

Research Article

Comparative Effects of Amino and Agriful on Growth and Yield Parameters of Rice

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Abstract

The purpose of this study was to assess how two bio-stimulants, Amino and Agriful, affect the growth and yield of rice (*Oryza sativa* L.). Bio-stimulants are increasingly recognized for their ability to boost plant performance in a sustainable way, and this study set out to examine their specific contributions under controlled conditions. To achieve this, pot experiments were used to clearly isolate and measure their effects. Two rice varieties, LEGON-1 and CRI-AMANKWATIA, were selected for the trials. The experiment involved applying Amino and Agriful at different concentrations, along with a control treatment that received no bio-stimulant. Key growth indicators such as plant height, leaf area, and biomass accumulation were monitored at different stages of development. Results showed that Amino significantly enhanced vegetative growth. Plants treated with Amino exhibited greater height and larger leaf area, which supported better photosynthetic activity and higher biomass production. In contrast, Agriful had a stronger influence on yield-related traits, promoting longer panicles, heavier grains, and higher overall grain yield. Soil tests conducted before and after the experiment indicated that both bio-stimulants improved soil conditions, particularly by increasing nutrient availability and stimulating microbial activity. Overall, the study demonstrates that incorporating bio-stimulants like Amino and Agriful into rice production can enhance growth and yield in a sustainable manner. Although both products were beneficial, their differing strengths, Amino favoring vegetative growth and Agriful enhancing yield components—underline the need to match bio-stimulant choice with specific agronomic objectives.

Keywords

Oryza Sativa L, Bio Stimulant, Amino and Agriful, Environmental, Microbial, Plant growth, Productivity

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1. Introduction

In sub-Saharan Africa (SSA), research on crop nutrition has primarily concentrated on macronutrients, specifically nitrogen, phosphorus, and potassium, for the past thirty years [1-4]. Nonetheless, several studies have shown compelling evidence that agricultural yield in Sub-Saharan Africa (SSA) is restricted by shortages in micronutrients and secondary nutrients, particularly when farming continuously without replenishing nutrients [4, 5]. Low-productivity patches in rice, for instance, have been linked to a zinc (Zn) shortage [5] following continuous cultivation without micronutrient application; however, these spots may also be associated with interactions with other variables, such as high plant-available soil phosphorus (P) and soil alkalinity.

In several regions of the country, boron deficits are on the rise, alongside micronutrient inadequacies, second only to zinc and iron, due to the ongoing depletion of soil reserves, particularly in alluvial soils used for rice cultivation [6]. A system of rice and wheat cropping is nutrient-exhaustive, meaning that soil nutrient removal exceeds fertilizer input by a large margin. As a result, the rice system had widespread boron deficiency. In vascular plants, boron (B), a vital mineral component, plays a crucial role in activating several physiological functions. According to Langridge et al. [7], it is crucial for the metabolism of carbohydrates, translocation, cell wall creation, and RNA metabolism [8, 9]. It has been discovered that boron is essential for the development of anthers, the plasma membrane, pollen tube expansion, floret fertility, and seed development [10, 11]. According to [12] a deficiency in B results in decreased leaf photosynthetic rate, dry matter production, plant height, and the quantity of reproductive structures during the squaring and fruiting stages. [13] reported a noticeably greater grain yield in the rice-wheat area from cumulative treatment as opposed to direct and residual application B.

Research on crop nutrition in Sub-Saharan Africa (SSA) has primarily focused on macronutrients, namely, nitrogen, phosphorus, and potassium, over the past three decades. However, compelling evidence suggests that agricultural yields in SSA are constrained by deficiencies in micronutrients and secondary nutrients, especially under continuous farming without nutrient replenishment. Despite its importance, relatively little research has been conducted on soil secondary and micronutrient deficiencies and the associated crop responses in SSA compared to other regions.

