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Enhancing lowland rice physiology with integrated nitrogen nutrient sources in Nigeria's derived savannah

Olumayowa Joseph Iyanda[1,*], **Akeem Abdulai Oyekanmi**[2], **Mufutau Olaoye Atayese**[2], **Christopher Adejuyigbe**[2], **Ayomide Afolabi**[2]

[1] Afe Babalola University, Ado-Ekiti, Nigeria
[2] Federal University of Agriculture, Abeokuta, Nigeria

* e-mail: iyandamayojo@abuad.edu.ng

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Abstract:
Nitrogen is an essential nutrient for optimal rice growth and yield. Many Nigerian rice fields encounter difficulties in their production process because of insufficient nitrogen in the soil leading to reduced crop yields. However, the sole reliance on expensive inorganic nitrogen fertilizers is economically challenging for small farmers in Nigeria's derived savannah. Therefore, integrated approaches to nutrient management have been put into practice to reduce the adverse effects of climate change and improve crop productivity in lowland rice cultivation. We aimed to investigate the impact of integrated nutrient inputs on the performance of NERICA L-34 and ARICA 3 rice varieties during the years 2017, 2018, and 2019.

Various treatments were administered, namely 100 kg of nitrogen/ha (NPK), 75 kg/ha (NPK) + 25 kg/ha (manure), 50 kg/ha (NPK) + 50 kg/ha (manure), 25 kg/ha (NPK) + 75 kg/ha (manure), and 100 kg/ha (manure). A control group was samples without fertilizers. Key physiological parameters were assessed, including partial factor productivity, nitrogen uptake, nitrogen utilization efficiency, nitrogen internal utilization efficiency, physiological efficiency, recovery efficiency, total leaf area index, chlorophyll content, as well as root fresh and dry weights. Our research followed a randomized complete block design with a split-plot arrangement, replicated three times. The data underwent analysis of variance and the Duncan multiple range test (with a significance level set at $p \leq 0.05$), and GENSTAT was used to compare the physiological traits of the rice varieties.

Our findings revealed that the combination of 75 kg/ha (NPK, inorganic) and 25 kg/ha (manure, organic) significantly enhanced nutrient recovery and uptake in the NERICA L-34 rice variety, resulting in improved nitrogen absorption. While the ARICA 3 variety consistently exhibited higher chlorophyll content, especially with the application of 100 kg nitrogen/ha (organic), NERICA L-34 displayed superior overall nutrient absorption, recovery, and nitrogen utilization. Therefore, we recommend that rice farmers prioritize cultivating NERICA L-34 for its high productivity and potential for sustainable rice farming.

Our findings can also guide farmers towards feasible integrated soil fertility management practices to enhance nutrient utilization efficiency, reduce environmental impact, and contribute to sustainable rice production in the derived savannah region of Nigeria.

Keywords: Physiology, lowland, rice productivity, rice varieties, climate change, fertilizers

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INTRODUCTION

In Nigeria, rice productivity is hindered by low nitrogen availability in soils, impacting the farmers' livelihoods and food security [1]. Climate change exacerbates these challenges, calling for sustainable solutions to enhance crop resilience and productivity [2]. The integration of nutrient management approaches, which involve a combination of synthetic fertilizers and organic compost, holds promise for enhancing nutrient absorption and rice growth [3]. The physiology of lowland rice varieties is closely linked to nitrogen supply, which influences their growth and yield [4]. Efficient nitrogen utilization and uptake systems are vital for optimal grain output [5]. Such factors as water availability and nitrogen levels affect the nutrient uptake by the rice plant [6]. Understanding these dynamics is crucial for devising effective strategies to address food security concerns [7]. The enhancement of soil structure through the use of organic compost creates a more favorable setting for root growth and the soil's ability to retain water [8]. This study aimed to evaluate how combined sources of nitrogen nutrients influence the physiological characteristics of lowland rice varieties. We sought to compare how these varieties perform under various nutrient management approaches and, subsequently, to offer valuable knowledge and practical suggestions for promoting sustainable rice cultivation and food security in Nigeria's derived savannah environment.

The influence of fertilizers on physiological parameters. The application of chemical fertilizers, particularly nitrogen, stimulates vigorous vegetative growth in rice plants; however, their excessive usage may result in diminished grain production [9]. Split nitrogen application based on crop needs can mitigate this effect [6]. However, overusing chemical fertilizers raises concerns about soil toxicity [10]. Root morphology and soil pH play crucial roles in nutrient uptake and rice growth [6]. Organic manure application over time improves rice yield and soil health [11]. Nutrient release synchronization by organic fertilizers reduces the need for inorganic fertilizers and enhances nitrogen use efficiency [12]. Nutritional physiology research, which uses the SPAD meter, shows that organic and inorganic fertilizers outperform chemical fertilizers [13]. Rice growth and yield are influenced by such factors as leaf area, nitrogen availability, and integrated nutrient management [14]. Root characteristics affect water and nutrient uptake [15]. Better root development leads to increased nutrient absorption and carbohydrate translocation [16]. Root systems are vital for nutrient and water uptake, as well as plant anchorage [17].

The system of rice intensification. The System of Rice Intensification (SRI) provides valuable insights into how rice plants respond to different soil conditions and adapt their roots. It has the potential to enhance crop production by boosting root and rhizosphere activity [18]. SRI-grown plants exhibit stronger stems, flood-resistant roots, and increased drought resistance due to better root establishment and reduced transplanting shock, leading to earlier maturity [19]. Direct measurements confirm that SRI practices result in greater and deeper root growth, facilitating enhanced nutrient uptake throughout the crop cycle compared to traditional flooding methods [20]. SRI management practices also promote larger root systems, making plants more resilient to both biotic and abiotic stresses, and creating favorable conditions for beneficial soil microorganisms [21]. The use of organic fertilizers further boosts root growth, nutrient uptake, and stress resistance in SRI-grown rice [22].

Nitrogen use efficiency in lowland rice varieties. Rice possesses two distinct uptake systems for nitrate (NO_3^-) and ammonium (NH_4^+), consisting of a high-affinity transport system (HATS) and a low-affinity transport system (LATS) [23]. Additionally, rice can absorb NO_3^- and NH_4^+ resulting from ammonium oxidation in the rhizosphere, facilitated by oxygen release from root aerenchyma [24]. This increased nutrient availability and improved growth conditions lead to enhanced physiological development and grain yield [25]. In modern agriculture, the application of nitrogen fertilizers is crucial for achieving high crop yields [26]. However, it often leads to the loss of excess reactive nitrogen to the environment, posing risks to air and water quality, as well as ecosystems. Nitrate (NO_3^-) losses through leaching can contaminate drinking water and contribute to eutrophication in freshwater and marine ecosystems, particularly during periods of high drainage rates [27]. Rice roots have two Casparian strips on the exodermis and endodermis, along with aerenchyma forming in mature root zones [28]. The establishment of a large root system early in the growth period is critical for effective nitrogen uptake [29]. Direct seeding of rice results in more panicles per square meter, attributed to smaller leaf size, increased root activity, and nutritional status at the initiation of panicles [30].

STUDY OBJECTS AND METHODS

Three field experiments were conducted in the wet seasons of 2017, 2018, and 2019 within the inland valley, specifically in the Teaching and Research Farms of the Federal University of Agriculture, Abeokuta (FUNAAB). The study area had a tropical climate with an average annual rainfall of over 1300 mm and an elevation of 83.10 meters above sea level. The region experienced two distinct rainy seasons, providing sufficient moisture for crop growth in the early stages of the growing season.

The research primarily focused on two specific lowland rice varieties: ARICA-3 (WAB 2076-WAC 1-TGR 1-B) and NERICA L-34 (FARO 61). These varieties were chosen due to their higher yield and productivity in comparison with upland rice types. ARICA-3 showed exceptional attributes, including a reduced cooking time, superior grain quality, heightened milling recovery, and diminished chalkiness. These qualities contributed to a 30% yield growth as opposed to NERICA L-19 (FARO 60). The necessary fertilizers, including an inorganic type (NPK 15:15:15), were provided by the Department of Plant Physiology and Crop Production. Furthermore, an organic fertilizer in the form of well-processed poultry manure was obtained from the College of Animal and Livestock Management (COLANIM) at FUNAAB. The incorporation of the cured poultry manure into the soil occurred two weeks before transplanting the rice seedlings, an approach adopted to enhance soil fertility. Soil samples from the topmost layer (0–15 cm deep) were collected randomly and subsequently analyzed in the laboratory to evaluate the soil's physical and chemical characteristics. The rice seeds, specifically ARICA 3 and NERICA L-34, were initially immersed in water for 24 hours. Subsequently, they were incubated for 48 hours to ensure consistent germination and early establishment. After germination, the seeds were planted in the nursery using the drilling technique, with a spacing of 20×20 cm between each seedling. This was carried out on a 4×8 m bed of fertile soil that had been effectively cleared manually.

