sprays at the active tillering (AT) and panicle initiation (PI) stages. The entire quantity of phosphorus @ 50 kg ha⁻¹ was applied as basal dose in all the plots using single super phosphate (16% P_2O_5) and 50 kg K ha⁻¹ were applied in three equal splits starting from basal, active tillering and panicle initiation stage in the form of muriate of potash (60% K_2O). Five sample plants were chosen at random from each plot and permanently tagged for biometric observations viz., plant height and dry matter yield, grain yield and straw yield were recorded from individual plots. The statistical analysis of the growth and yields of rice was done as per the methodology given by Gomez and Gomez (2010) ^[8].

Results and Discussion

Growth characters

The results showed that the main plot treatments integrated nutrient management on 50% N as urea + foliar application of 50% N as nano urea (2 spray at active tillering and panicle initiation stage) + fresh *Azolla* 500 kg ha⁻¹ (M_3) registered higher plant height of 95.5 cm and dry matter yield of 10699 kg ha⁻¹. The treatments 100% nano urea (2 spray at active tillering and panicle initiation stage) + fresh *Azolla* 500 kg ha⁻¹ (M_2) had the lowest plant height of 80.4 cm and dry matter yield of 7780 kg ha⁻¹.

Among the integrated weed management practices, twice hand weeding on 20 & 40 DAT (S_2) recorded taller plant of 94.9 cm and dry matter yield of 10885 kg ha⁻¹. This was statistically on par with the Pre emergence application of Penoxsulam 0.97% + Butachlor 38.7% SE@ 2 lit ha⁻¹ at 3 DAT *fb* Post emergence application of Bispyribac sodium 10% SC @ 0.25 lit ha⁻¹ (S_3). The unweeded control (S_2) caused least plant height of 74.5 cm and dry matter yield of 6289 kg ha⁻¹.

Regarding the interaction effects, integrated nutrient and weed management practices of 50% N as urea + foliar application of 50% N as nano urea (2 spray at active tillering and panicle initiation stage) + fresh *Azolla* 500 kg ha⁻¹ along with twice hand weeding on 20 & 40 DAT (M_3S_2) produced taller plant of 103.6 cm and dry matter yield of 12280 kg ha⁻¹. This treatment combination was statistically comparable with integrated employment of 50% N as conventional urea+ foliar application of 50% N as nano urea + fresh *Azolla* 500 kg ha⁻¹ along with Pre-emergence application of Penoxsulam 0.97% + Butachlor

38.7% SE@ 2 lit ha⁻¹ at 3 DAT *fb* Post emergence application of Bispyribac sodium 10% SC @ 0.25 lit ha⁻¹ (M₃S₃). On contrast, combined effect of 100% nano urea (2 spray at active tillering and panicle initiation stage) + fresh *Azolla* 500 kg ha⁻¹ along with unweeded control (M₂S₁), with the registered minimum plant height of 68.2 cm and dry matter yield of 5315 kg ha⁻¹ (Table 1 and 2).

The increased growth characters of transplanted rice were due to the external application of N through nano formulation enhanced the growth of rice, internode expansion, metabolism, and assimilate generation, which resulted in improved crop growth (Benzon *et al.*, 2015) [2]. Moreover, integrated application of conventional and nano urea increased nitrogen availability, which is critical for amino acid synthesis and plant hormone production (auxin and gibberellic acid), both of which are required for cell division and cell growth, resulting in increased plant height and DMP (Midde *et al.*, 2022) [14]. Furthermore, introduction of *Azolla* in the puddled rice field enhanced soil organic matter, improves the availability of essential nutrients coupled enhanced with enzymatic activities which resulted in increased plant height and dry matter yield. These results are in line with the findings of Das *et al.* (2025) [4].

Additionally, the enhanced plant height and dry-matter yield were pointed by the integrated weed management treatment is, an ancillary effect on account of the least competition for plant growth inputs as the plant gets sufficient space for growth. Adequate availability of light, space as well as better edaphic and nutritional environment along with improvement in physiological and morphological characters of the plant in rhizosphere ameliorated the photosynthetic efficiency, thereby led to more accumulation of dry matter under this treatment combinations.

Yield attributes

Among the integrated nutrient management, application of 50% N as urea + foliar application of 50% N as nano urea (2 spray at active tillering and panicle initiation stage) + fresh *Azolla* 500 kg ha⁻¹ (M₃) registered the highest grain yield of 5183 kg ha⁻¹ and straw yield of 7241 kg ha⁻¹. The treatments 100% nano urea (2 spray at active tillering and panicle initiation stage) + fresh *Azolla* 500 kg ha⁻¹ (M₂) resulted lowest grain yield of 3190 kg ha⁻¹ and straw yield of 4654 kg ha⁻¹.