Relatively little research has been conducted on soil secondary and micronutrient deficiencies and their accompanying crop responses in Sub-Saharan Africa (SSA) compared to other parts of the world. Experts from several generations have highlighted the lack of attention paid to micronutrients and the corresponding crop response in Sub-Saharan Africa [14-17]. Molybdenum (Mo), zinc (Zn), and boron (B) were recognized as the most crucial micronutrients as early as the 1970s, but only for specific crops like cotton and groundnuts, mostly in areas undergoing intensification [18].

Aside from these areas of intensification, the ancient agricultural system was unlikely to suffer from deficiencies, as extensive fallow periods under the then-shifting cropping system restored adequate macro-, secondary, and micronutrients. Only a few studies on micronutrients (Mn, Zn, B, Fe, and Mo) conducted in sub-Saharan Africa are mentioned in Lopes' [14] study. As with [18] review, none of the research examined grains (such as maize, wheat, rice, sorghum, or millet) in field settings. Ten years later, [19] conducted a global study involving thirty countries and found that two types of cereal (wheat and corn) in Ethiopia, Ghana, Malawi, Nigeria, Sierra Leone, Tanzania, and Zambia had micronutrient deficiencies. She also emphasized the need for micronutrient supplies, particularly copper (Cu), boron (B), zinc (Zn), and molybdenum (Mo), to correct identified inadequacies and reach the maximum level of agricultural productivity in developing nations. In western Kenya, a location with a potential yield of at least 10 t ha⁻¹, [20] recently reported that the greatest maize grain yield obtained in fields under researcher administration stopped at 7 t ha⁻¹. This could be the consequence of low soil pH and related toxicities (such as aluminum), or it could be the result of deficits in secondary and micronutrients during crop growth. In fact, over the past ten years, there has been an increasing amount of evidence from the region of soils that, under smallholder farming, barely react to the application of the frequently stressed macronutrient-based fertilizers [21]. Researchers note that this is likely due to deficiencies in secondary and micronutrients [4]. The sparse and dispersed research on possible responses to secondary and micronutrients has not been examined to understand their contribution to agricultural yield, despite the growing calls in SSA [22] for their inclusion in fertilizers. Humic substances are characterized by variation in elemental ratio, chemical function, and molecular weight distribution, which can affect the behavior of some pollutants in the natural environment, such as heavy metals and organic pollutants, in significantly different ways [21, 22]. The complexation of heavy metals by humic substances is extremely important because of its relation to the retention and mobility of the heavy metals during the stabilization process in the landfill [23].

This study aimed to evaluate the productivity increase and nutrient use efficiency associated with the application of secondary and micronutrients in rice.

2. Materials and Methods

Two rice varieties, LEGON-1 and CRI-AMANKWATIA, were obtained from the CSIR-Crops Research Institute for the study (lat N 6°43' 4.25676" and long 1°31'54.12612"). The experimental design was a complete block design in a 2 x 2 x 3 factorial arrangement with three replicates, conducted as a pot experiment at the Rice Breeding Nursery in Kumasi, Fumesua. Two micronutrient treatments used were AMINO

(AgriTecn) and Agriful (AgriTecn) from Dizengoff Ghana at treatment level T1=0%, T2=50%, and T3=100% levels for each of the micronutrient used. Soil samples were analyzed for various physicochemical properties, and plant growth and yield attributes were measured at multiple growth stages (Table 1).

Table 1. Initial Soil Physico-Chemical Properties Before Planting.

Parameter	Method Used	Value	Unit
Soil pH (1:2.5 H ₂ O)	[25]. Jackson (1973)	5.8	–
Electrical Conductivity	[26] Bower & Wilcox (1965)	0.15	dS/m
Organic Carbon	[27] Walkley (1934)	1.25	%
Available Nitrogen	[28] Subbiah & Asija (1956)	120	mg/kg
Available Phosphorus	[29] Olsen et al. (1954)	15.2	mg/kg
Available Potassium	[30] Hanway & Heidel (1952)	140	mg/kg
Available Sulphur	[31] Williams & Steinbergs (1969)	10.5	mg/kg
Available Boron	[32] Berger & Troug (1993)	0.45	mg/kg

2.1. Constitution of the Micronutrients Used for the Experiments

AMINO (AgriTecn) (Free L-Amino, iron, Manganese, Zinc, Copper, Boron and Molybdenum) at 0%, 50% and 100% levels

Agriful (AgriTecn) (Total humic, Fulvic extract, nitrogen, phosphorus, Potassium, Organic matter) at 0%, 50% and 100% levels.