The study employed a randomized complete block arrangement with a split-plot design, replicated three times. The main plot consisted of two rice varieties: 1) ARICA 3, a rain-fed lowland variety with short grain, high yield, and superior grain quality, and 2) NERICA L-34, a rain-fed lowland variety with long grain, early maturity, resistance to lodging and pests, and higher protein content. In the sub-plot, different nutrient sources of nitrogen were applied: 100 kg of nitrogen/ha (NPK), 75 kg/ha (NPK) + 25 kg/ha (manure), 50 kg/ha (NPK) + 50 kg/ha (manure), 25 kg/ha (NPK) + 75 kg/ha (manure), and 100 kg/ha (manure). A control sample was without fertilizers.

Data collection

Partial factor of productivity, kg/kg = Crop yield with applied nutrient, kg/ha / Amount of nutrient applied;

Nitrogen uptake, kg/kg = (Nutrient concentration, % × Dry weight, kg) / 100;

Nitrogen uptake in grain, kg/ha = (Nitrogen content in grain, % × Yield, kg/ha) / 100;

Nitrogen uptake in straw, kg/ha = (Nitrogen content in straw, % × Yield, kg/ha) / 100;

Total nitrogen uptake, kg/ha = Nitrogen uptake in grain, kg/ha + Nitrogen uptake in straw, kg/ha;

Nitrogen utilization efficiency = (Nitrogen uptake in grain, kg/ha × 100) / Total nitrogen uptake, kg/ha.

$$\text{Internal utilization efficiency} = \frac{Y}{U}$$

$$\text{Physiological efficiency} = \frac{Y - Y_0}{U - U_0}$$

$$\text{Recovery efficiency} = \frac{U - U_0}{F}$$

where Y is the crop yield with applied nutrient, kg/ha; U is the total plant nutrient uptake above ground biomass, kg/ha, in a plant that received fertilizer; Y_0 is the crop yield without nutrient, kg/ha; U_0 is the total nutrient uptake in above-ground biomass, kg/ha, in a plot that received no fertilizer; and F is the amount of nutrient applied.

The total leaf area index was divided by feeding area, cm^2, and the average was determined.

Chlorophyll content, %, of the tagged plant was obtained by using a chlorophyll meter (at LEAF CHL PLUS).

Root fresh and dry weight, g, was determined after oven-drying the samples using a sensitive scale.

Data analysis. The collected data was subjected to a mixed model of Analysis of Variance (ANOVA), and the treatment means that exhibited statistical significance were further evaluated through Duncan's Multiple Range Test (DMRT) at a significance level of 5% ($p \leq 0.05$). GenStat 12th edition software was employed for these statistical analyses.

RESULTS AND DISCUSSION

We studied the effects of integrated nitrogen nutrient sources on the physiological traits of two lowland rice varieties, ARICA 3 and NERICA L-34, in the derived savannah region of Nigeria. Effective nutrient management plays a pivotal role in elevating rice crop performance and overall agricultural productivity [31]. We also considered environmental conditions for optimizing crop performance, although it is essential to recognize that our findings are region-specific [32]. Furthermore, higher rice yields depend on the physiological characteristics of rice, including translocation, assimilate production, stomatal opening, and leaf area [13]. Our study highlighted that integrated nutrient management (INM) practices contribute to superior growth and yield parameters compared to the control methods [9]. Therefore, INM strategies need to be employed to enhance crop productivity and sustainability [33].

Physiological efficiency and recovery efficiency of applied nutrient. In 2017, physiological efficiency, kg/kg, was significantly impacted by integrated nitrogen nutrient sources. The physiological efficiency of 100 kg nitrogen/ha (organic) was 10.34 kg/kg, while the physiological efficiency of 50 kg/ha (organic) + 50 kg/ha was 0.300 kg/kg. The choice of nitrogen source (organic vs. inorganic) significantly affects the physiological efficiency of applied nutrients and their utilization by the rice plants [34, 35]. The application of inorganic fertilizers enhanced the activity of beneficial microbes and mycorrhizal fungal colonization in lowland rice. These microbes and fungi are important in mobilizing nutrients and improving nutrient availability, which in turn facilitates the plant's uptake and results in higher nitrogen use efficiency. Similar observations were made by earlier studies of variations in nutrient supplies and nitrogen levels [36–39].

The variety had a significant impact on recovery efficiency, kg/kg, in 2017 ($p \leq 0.05$). The nutrient recovery efficiency of NERICA L-34's (0.243 kg/kg) was higher than that of ARICA 3 (0.004 kg/kg), as shown in Table 1. Notably, NERICA L-34 consistently surpassed ARICA 3 in various growth-related aspects, suggesting that farmers should consider cultivating NERICA L-34 for its superior productivity and resilience [40].

Nitrogen uptake. Table 2 shows that integrated nitrogen nutrient sources had a significant ($p \leq 0.05$) effect on nitrogen uptake, kg/kg, in 2019. The highest nitrogen uptake (0.5237 kg/kg) was obtained when 75 kg/ha (inorganic) + 25 kg/ha (organic) of nitrogen was applied in 2019, while the lowest nitrogen uptake (0.4602 kg/kg) was obtained when neither organic nor inorganic fertilizer was applied. Specifically, the blend of 75 kg/ha (inorganic) and 25 kg/ha (organic) had remarkable effectiveness in boosting nitrogen uptake [41]. This indicated that specific nutrient combinations can optimize nutrient uptake, vital for plant growth and yield [42]. The study revealed that different combinations of integrated nutrient sources exerted a significant influence on nitrogen uptake by rice plants [43]. The data clearly showed that,

Table 1 Effects of integrated nutrient sources of nitrogen-on-nitrogen internal utilization efficiency, physiological efficiency, and recovery efficiency of applied nutrient for lowland rice varieties in a derived savannah

Treatment	Nitrogen internal utilization efficiency, kg/kg			Physiological efficiency, kg/kg			Recovery efficiency of applied nutrient, kg/kg		
Varieties (V)	2017	2018	2019	2017	2018	2019	2017	2018	2019
ARICA 3	1.51	1.20	1.34	4.19	0.15	5.70	0.0040^{b}	0.0030	0.10
NERICA L-34	1.52	1.42	2.25	2.31	1.35	–16.50	0.2430^{a}	0.0020	0.63
SED ± ($p \leq 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.3938*	n.s.	n.s.
Nutrient sources of nitrogen (N)									
100 kg/ha (inorganic)	1.48	1.28	1.62	10.34^{a}	2.18	–7.30	0.0360	0.0010	0.28
75 kg/ha (inorganic) + 25 kg/ha (organic)	1.53	1.33	2.23	1.80^{c}	–0.35	–1.00	0.1780	0.0014	0.92
50 kg/ha (inorganic) + 50 kg/ha (organic)	1.49	1.32	1.41	0.30^{f}	0.28	–49.40	0.1440	0.0038	0.08
25 kg/ha (inorganic) + 75 kg/ha (organic)	1.51	1.27	1.79	4.61^{b}	–1.17	4.50	0.1100	0.0033	0.57
100 kg/ha (organic)	1.55	1.30	1.82	1.06^{e}	–0.41	5.80	0.1330	0.0029	0.45
Control (no organic; no inorganic)	1.53	1.36	1.89	1.37^{cd}	3.97	15.20	0.1390	0.0026	–0.10
SED ± ($p \leq 0.05$)	n.s.	n.s.	n.s.	0.11**	n.s.	n.s.	n.s.	n.s.	n.s.
V × N ($p \leq 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

SED ± – standard error of difference, WAP – weeks after planting, * – significant at $p \leq 0.05$, ** – significant at $p \leq 0.01$, n.s. – not significant. Means with the same letter in the same column are not significantly different at $p \leq 0.05$

Table 2 Effects of integrated nutrient sources of nitrogen-on-nitrogen uptake, partial factor productivity, and nitrogen utilization efficiency of lowland rice varieties in a derived savannah