With regards to integrated weed management practices, twice hand weeding on 20 & 40 DAT (S₂) recorded higher grain yield of 5482 kg ha⁻¹ and straw yield of 7522 kg ha⁻¹. It was statistically on par with the Pre-emergence application of Penoxsulam 0.97% + Butachlor 38.7% SE@ 2 lit ha⁻¹ at 3 DAT *fb* Post emergence application of Bispyribac sodium 10% SC @ 0.25 lit ha⁻¹ (S₃). The treatment unweeded control (S₁) registered to least grain yield of 2220 kg ha⁻¹ and straw yield of 3561 kg ha⁻¹. Among the interaction effects, integrated nutrient and weed management practices of 50% N as urea + foliar application of 50% N as nano urea (2 spray at active tillering and panicle initiation stage) + fresh *Azolla* 500 kg ha⁻¹ along with twice hand weeding on 20 & 40 DAT (M₃S₂) produced higher grain yield of 6192 kg ha⁻¹ and straw yield of 8549 kg ha⁻¹. This treatment combination was statistically comparable with integrated employment of 50% N as conventional urea+ foliar application of 50% N as nano urea + fresh *Azolla* 500 kg ha⁻¹ along with pre-emergence application of Penoxsulam 0.97% + Butachlor 38.7% SE@ 2 lit ha⁻¹ at 3 DAT *fb* post emergence application of Bispyribac sodium 10% SC @ 0.25 lit ha⁻¹ (M₃S₃). Combine application of 100% Nano urea (2 spray at active tillering and panicle initiation stage) + Fresh *Azolla* 500 kg ha⁻¹ along with unweeded control (M₂S₁), registered lower grain yield of 1750 kg ha⁻¹ and straw yield of 2994 kg ha⁻¹ (Table 3 and 4).

The increased grain and straw yield of rice could be attributed to the combined application of conventional urea and nano urea, which ensured optimum and balanced nutrient availability throughout the crop growth period, particularly during critical stages. The smaller particle size and larger effective surface area of nano urea facilitate easy penetration into plant tissues, resulting in improved nutrient uptake. Enhanced nutrient absorption promotes better growth of plant parts and stimulates metabolic processes such as photosynthesis, leading to greater accumulation and translocation of photosynthates to economically productive plant organs. This ultimately enhances biomass production, yield-attributing characters, and grain and straw yield through improved assimilate movement towards the grains. These findings are in agreement with those reported.

Table 1: Effect of conjoint use of nano urea and new generation herbicides on the plant height at harvest stage (cm) of transplanted rice

Treatments	M ₁	M ₂	M ₃	M ₄	M ₅	Mean
S ₁	71.7	68.2	78.7	78.6	75.2	74.5
S ₂	92.7	85.7	103.6	99.9	92.8	94.9
S ₃	92.6	85.6	103.4	99.8	92.7	94.8
S ₄	89.1	82.2	96.3	96.3	89.2	90.6
Mean	86.5	80.4	95.5	93.6	87.5	
	M	S	M*S	S*M		
S. Ed.	0.93	0.68	1.60	1.51		
CD	2.14	1.38	3.42	3.09		

Table 2: Effect of conjoint use of nano urea and new generation herbicides on the dry matter yield at harvest stage (kg ha⁻¹) of transplanted rice

Treatments	M ₁	M ₂	M ₃	M ₄	M ₅	Mean
S ₁	5810	5315	7031	6983	6310	6289
S ₂	10683	8956	12280	11807	10699	10885
S ₃	10547	8798	12259	11792	10596	10798
S ₄	9898	8054	11227	11191	9964	10066
Mean	9234	7780	10699	10443	9392	
	M	S	M*S	S*M		
S. Ed.	118.20	100.29	227.36	224.26		
CD	272.58	204.82	480.54	458.00		

Table 3: Effect of conjoint use of nano urea and new generation herbicides on the grain yield (kg ha⁻¹) of transplanted rice

Treatments	M ₁	M ₂	M ₃	M ₄	M ₅	Mean
S ₁	1969	1750	2610	2588	2187	2220
S ₂	5628	3989	6192	5968	5635	5482
S ₃	5610	3918	6186	5965	5618	5459
S ₄	5096	3105	5746	5742	5120	4961
Mean	4575	3190	5183	5065	4640	
	M	S	M*S	S*M		
S. Ed.	51.87	46.41	103.77	103.78		
CD	119.62	94.79	218.77	211.96		

Table 4: Effect of conjoint use of nano urea and new generation herbicides on the straw yield (kg ha⁻¹) of transplanted rice

Treatments	M ₁	M ₂	M ₃	M ₄	M ₅	Mean
S ₁	3303	2994	3956	3946	3610	3561
S ₂	7601	5526	8549	8329	7605	7522
S ₃	7590	5487	8544	8324	7596	7508
S ₄	7199	4611	7916	8007	7250	6996
Mean	6423	4654	7241	7151	6515	
	M	S	M*S	S*M		
S. Ed.	75.50	63.73	144.67	142.50		
CD	174.10	130.15	305.85	291.03		

Likewise, *Azolla* as enhances its symbiotic capacity to fix atmospheric nitrogen and accumulate organic carbon at accelerated rates, making it an exceptional agronomic option that ultimately leads to increased grain and straw yields. These findings are consistent with the results reported by Kollah *et al.* (2016)^[12].

In split of that, integrated weed management treatments recorded the highest grain and straw yields, primarily due to effective weed control and reduced crop-weed competition throughout the growing season. This created a favourable environment for the crop to efficiently utilize nutrients, moisture, light, and space. The improved resource availability enhanced photosynthetic activity, which ultimately resulted in increased grain and straw production. Similar findings were reported by Teja *et al.* (2017)^[21].

Conclusion

The present study concluded that the combined application of 50% N as urea + foliar application of 50% N as nano urea (2 spray at active tillering and panicle initiation stage) + fresh *Azolla* 500 kg ha⁻¹ along with pre-emergence application of Penoxsulam 0.97% + Butachlor 38.7% SE@ 2 l ha⁻¹ at 3 DAT *fb* post emergence application of Bispyribac sodium 10% SC @ 0.25 lit ha⁻¹ at 21 DAT was found to be most effective in maximizing the growth and yield of transplanted rice.

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