Figure 1. Front view Agriful (AgriTecn) (L) and AMINO (AgriTecn) (R).



Figure 2. Front view Agriful (AgriTecn) (L) and AMINO (AgriTecn) (R).

2.2. Soil Analysis

Soil samples were collected from soil used for the pot experiment. Depth from each plot. These samples were processed and analyzed for various physico-chemical properties in the laboratory of department of plant and soil Chemistry laboratory, CSIR-Soil Research Institute. Soil pH (1:2.5 soil water) was determined by pH meter [25]. EC (dS m⁻¹ at 25 °C) (1:2.5 Soil: Water) was determined EC meter [26]. Organic carbon (%) was determined by the Walkley and Black [27] method. Available nitrogen in soil was determined by the alkaline potassium permanganate method [28]. Available phosphorus was determined by the Ascorbic acid method [29]. Available K in the soil was determined by the extraction method [30]. Available sulphur was determined by the turbidimetric procedure [31]. The available boron in soil was determined by the hot water extraction method of soil as developed by Berger and Troug [32].

2.3. Data Collection

Growth and yield data were collected using standard agronomic procedures. In each plot, four representative plants were randomly selected and tagged for repeated measurements throughout the growing period.

Plant height was measured at 4, 6, 8, and 10 weeks after planting (WAP) using a measuring ruler. Measurements were taken from the soil surface to the tip of the fully expanded uppermost leaf, and mean plant height per plot was calculated.

The number of tillers per plant was recorded from the tagged plants at 4, 6, 8, and 10 WAP. At physiological maturity, the number of panicles per plant was counted from the same tagged plants.

Days to 50% flowering were determined as the number of days from planting until approximately half of the plants in each plot had initiated flowering.

Leaf chlorophyll content was assessed at 4, 6, 8, and 10 WAP using a CCM-200 Plus chlorophyll content meter, following the manufacturer's guidelines.

The maturity period was recorded as the number of days from planting to physiological maturity.

At harvest, plants from each plot were harvested separately, bundled, and weighed to obtain biological yield. Threshing

was carried out manually one week after harvest to separate grain from straw. 1000 seed weight in grams was recorded after threshing, while straw yield was determined by subtracting grain yield from biological yield. The harvest index was calculated as the ratio of grain yield to biological yield.

2.4. Data Analysis

The data were analyzed using Statistical Tool for Agricultural Research version 6, means separation using Tukey's Honest Significant Difference (HSD) for response variables at 5%.



Figure 3. Nursery setup.



Figure 4. Before application of micro nutrients.



Figure 5. After the application of micronutrients.



Figure 6. Flowering of the pot experiment.

3. Results

The initial soil analysis conducted before planting revealed moderate to low fertility status of the experimental soil (Table 1). The soil pH was 5.8, indicating a slightly acidic condition. Such pH levels are common in many tropical soils and can limit the availability of essential nutrients, particularly phosphorus, calcium, magnesium, and some micronutrients, thereby constraining crop growth if not properly managed.

Electrical conductivity was low (0.15 dS m^{-1}), indicating that the soil was non-saline and suitable for crop production, with no risk of salinity-induced stress. Organic carbon content was 1.25%, reflecting low organic matter status. Low organic matter reduces nutrient retention, microbial activity, and overall soil productivity, emphasizing the need for external nutrient inputs to support optimal crop growth.