Treatment	Nitrogen uptake, kg/kg			Partial factor productivity, kg/kg			Nitrogen utilization efficiency, kg/kg		
Varieties (V)	2017	2018	2019	2017	2018	2019	2017	2018	2019
ARICA 3	6.65	1.19	0.49	4.80	0.93	9.56	15.37^{b}	15.39^{b}	62.20
NERICA L-34	6.61	0.52	0.48	6.67	1.27	8.18	21.57^{a}	21.57^{a}	47.90
SED ± ($p \leq 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	5.64*	5.70*	n.s.
Nutrient sources of nitrogen (N)									
100 kg/ha (inorganic)	6.78	0.90	0.50^{ab}	4.66^{b}	1.22	9.79	17.59	17.58	64.60
75 kg/ha (inorganic) + 25 kg/ha (organic)	6.58	0.83	0.52^{a}	4.67^{b}	0.66	10.54	18.76	18.75	65.30
50 kg/ha (inorganic) + 50 kg/ha (organic)	6.75	1.12	0.49^{ab}	5.13^{b}	1.02	8.82	18.91	18.93	57.40
25 kg/ha (inorganic) + 75 kg/ha (organic)	6.62	0.85	0.47^{b}	5.28^{b}	0.84	6.44	18.03	18.03	48.30
100 kg/ha (organic)	6.48	0.76	0.47^{b}	10.28^{a}	1.24	10.88	18.82	18.83	59.20
Control (no organic; no inorganic)	6.55	0.69	0.46^{b}	4.39^{b}	1.61	6.75	18.74	18.75	35.50
SED ± ($p \leq 0.05$)	n.s.	n.s.	0.02*	1.82*	n.s.	n.s.	n.s.	n.s.	n.s.
V × N ($p \leq 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

SED ± – standard error of difference, WAP – weeks after planting, * – significant at $p \leq 0.05$, n.s.– not significant. Means with the same letter in the same column are not significantly different at $p \leq 0.05$

in comparison with other treatments, those containing a larger amount of inorganic nitrogen facilitated greater nutritional absorption. This might be because there was enough nitrogen available from both organic and inorganic sources for a long time, which eventually increased nitrogen uptake [44]. Our results are consistent with the works of Vishwanathan and Singaravel [45], Mohan Rao *et al.* [46], Kumar *et al.* [47], Ganguly *et al.* [48], and Shultana *et al.* [49].

Partial factor of productivity. In 2017, the partial factor of productivity was significantly ($p \leq 0.05$) affected by integrated nitrogen nutrient sources. The organic nitrogen application of 100 kg/ha produced the highest partial factor productivity (10.28 kg/kg), while the control sample (without fertilizers) produced the lowest (4.39 kg/kg), as shown in Table 2. This indicated better economic output and use of fertilizers, as well as better utilization of all the nutrients under treatment. An estimate of the economic production of the use of all nutrition sources is given by the partial factor productivity of applied nutrients. Better crop management techniques, more fertilizer application, and higher nutrient conversion ratios of the plant systems all contribute to the partial factor productivity [50]. A balanced application of N, P, and K (NPK) also optimized nutrient utilization efficiency, as reported by Korneeva [51]. This underscores the critical importance of striking the right balance between nutrient sources to achieve optimal productivity in rice cultivation [52].

Nitrogen utilization efficiency. In 2017 and 2018, the varieties had a significant effect ($p \leq 0.05$) on nitrogen utilization efficiency, kg/kg. In particular, the nitrogen utilization efficiencies of NERICA L-34 in 2017 and 2108 were higher (21.57 and 21.57 kg/kg, respectively) than those of ARICA 3 (15.37 and 15.39 kg/kg, respectively), as shown in Table 2. This can assist farmers in selecting those rice varieties which make more efficient use of nitrogen resources [33]. The research underscores the advantages of merging organic and inorganic fertilizers to enhance nitrogen utilization efficiency in rice farming [53].

Leaf area index. Our findings showed significant effects of the integrated nutrient sources on the leaf area index at different time after planting in 2017, 2018, and 2019. At 4 weeks after planting in 2018, the application of 50 kg/ha (inorganic) + 50 kg/ha (organic) resulted in the highest leaf area index, while the control sample led to the lowest leaf area index. At 6 weeks, various combinations of the integrated nutrient sources influenced the leaf area index differently, with different optimal combinations for each year. At 8 weeks, the integrated nutrient sources had a highly significant effect on the leaf area index, with the highest leaf area index varying between the years. 10 weeks after planting affected the leaf area index, with different combinations leading to variations in this index. At 12 weeks in 2017 and 2018, the integrated nutrient sources had a highly significant effect on the leaf area index. Different nutrient combinations influenced the leaf area index differently. 14 weeks after planting in 2017 demonstrated a significant effect on the leaf area index, with a nitrogen application of 75 kg/ha (inorganic) + 25 kg/ha (organic) resulting in the highest index (Tables 3 and 4).

In a study of Ikkonen *et al.*, integrated nutrient sources had a substantial influence on the leaf area index at

Table 3 Effects of integrated nutrient sources of nitrogen on the leaf area index of lowland rice varieties after planting in a derived savannah

Treatment	Leaf area index								
	4 weeks			6 weeks			8 weeks		
Varieties (V)	2017	2018	2019	2017	2018	2019	2017	2018	2019
ARICA 3	0.111	0.173	0.167	0.138	0.217	0.217	0.168	0.250	0.231
NERICA L-34	0.071	0.164	0.178	0.087	0.164	0.147	0.091	0.219	0.186
SED ± ($p \leq 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Nutrient sources of nitrogen (N)									
100 kg/ha (inorganic)	0.097	0.167^{a}	0.162	0.109^{a}	0.190^{a}	0.170^{bc}	0.121a	0.213^{ab}	0.207^{bc}
75 kg/ha (inorganic) + 25 kg/ha (organic)	0.089	0.182^{a}	0.166	0.118^{a}	0.203^{a}	0.192^{abc}	0.141^{a}	0.218^{a}	0.211^{ab}
50 kg/ha (inorganic) + 50 kg/ha (organic)	0.095	0.187^{a}	0.214	0.106^{a}	0.192^{a}	0.219^{a}	0.122^{a}	0.202^{abc}	0.228^{a}
25 kg/ha (inorganic) + 75 kg/ha (organic)	0.097	0.180^{a}	0.164	0.108^{a}	0.211^{a}	0.198^{ab}	0.125^{ab}	0.204^{ab}	0.208^{ab}
100 kg/ha (organic)	0.090	0.163^{a}	0.164	0.130^{a}	0.187^{b}	0.171^{abc}	0.132^{c}	0.193^{bc}	0.207^{bc}
Control (no organic; no inorganic)	0.079	0.090^{b}	0.138	0.101^{b}	0.113^{c}	0.143^{c}	0.104d	0.146^{c}	0.147^{c}
SED ± ($p \leq 0.05$)	n.s.	0.0044**	n.s.	0.018**	0.064*	0.039*	0.023**	0.077*	0.080**
V × N ($p \leq 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

SED ± – standard error of difference, * – significant at $p \leq 0.05$, ** – significant at $p \leq 0.01$, n.s. – not significant. Means with the same letter in the same column are not significantly different at $p \leq 0.05$

Table 4 Effects of integrated nutrient sources of nitrogen on the leaf area index of lowland rice varieties after planting and maturity in a derived savannah

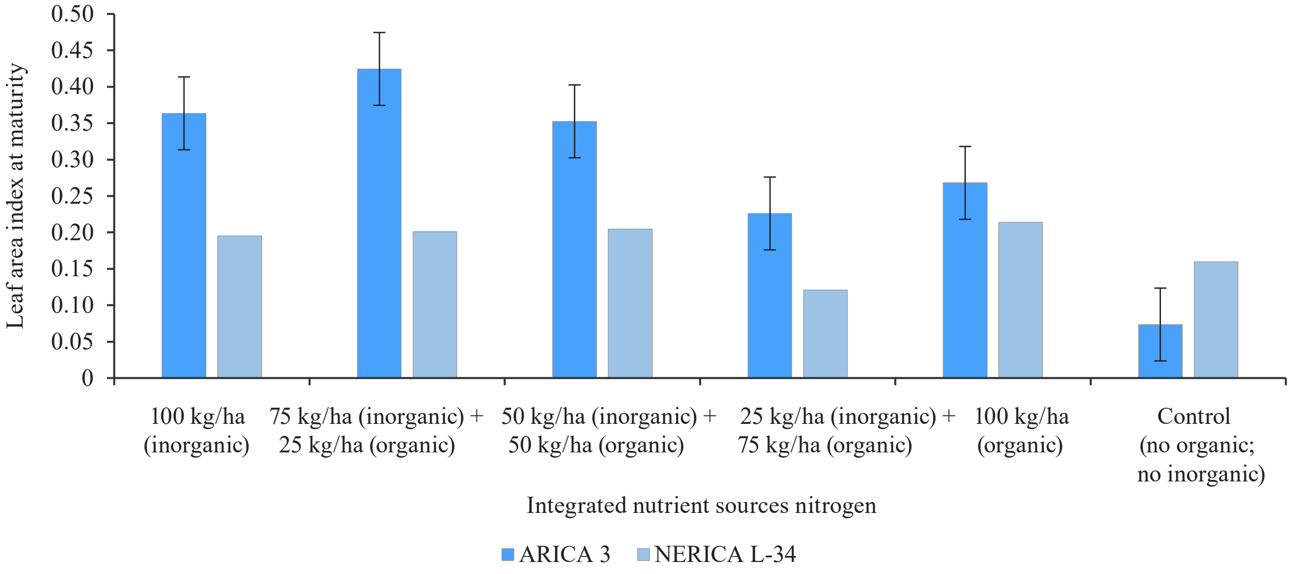
Treatment	Leaf area index											
	10 weeks			12 weeks			14 weeks			Maturity		
Varieties (V)	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
ARICA 3	0.46	0.30	0.45	0.32	0.29	0.46^{a}	0.17	0.33	0.46	0.29	0.20	0.29
NERICA L-34	0.67	0.17	0.24	0.31	0.14	0.23^{b}	0.23	0.13	0.22	0.18	0.10	0.18
SED ± ($p \leq 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	0.07*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Nutrient sources of nitrogen (N)												
100 kg/ha (inorganic)	0.74^{a}	0.33^{a}	0.35	0.52^{a}	0.28^{ab}	0.39	0.21^{ab}	0.30	0.34	0.22	0.33	0.28
75 kg/ha (inorganic) + 25 kg/ha (organic)	0.70^{a}	0.31^{a}	0.35	0.27c	0.23^{b}	0.38	0.26^{a}	0.24	0.36	0.32	0.13	0.31
50 kg/ha (inorganic) + 50 kg/ha (organic)	0.71^{a}	0.18^{a}	0.48	0.41^{ab}	0.14^{bc}	0.46	0.22^{ab}	0.21	0.48	0.28	0.14	0.28
25 kg/ha (inorganic) + 75 kg/ha (organic)	0.69^{a}	0.37^{a}	0.39	0.32c	0.41^{a}	0.37	0.16^{ab}	0.39	0.37	0.14	0.20	0.17
100 kg/ha (organic)	0.41^{ab}	0.19^{ab}	0.39	0.25^{c}	0.20^{b}	0.34	0.19^{ab}	0.18	0.31	0.20	0.09	0.24
Control (no organic; no inorganic)	0.12^{c}	0.04^{b}	0.12	0.09^{d}	0.03^{c}	0.15	0.15^{c}	0.04	0.18	0.12	0.03	0.12
SED ± ($p \leq 0.05$)	0.16**	0.10*	n.s.	0.08**	0.08**	n.s.	0.04*	n.s.	n.s.	n.s.	n.s.	n.s.
V × N ($p \leq 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s	n.s.	n.s.	n.s.	n.s.	n.s.	5.02*

SED ± – standard error of difference, * – significant at $p \leq 0.05$, ** – significant at $p \leq 0.01$, n.s. – not significant. Means with the same letter in the same column are not significantly different at $p \leq 0.05$

various stages of rice growth [54]. Nitrogen causes vegetative growth through an increased leaf area. Therefore, more nitrogen available to plants can increase the leaf area. This highlights the capacity of nutrient management to affect the development of leaf area, which is pivotal for photosynthesis and overall plant health [55].

Effects of variety and integrated sources of nitrogen on the leaf area index at maturity in 2019. The interaction between the lowland rice varieties and the integrated nutrient sources of nitrogen had a significant effect ($p \leq 0.05$) on the leaf area index at maturity in 2019. ARICA 3 had the highest leaf area index (0.424) when 75 kg/ha (inorganic) + 25 kg/ha (organic) f nitrogen was applied at maturity. However, applying the control sample (no fertilizer) to ARICA 3 produced the lowest leaf area index (0.074) at maturity in 2019 (Fig. 1).

Chlorophyll content. At 4 weeks after planting, the highest chlorophyll content was observed with the nitrogen application of 100 kg/ha (inorganic) in 2018 and 100 kg/ha (organic) in 2019. 6 weeks after planting in 2017 showed a significant effect on the chlorophyll content, with NERICA L-34 exhibiting a higher content than ARICA 3. At 8 weeks in 2017 and 2018, the highest chlorophyll content was observed with the nitrogen application of 100 kg/ha (inorganic) in 2017 and 75 kg/ha (inorganic) + 25 kg/ha (organic) in 2018. At 10 WAP in 2017 and 2018, the integrated nutrient sources had a significant effect on the chlorophyll content, with different optimal combinations leading to its variations. At 12 WAP in 2019, the rice varieties had a highly significant effect on the chlorophyll content, with NERICA L-34 exhibiting a higher content than ARICA 3. At 14 WAP in 2017



I – Standard error of difference at $p \leq 0.05$

Figure 1 Effects of rice variety and integrated nutrient sources of nitrogen on leaf area index at maturity in 2019

Table 5 Effects of integrated nutrient sources of nitrogen on chlorophyll content of lowland rice varieties after planting in a derived savannah

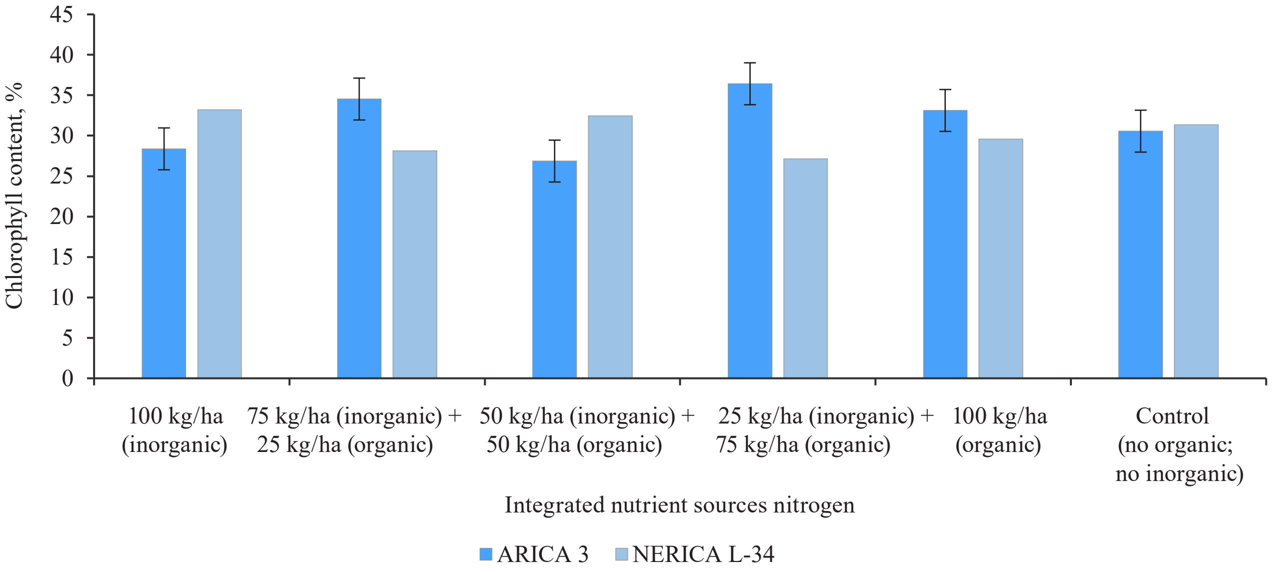
Treatment	Chlorophyll content, %								
	4 weeks			6 weeks			8 weeks		
Varieties (V)	2017	2018	2019	2017	2018	2019	2017	2018	2019
ARICA 3	31.54	32.77	37.87	37.11^{b}	40.54	43.10	38.31	39.37	41.47
NERICA L-34	31.98	30.61	35.69	37.82^{a}	35.88	41.34	36.57	37.84	39.05
SED ± ($p \leq 0.05$)	n.s.	n.s.	n.s.	0.09*	n.s.	n.s.	n.s.	n.s.	n.s.
Nutrient Sources (N)									
100 kg/ha (inorganic)	31.37	34.59^{a}	37.39^{ab}	35.46	39.80	42.82	39.97^{a}	39.40^{ab}	41.02
75 kg/ha (inorganic) + 25 kg/ha (organic)	31.10	34.43^{a}	33.54^{c}	37.11	39.16	43.13	38.86^{a}	41.71^{a}	40.03
50 kg/ha (inorganic) + 50 kg/ha (organic)	32.80	32.52^{a}	34.86^{bc}	37.75	38.67	42.32	37.62^{ab}	37.55^{b}	40.25
25 kg/ha (inorganic) + 75 kg/ha (organic)	33.48	32.05^{a}	37.25^{ab}	38.54	38.91	42.42	37.37^{ab}	39.01^{ab}	39.87
100 kg/ha (organic)	32.14	31.16^{a}	38.93^{a}	38.38	37.68	42.44	37.31^{ab}	38.25^{ab}	42.22
Control (no organic; no inorganic)	29.70	25.38^{b}	38.70^{a}	37.52	35.05	40.22	33.52^{c}	35.71^{b}	38.16
SED ± ($p \leq 0.05$)	n.s.	2.18**	1.46**	n.s.	n.s.	n.s.	1.88*	1.63*	n.s.
V×N ($p \leq 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