Available nitrogen content was 120 mg kg^{-1} , which falls within the low range and is inadequate to meet crop nitrogen demand throughout the growing season. Nitrogen deficiency at such levels can result in poor vegetative growth and reduced yield potential. Available phosphorus was 15.2 mg kg^{-1} , considered marginal to moderately low, especially under acidic soil conditions where phosphorus fixation is high. Available potassium was 140 mg kg^{-1} , indicating a moderate level but still insufficient to sustain high crop yields without supplementation.

Available sulphur content was 10.5 mg kg^{-1} , suggesting potential sulphur deficiency, particularly for crops with high sulphur demand. Sulphur deficiency can impair protein synthesis and reduce nutrient use efficiency. Available boron was 0.45 mg kg^{-1} , which is below the critical level required for most field crops. Boron deficiency is known to adversely affect flowering, pollen viability, grain formation, and overall yield.

Overall, the soil fertility status indicates clear limitations in both macro- and micronutrients. The low levels of nitrogen, phosphorus, sulphur, and boron, combined with low organic carbon and acidic pH, justify the application of balanced macronutrients (N, P, K, and S) alongside essential micronutrients, particularly boron. The use of both macro- and micronutrient fertilizers was therefore necessary to correct inherent soil nutrient deficiencies, improve nutrient availability, and support optimal crop growth, development, and yield performance under the experimental conditions.

The overall positive response to micronutrients indicates that these nutrients are holding back crop productivity, particularly in areas with low response to macronutrients, and that their application can have a huge effect.

3.1. Plant Height

There was a significant difference for the period 4, 6, 8 and 10 for Amankwatia, but only weeks 4 and 6 recorded a significant difference, not weeks 8 and 10, as shown in Table 2. At the end of the 10 weeks of study Amankwatia at Ag (100) and Am (100) recorded the highest 74.3 and 91.9 cm and lowest

Ag (0) and Am (0) with 65.2 and 64.3 cm respectively while Legon-1 at Ag (100) and Am (100) recorded the highest height of 74.9 and 74.2 and lowest Ag (0) and Am (0) with 59.4 and 48.9 cm and respectively for plant height. There was a gradual increase in the plant height till maturity. This was mainly due to an increase in the length of leaves and the size of the panicle until harvest.

3.2. Number of Tiller

There was a significant difference between the periods of 8 and 10 weeks for Amankwatia and Legon-1, as shown in Table 3. At the end of the 10 weeks of study Amankwatia at Ag (100) and Am (100) recorded the highest 27 and 34 and lowest Ag (0) and Am (0) with 20 while Legon-1 at Ag (100) and Am (100) recorded the highest height of 41 and 35 and lowest Ag (0) and Am (0) with 19 and 25 cm and respectively for number of tiller.

3.3. Straw Yield

There was a significant difference between Amankwatia and Legon-1, as shown in Table 4. Amankwatia at Ag (50) and Am (100) recorded the highest 86.75 and 104.92 and lowest Ag (0) and Am (0) with 78.45 and 82.14 respectively while Legon-1 at Ag (50) and Am (100) recorded the highest weight of 87.85 and

83.17 and lowest Ag (0) and Am (0) with 79.79 and 74.53 and respectively for straw weight.

3.4. Harvest Index (HI)

There was a significant difference between Amankwatia and Legon-1, as shown in Table 4. Amankwatia at Ag (100) and Am (100) recorded the highest 0.23 and 0.21 and lowest Ag (0) and Am (0) with 0.16 and 0.14 respectively while Legon-1 at Ag (100) and Am (100) recorded the highest HI of 0.15 and 0.16 and lowest Ag (0) and Am (0) with 0.12 and 0.10 and respectively for harvest Index.

3.5. 1000 Grain or Seed Weight

There was a significant difference between Amankwatia and Legon-1, as shown in Table 4. Amankwatia at Ag (100) and Am (100) recorded the high weight 26.83 and 23.17 and lowest Ag (0) and Am (0) with 20.17 and 20.33 respectively while Legon-1 at Ag (100) and Am (100) recorded the high weight of 26.83 and 23.17 and lowest Ag (0) and Am (0) with 22.00 and 20.83 and respectively for 1000 seed weight. The application of macro- and micro-nutrients, such as those found in Amino (AgriTecno) and Agriful (Agritecno), can significantly influence the 100-grain weight of rice, a key component.