SED ± – standard error of difference, * – significant at $p \leq 0.05$, ** – significant at $p \leq 0.01$, n.s. – not significant. Means with the same letter in the same column are not significantly different at $p \leq 0.05$

Table 6 Effects of integrated nutrient sources of nitrogen on chlorophyll content of lowland rice varieties after planting and maturity in a derived savannah

Treatment	Chlorophyll content, %											
	10 weeks			12 weeks			14 weeks			Maturity		
Varieties (V)	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
ARICA 3	40.57	38.03	42.39	42.61	39.58	39.01^{b}	41.16	42.21	42.06	29.14	32.46	31.64
NERICA L-34	38.46	36.57	37.93	42.23	37.95	43.53^{a}	40.46	36.63	42.85	29.14	32.24	30.32
SED ± ($p \leq 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	2.19**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Nutrient Sources (N)												
100 kg/ha (inorganic)	39.76^{a}	38.01^{a}	39.61	43.62	39.03	41.51	41.33^{ab}	41.99^{ab}	42.56	31.23	32.98	30.80
75 kg/ha (inorganic) + 25 kg/ha (organic)	39.96^{a}	37.69^{a}	41.33	42.53	39.35	43.08	42.84^{a}	43.39^{a}	42.48	30.03	30.46	31.34
50 kg/ha (inorganic) + 50 kg/ha (organic)	41.22^{a}	37.72^{a}	39.37	42.3	37.58	39.70	40.42^{bc}	38.95^{ab}	42.85	31.06	32.55	29.66
25 kg/ha (inorganic) + 75 kg/ha (organic)	39.35^{ab}	37.98^{a}	42.01	42.78	40.03	39.26	39.03^{d}	33.83^{c}	41.44	28.01	32.81	31.79
100 kg/ha (organic)	39.56^{ab}	38.03^{a}	39.88	43.81	39.71	42.32	40.39^{bc}	42.27^{ab}	43.88	28.83	34.44	31.35
Control (no organic; no inorganic)	37.26^{c}	34.35^{b}	38.76	39.47	36.87	41.75	40.88^{abc}	36.10^{bc}	41.52	25.69	30.87	30.96
SED ± ($p \leq 0.05$)	1.06*	0.88**	n.s.	n.s.	n.s.	n.s.	0.96*	2.92*	n.s.	n.s.	n.s.	n.s.
V×N ($p \leq 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	2.59**

SED ± – standard error of difference, * – significant at $p \leq 0.05$, ** – significant at $p \leq 0.01$, n.s. – not significant. Means with the same letter in the same column are not significantly different at $p \leq 0.05$



I – Standard error of difference at $p \leq 0.05$

Figure 2 Effects of rice variety and integrated nutrient sources of nitrogen on chlorophyll content at maturity in 2019

and 2018, the nitrogen combination of 75 kg/ha (inorganic) + 25 kg/ha (organic) resulted in the highest chlorophyll content in both years (Tables 5 and 6).

The chlorophyll content, a crucial indicator of plant health and photosynthetic capacity, is significantly affected by nutrient sources, with various sources yielding varying results [56]. This underscores the importance of nutrient management in optimizing photosynthetic activity in rice plants [54].

Effects of variety and integrated sources of nitrogen on chlorophyll content at maturity in 2019. The interaction between the lowland rice varieties and the integrated nutrient sources of nitrogen had a significant effect ($p \leq 0.05$) on the chlorophyll content, %, at maturity in 2019. ARICA 3 had the highest content (36.42%) at 25 kg/ha (inorganic) + 75 kg/ha (organic) of nitrogen was applied, while NERICA L-34 had the lowest content (27.16%), as shown in Figure 2.

Root fresh weight. At 4 weeks after planting in 2019, a combination of 50 kg/ha (inorganic) + 50 kg/ha (organic) resulted in the heaviest roots. At 6 weeks in 2017 and 2018, a combination of 50 kg/ha (inorganic) + 50 kg/ha (organic) produced the heaviest roots in both years. 8 weeks in 2017 demonstrated a significant effect on the root fresh weight, with ARICA 3 having heavier roots than NERICA L-34. The integrated nutrient sources also had a significant effect, with the nitrogen application of 100 kg/ha (inorganic) resulting in the heaviest roots. The varieties also had a significant effect on the root fresh weight at 10 weeks after planting in 2018, while the integrated nutrient sources had a significant effect on this indicator in 2017 and 2019 (Tables 7 and 8).

Effects of variety and integrated sources of nitrogen on root fresh weight. At 12 weeks after planting in 2017, ARICA 3 exhibited the heaviest root fresh weight (93.6 g) when 100 kg/ha of nitrogen (inorganic) was applied, while the sample without fertilizers resulted in the lightest roots (64.5 g). At 14 weeks in 2017, ARICA 3 also had the heaviest root fresh weight (267 g) when 25 kg/ha (inorganic) + 75 kg/ha (organic) was applied. However, NERICA L-34 had the lightest roots (67 g) when 75 kg/ha (inorganic) + 25 kg/ha (organic) was used. At maturity in 2017, ARICA 3 had the heaviest root fresh weight (283 g) at 100 kg/ha (organic), whereas NERICA L-34 had the lightest root fresh weight (62 g) when no organic or inorganic nutrients were applied (control sample). 14 weeks after planting in 2019, ARICA 3 again exhibited the heaviest roots (92.1 g) at 25 kg/ha (inorganic) + 75 kg/ha (organic), while NERICA L-34 had the lightest roots (34 g) when the control sample was applied (Figures 3 and 4).

Table 7 Effects of integrated nutrient sources of nitrogen on root fresh weight of lowland rice varieties after planting in a derived savannah

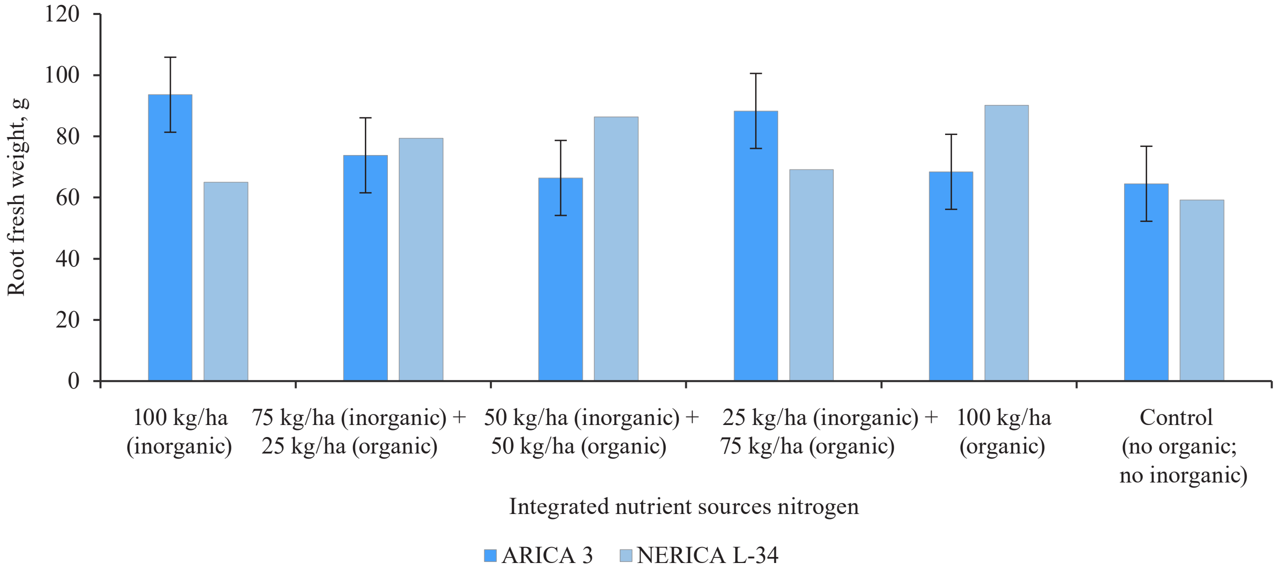
Treatment	Root fresh weight, g								
	4 weeks			6 weeks			8 weeks		
Varieties (V)	2017	2018	2019	2017	2018	2019	2017	2018	2019
ARICA 3	1.78	3.51	0.20	25.90	13.48	2.54	40.30^{a}	39.50	5.96
NERICA L-34	1.65	2.86	0.16	15.20	14.02	3.40	29.00^{b}	48.40	7.28
SED ± ($p \le 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	6.30*	n.s.	n.s.
Nutrient Sources (N)									
100 kg/ha (inorganic)	1.70	2.57	0.15^{b}	30.10^{a}	13.13^{ab}	2.89	52.00^{a}	40.90	7.42
75 kg/ha (inorganic) + 25 kg/ha (organic)	2.00	4.03	0.17^{b}	13.80^{c}	17.21^{a}	2.92	30.60^{c}	40.10	6.35
50 kg/ha (inorganic) + 50 kg/ha (organic)	2.01	4.25	0.27^{a}	30.40^{a}	15.38^{a}	2.99	38.40^{ab}	68.90	8.03
25 kg/ha (inorganic) + 75 kg/ha (organic)	1.23	3.14	0.18^{b}	12.80^{c}	11.77^{ab}	3.43	31.20^{c}	37.10	6.72
100 kg/ha (organic)	1.85	1.66	0.18^{b}	20.20^{ab}	18.24^{a}	2.91	28.90^{c}	47.30	6.17
Control (no organic; no inorganic)	1.51	3.47	0.13^{b}	15.90^{ab}	6.81^{b}	2.68	27.00^{c}	29.20	5.02
SED ± ($p \le 0.05$)	n.s.	n.s.	0.04*	6.85*	3.30**	n.s.	6.84*	n.s.	n.s.
V×N ($p \le 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

SED ± – standard error of difference, * – significant at $p \le 0.05$, ** – significant at $p \le 0.01$, n.s. – not significant. Means with the same letter in the same column are not significantly different at $p \le 0.05$

Table 8 Effects of integrated nutrient sources of nitrogen on root fresh weight of lowland rice varieties after planting and maturity in a derived savannah

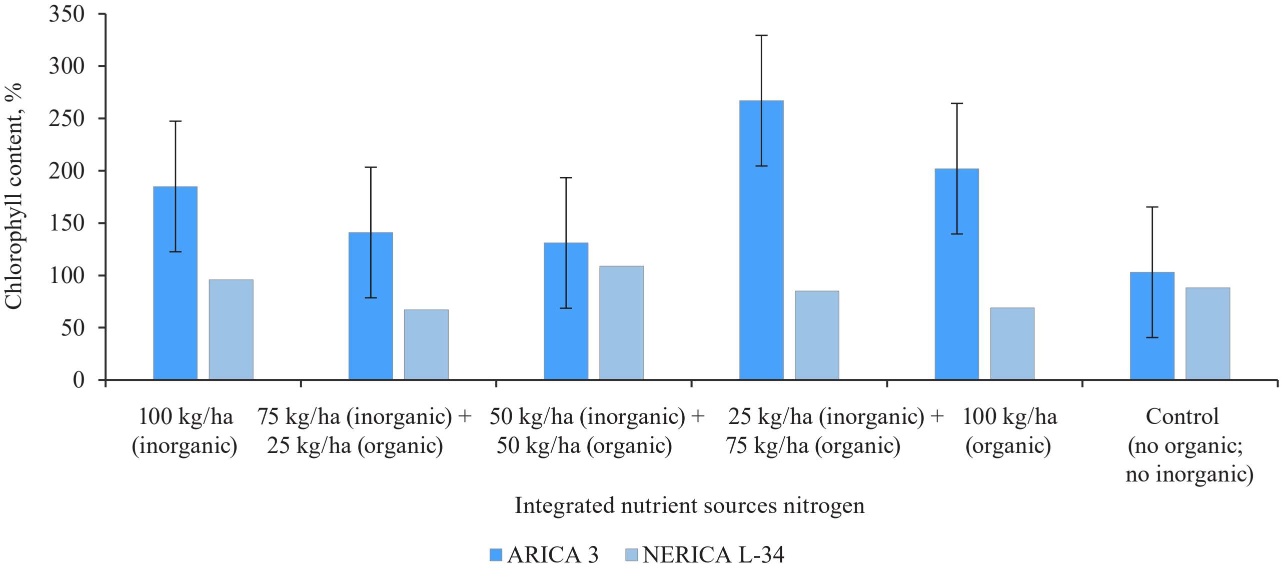
Treatment	Root fresh weight, g											
	10 weeks			12 weeks			14 weeks			Maturity		
Varieties (V)	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
ARICA 3	86.40	107.90^{a}	60.70	85.70	114.10	41.80	172.00	223.00	58.90	150.00a	214.00	48.90
NERICA L-34	67.50	85.10^{b}	70.28	95.90	81.60	33.00	86.00	59.00	43.60	101.00b	101.00	30.60
SED ± ($p \le 0.05$)	n.s.	17.98*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	7.69**	n.s.	n.s.
Nutrient Sources (N)												
100 kg/ha (inorganic)	80.70^{ab}	84.80	68.83^{a}	93.30	100.40^{a}	34.50	141.00	164.00	51.30^{ab}	112.00^{ab}	179.00	38.20
75 kg/ha (inorganic) + 25 kg/ha (organic)	80.50^{ab}	85.40	68.83^{a}	88.80	120.10^{a}	40.40	104.00	187.00	44.50^{b}	137.00^{ab}	97.00	41.30
50 kg/ha (inorganic) + 50 kg/ha (organic)	76.10^{ab}	107.10	66.13^{ab}	86.70	89.40^{ab}	42.80	120.00	86.00	51.30^{ab}	131.00^{ab}	278.00	35.10
25 kg/ha (inorganic) + 75 kg/ha (organic)	93.00^{a}	130.20	62.23^{b}	108.90	99.20^{a}	35.20	176.00	101.00	66.30^{a}	102.00^{ab}	166.00	54.50
100 kg/ha (organic)	61.40^{c}	97.70	65.49^{ab}	107.90	136.30^{a}	28.70	136.00	179.00	52.30^{ab}	189.00^{a}	160.00	38.10
Control (no organic; no inorganic)	69.90^{c}	73.60	61.43^{b}	59.10	41.90^{b}	43.00	96.00	130.00	41.50^{b}	81.00^{c}	65.00	31.20
SED ± ($p \le 0.05$)	9.01*	n.s.	2.64*	n.s.	24.91*	n.s.	n.s.	n.s.	7.36*	4.35**	n.s.	n.s.
V×N ($p \le 0.05$)	n.s.	n.s.	n.s.	12.26*	n.s.	n.s.	n.s.	n.s.	13.53*	5.89**	n.s.	n.s.