Table 2. Plant height(PH) response to different levels of Agriful (Ag) and Amino Mix (Am) Micronutrients.

Treatment	Amankwatia				Legon - 1			
	PH4wk	PH6wk	PH8wk	PH10wk	PH4wk	PH6wk	PH8wk	PH10wk
Ag(0)	34.5 ab	44.8 b	56.0 b	65.2 c	28.1 b	40.9 a	52.8	59.4
Ag(50)	36.6 a	49.7 b	62.8 ab	73.2 bc	36.6 ab	52.3 a	65.2	72.5
Ag(100)	34.3 ab	51.3 ab	66.9 ab	74.3 bc	37.9 a	53.3 a	65.2	74.9
Am(0)	26.7 b	44.6 b	54.4 b	64.3 c	33.8 ab	46.2 a	60.8	48.9
Am(50)	36.7 a	57.6 a	73.2 a	83.0 ab	33.3 ab	45.1 a	62.2	69.2
Am(100)	38.8 a	49.0 b	71.2 a	91.9 a	34.6 ab	52.0 a	67.1	74.2
CV(%)	14.89	8.78	12.46	11.81	14.74	15.34	14.31	19.16
Mean	34.6	49.5	64.1	75.3	34.1	48.3	62.2	83.2
StdDev	6.16	5.99	10.31	12.83	5.62	8.26	9.52	82.14
LSD (0.05)	9.04	7.63	14.01	15.62	8.82	13.01		

Means with the same letter are not significantly different.

Table 3. Number of tillers (NT) response to different levels of Agriful (Ag) and Amino (Am) mix Micronutrients.

Treatment	Amankwatia				Legon - 1			
	NT4wk	NT6wk	NT8wk	NT10wk	NT4wk	NT6wk	NT8wk	NT10wk
Ag(0)	3	9	18 ab	20 b	4	9	12 b	19 c
Ag(50)	4	11	20 ab	23 ab	4	15	19 ab	32 abc
Ag(100)	4	15	25 ab	27 ab	4	18	29 a	41 a
Am(0)	3	12	16 b	20 b	4	13	23 ab	25 bc
Am(50)	4	13	17 b	22 b	4	13	25 a	25 bc
Am(100)	4	14	27 a	34 a	4	14	29 a	35 ab
CV(%)	12.54	12.51	16.91	16.96	12.44	10.68	11.50	18.79
Mean	4	12	21	24	4	14	23	29
StdDev	0.87	6.27	6.64	7.85	0.50	6.85	8.95	10.79
HSD (0.05)			9.66	11.53			12.63	14.85

Means with the same letter are not significantly different.

Table 4. Response of straw Kg, Harvest Index and 1000 seed weight to different levels of Agriful and Amino mix.

Treatment	Amankwatia	Legon -1	Amankwatia	Legon -1	Amankwatia	Legon -1
	Straw/kg	Straw/kg	Harvest Ind.	Harvest Ind.	1000 seed wt/g	1000 seed wt/g
Ag(0)	78.45 d	79.79 bc	0.16 cd	0.12 ab	20.17 c	22.00 bc
Ag(50)	86.75 bc	87.85 ab	0.17 cd	0.13 ab	21.83 ab	25.83 a
Ag(100)	75.69 d	83.17 abc	0.23 a	0.15 a	22.67 a	26.83 a
Am(0)	82.14 cd	74.53 c	0.14 d	0.10 b	20.33 bc	20.83 c
Am(50)	90.74 b	77.38 c	0.19 bc	0.12 ab	21.00 bc	21.83 bc
Am(100)	104.92 a	93.31 a	0.21 ab	0.16 a	21.50 abc	23.17 b
CV(%)	4.53	7.03	11.13	19.37	4.19	5.52
Mean	86.45	82.67	0.18	0.13	21.25	23.42
StdDev	10.43	8.4	0.04	0.03	1.20	2.52
LSD (0.05)	6.87	10.21	0.04	0.04	1.57	2.27

Means with the same letter are not significantly different.