SED ± – standard error of difference, * – significant at $p \le 0.05$, ** – significant at $p \le 0.01$, n.s. – not significant. Means with the same letter in the same column are not significantly different at $p \le 0.05$



I – Standard error of difference at $p \leq 0.05$

Figure 3 Effects of rice variety and integrated nutrient sources of nitrogen on root fresh weight at 12 weeks after planting in 2017



I – Standard error of difference at $p \leq 0.05$

Figure 4 Effects of rice variety and integrated nutrient sources of nitrogen on root fresh weight at 14 weeks after planting in 2017

Root dry weight. 4 weeks after planting in 2018, ARICA 3 had heavier roots (1.19 g) compared to NERICA L-34 (0.80 g). 100 kg nitrogen/ha (inorganic) resulted in the heaviest root dry weight (1.39 g), while the control sample produced the lightest root dry weight (0.71 g). 6 weeks after planting in 2018, NERICA L-34 had heavier roots (5.01 g) compared to ARICA 3 (3.81 g). At 8 weeks in 2018, NERICA L-34 again had heavier roots (11.9 g) compared to ARICA 3 (8.6 g). At 10 weeks in both 2018 and 2019, the varieties had a significant effect on the root dry weight, with NERICA L-34 consistently having heavier roots compared to ARICA 3. In 2019, the integrated nutrient sources of nitrogen had a highly significant effect on the root dry weight at 10 weeks after planting, with 75 kg/ha (inorganic) + 25 kg/ha (organic) resulting in the heaviest roots (18.66 g). 12 weeks in 2018 demonstrated that ARICA 3 had heavier roots (36.3 g) compared to NERICA L-34 (28 g). 100 kg nitrogen/ha (organic) produced the heaviest root dry weight (56.2 g). At maturity in both 2018 and 2019, the varieties had a significant effect on the root dry weight, with ARICA 3 consistently having heavier roots compared to NERICA L-34 (Tables 9 and 10).

Effects of variety and integrated sources of nitrogen on root dry weight. At 10 weeks after planting in 2019, the interaction between the rice varieties and the integrated nutrient sources of nitrogen had a highly significant effect on the root dry weight. NERICA L-34 recorded

Table 9 Effects of integrated nutrient sources of nitrogen on root dry weight of lowland rice varieties after planting in a derived savannah

Treatment	Root dry weight, g								
	4 weeks			6 weeks			8 weeks		
Varieties (V)	2017	2018	2019	2017	2018	2019	2017	2018	2019
ARICA 3	0.95	1.19^{a}	0.06	6.74	3.81^{b}	0.76	23.80	8.60^{b}	1.58
NERICA L-34	0.84	0.80^{b}	0.05	4.76	5.01^{a}	0.66	21.20	11.90^{a}	2.81
SED ± ($p \leq 0.05$)	n.s.	0.38*	n.s.	n.s.	0.81*	n.s.	n.s.	2.46*	n.s.
Nutrient Sources (N)									
100 kg/ha (inorganic)	0.90	1.39^{a}	0.04	9.14	5.36	0.87	32.90	9.60	3.20
75 kg/ha (inorganic) + 25 kg/ha (organic)	1.02	0.94^{ab}	0.06	3.91	4.47	0.59	17.80	12.30	1.90
50 kg/ha (inorganic) + 50 kg/ha (organic)	1.10	0.73^{b}	0.06	7.77	4.66	0.87	33.70	13.80	2.70
25 kg/ha (inorganic) + 75 kg/ha (organic)	0.61	1.14^{ab}	0.06	3.44	3.86	0.71	20.10	8.40	1.99
100 kg/ha (organic)	1.09	1.08^{ab}	0.05	6.24	5.67	0.74	17.00	12.70	1.93
Control (no organic; no inorganic)	0.66	0.71^{b}	0.04	3.98	2.45	0.49	13.70	4.50	1.46
SED ± ($p \leq 0.05$)	n.s.	0.21*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
V×N ($p \leq 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

SED ± – standard error of difference, * – significant at $p \leq 0.05$, n.s. – not significant. Means with the same letter in the same column are not significantly different at $p \leq 0.05$

Table 10 Effects of integrated nutrient sources of nitrogen on root dry weight of lowland rice varieties after planting and maturity

Treatment	Root dry weight (g)											
	10 weeks			12 weeks			14 weeks			Maturity		
Varieties (V)	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
ARICA 3	34.00	8.60^{b}	16.00^{b}	26.51	36.30^{a}	11.70	73.80^{a}	69.80	21.00	67.70	63.20^{a}	14.48^{a}
NERICA L-34	32.40	11.90^{a}	18.57^{a}	24.80	28.00^{b}	11.70	31.40^{b}	18.20	15.80	48.30	28.40^{b}	12.36^{b}
SED ± ($p \leq 0.05$)	n.s.	2.46*	1.91*	n.s.	6.43*	n.s.	43.26*	n.s.	n.s.	n.s.	4.88*	1.40*
Nutrient Sources (N)												
100 kg/ha (inorganic)	29.30	9.60	18.45^{a}	30.76^{a}	34.80^{ab}	14.00	58.80	51.70	20.70	50.00	54.80	14.76
75 kg/ha (inorganic) + 25 kg/ha (organic)	36.70	12.30	18.66^{a}	25.97^{ab}	33.20^{ab}	9.70	47.80	64.80	15.00	65.50	38.00	14.77
50 kg/ha (inorganic) + 50 kg/ha (organic)	34.20	13.80	17.23^{ab}	25.08^{ab}	24.70^{b}	15.00	41.60	29.60	16.10	55.40	63.50	13.00
25 kg/ha (inorganic) + 75 kg/ha (organic)	51.10	8.40	16.33^{b}	25.71^{ab}	32.00^{ab}	10.50	79.30	30.30	23.00	52.00	44.20	13.10
100 kg/ha (organic)	26.00	12.70	16.83^{b}	27.26^{a}	56.20^{a}	11.00	52.30	49.10	19.50	81.50	45.20	13.08
Control (no organic; no inorganic)	21.80	4.50	16.23^{b}	19.17^{c}	11.90^{b}	10.20	36.00	38.40	16.00	43.80	29.20	11.82
SED ± ($p \leq 0.05$)	n.s.	n.s.	0.72**	3.26*	11.24*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
V×N ($p \leq 0.05$)	n.s.	n.s.	1.03*	4.65**	n.s.	n.s.	n.s.	n.s.	8.31*	n.s.	n.s.	n.s.

SED ± – standard error of difference, * – significant at $p \leq 0.05$, ** – significant at $p \leq 0.01$, n.s. – not significant. Means with the same letter in the same column are not significantly different at $p \leq 0.05$

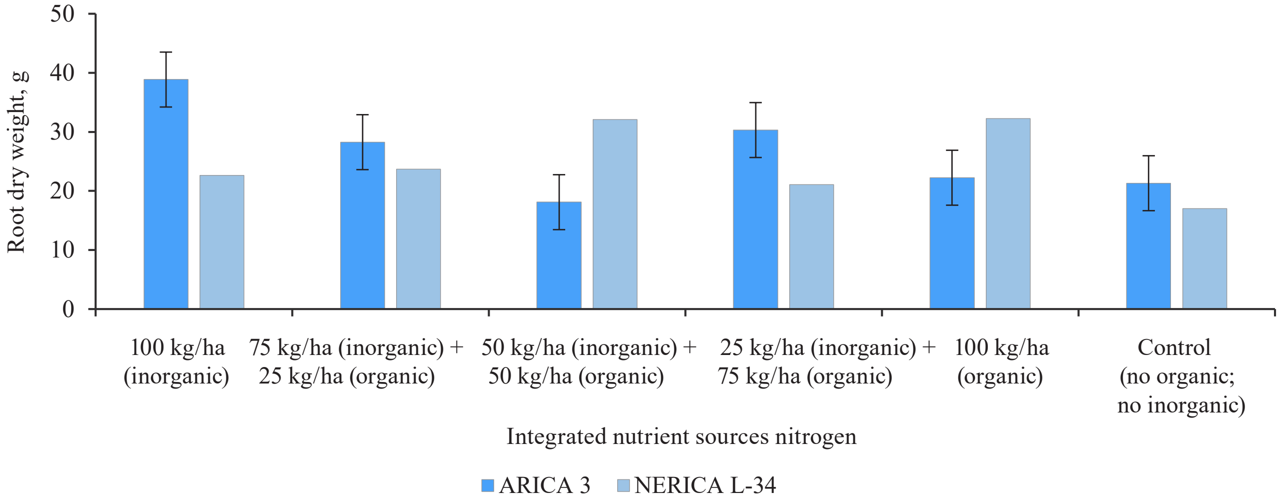
the heaviest roots (21.01 g) when 75 kg nitrogen/ha (inorganic) + 25 kg/ha (organic) was applied. ARICA-3 had the lightest roots (15.07 g) at 50 kg/ha (inorganic) + 50 kg/ha (organic) of nitrogen. At 14 weeks in 2019, ARICA 3 had the heaviest roots (34.4 g) at 25 kg/ha (inorganic) + 75 kg/ha (organic) of nitrogen. NERICA L-34 had the lightest roots (11.6 g) when 25 kg/ha (inorganic) + 75 kg/ha (organic) was applied (Figures 5, 6, and 7).

The weight of roots, a critical indicator of plant health and nutrient uptake, is substantially influenced by both integrated nutrient sources and rice varieties [57]. These findings can provide valuable guidance for decisions regarding nutrient management and variety selection to promote root development and nutrient uptake [58].

The interaction between rice varieties and integrated nutrient sources yields significant effects on several parameters, including the leaf area index, chlorophyll content, root dry weight, and root fresh weight. This suggests that the choice of a rice variety should be considered alongside nutrient management practices to maximize crop performance [59].

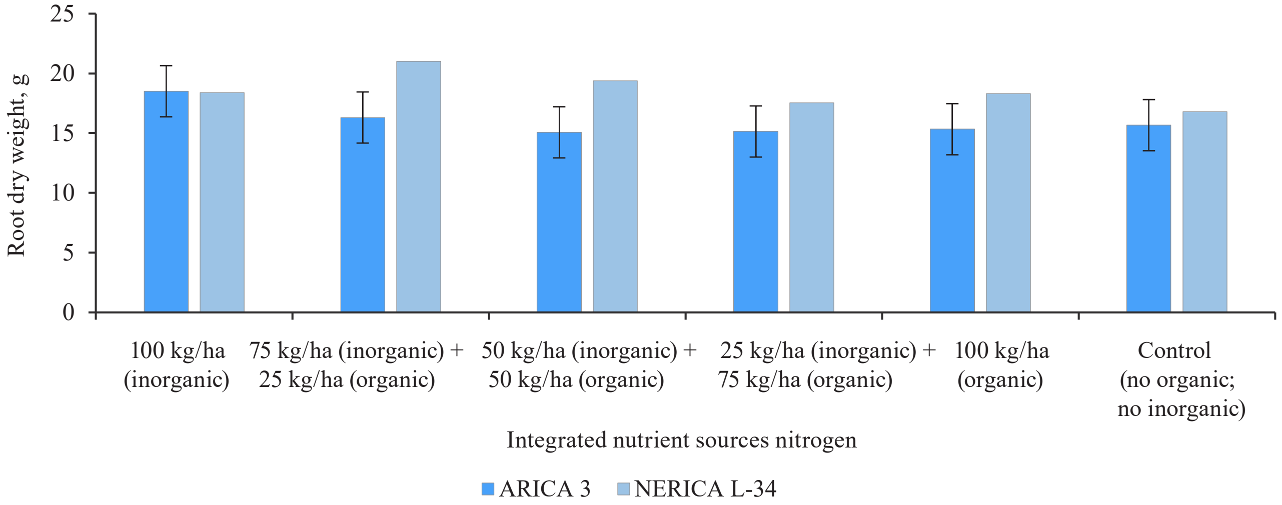
CONCLUSION

In conclusion, our results highlighted the significance of integrated nitrogen nutrient sources in influencing the physiological parameters of lowland rice varieties, ARICA 3 and NERICA L-34, in Nigeria's derived savannah. Nutrient management strategies play



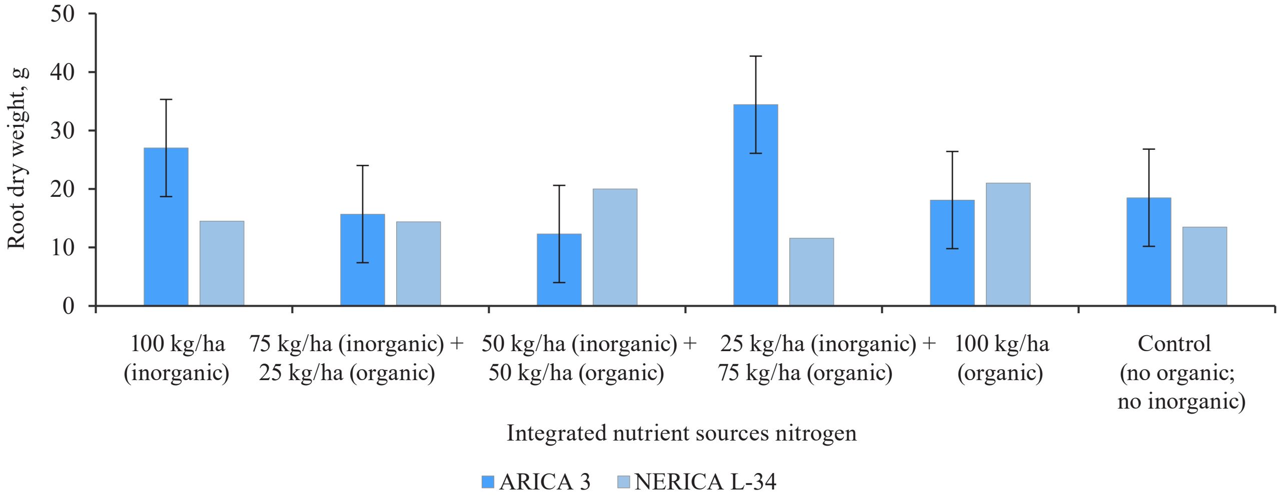
I – Standard error of difference at $p \leq 0.05$

Figure 5 Effects of rice variety and integrated nutrient sources of nitrogen on root dry weight at 12 weeks after planting in 2017



I – Standard error of difference at $p \leq 0.05$

Figure 6 Effects of rice variety and integrated nutrient sources of nitrogen on root dry weight at 10 weeks after planting in 2019



I – Standard error of difference at $p \leq 0.05$

Figure 7 Effects of rice variety and integrated nutrient sources of nitrogen on root dry weight at 14 weeks after planting in 2019 a critical role in enhancing rice crop performance and overall agricultural productivity in the region. Specific combinations of integrated nutrients, such as 75 kg nitrogen/ha (inorganic) + 25 kg/ha (organic) in 2019, proved effective in promoting nutrient absorption by the rice plants. Our study underscores the importance of varietal selection, with NERICA L-34 consistently outperforming ARICA 3 in applied nutrient recovery efficiency and nitrogen utilization efficiency.

In 2017, 2018, and 2019, the chlorophyll content was higher in the rice plants of ARICA 3 than in those of NERICA L-34. Furthermore, 100 kg nitrogen/ha (organic) produced the highest chlorophyll content in 2017, 2018, and 2019 compared to the other levels of nitrogen nutrient sources applied.

RECOMMENDATIONS

Based on our findings, we recommend that the rice plant NERICA L-34 should be adopted and cultivated by rice farmers. We also support the Integrated Nutrient Management approaches, which entail combining both organic and inorganic fertilizers to enhance the soil's nutrient content. In our study, specific combinations of nutrients, such as 75 kg/ha (inorganic) + 25 kg/ha (organic), improved nutrient absorption by the rice plants. NERICA L-34 demonstrated its superior performance in applied nutrient recovery efficiency and nitrogen utilization efficiency, as compared to ARICA 3. Considering environmental factors in nutrient management is crucial for optimizing crop performance and promoting sustainability. Further research in diverse ecological zones is needed to validate our findings and develop location-specific nutrient management recommendations. Education and awareness programs should be promoted to encourage farmers to adopt proper nutrient management practices and varietal selection. Conducting long-term studies on integrated nutrient sources can provide deeper insights into their sustainability. Governmental support in providing access to quality fertilizers, training, and extension services is vital for successful implementation. By following these recommendations, rice farmers can enhance productivity, ensure food security, and build a resilient agricultural sector for the nation's future.

CONTRIBUTION

All the authors were equally involved in conducting the research and writing the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the publication of this article.

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ORCID IDs
Olumayowa Joseph Iyanda https://orcid.org/0000-0002-5340-9884
Akeem Abdulai Oyekanmi https://orcid.org/0000-0001-7704-1634
Mufutau Olaoye Atayese https://orcid.org/0000-0001-8363-6677
Ayomide Afolabi https://orcid.org/0000-0002-5171-886X