4. Discussion

The system of rice intensification recorded significantly higher plant heights than the conventional method of cultivation at all the growth stages (Table 2). Higher plant height under the system of rice intensification (micronutrient application) as compared to the conventional method. A similar result

was found by [33]. L-Amino acids enhance plant growth by stimulating metabolic pathways and increasing chlorophyll content, contributing to stem elongation [34]. Micronutrient sprays significantly improved rice height, especially with Zn and Fe [35]. Highlights the role of micronutrients in physiological functions that impact shoot elongation [36]. Humic acids enhance root growth and shoot elongation in rice through auxin-like activities [37]. Fulvic acids increase nutrient uptake and chlorophyll, improving plant vigor [38]. NPK improves

rice height significantly, especially nitrogen in early tillering stages [39]. Eyheraguibel et al. [40] showed that humic substances stimulated shoot growth and cell expansion in rice.

The total number of tillers per square meter increased significantly with the system of rice intensification. Tillering ability is genetically controlled, but is also much dependent on environmental factors. The system of rice intensification has a higher tiller number compared to wide spacing, as each individual crop can effectively utilise more available resources, such as space, foraging area for the root system, better root spread, and more light interception, resulting in enhanced tiller production [41]. Biostimulants containing amino acids and micronutrients have been shown to increase the number of productive tillers in cereals [34]. Amino acid-based formulations enhanced tillering by influencing nitrogen metabolism and shoot differentiation [42]. Foliar micronutrient application (Zn, Fe) increased tiller number in rice due to improved plant vigour and root function [43]. Micronutrient excess can induce antagonistic effects (e.g., Fe-Zn, Cu-Mn) and reduce tillering [44]. Excessive nitrogen or unbalanced fertilization can lead to high non-productive tiller numbers [45].

The application of macro- and micronutrient biostimulants such as AMINO (AgriTecn) and Agriful (AgriTecn) can significantly influence rice straw yield, which is an important agronomic trait for multiple uses (fodder, composting, mulching, and even bioenergy). The impact on straw yield is largely driven by the stimulation of vegetative growth, nutrient uptake, and photosynthetic efficiency. Amino acid biostimulants enhanced biomass and vegetative growth in cereals by improving enzymatic activity and nutrient mobilisation [34]. Foliar application of Fe, Zn, and B in rice significantly increased both grain and straw yields [35]. Micronutrient combinations resulted in greater shoot biomass and total dry matter production in rice [43]. Humic acids increased root and shoot biomass in rice and maize by mimicking hormone activity [46]. The application of humic substances significantly increased straw yield, due to enhanced nutrient uptake and increased photosynthetic capacity [47]. The application of balanced macronutrients increased rice straw yield, particularly nitrogen, which is crucial for leaf and stem growth [48, 49]. Marschner [36] notes that micronutrient interactions must be balanced for optimal biomass accumulation.

The harvest index (HI) in rice, defined as the ratio of grain yield to total aboveground biomass, is a crucial measure of a plant's efficiency in converting assimilates into harvestable grain. The application of macro- and micronutrient-based biostimulants, such as Amino (AgriTecn) and Agriful (AgriTecn), can influence HI through their impact on vegetative versus reproductive growth, nutrient partitioning, and stress tolerance. Biostimulants with amino acids improved nutrient use efficiency and reproductive biomass in cereals [34]. Micronutrient foliar sprays (Zn, Fe, B) increased HI in rice due to enhanced photosynthate translocation [50]. Application of amino acid-based fertilizers increased the grain-to-biomass ratio in wheat and rice [48]. Humic substances have been

shown to improve the allocation of assimilates to grain in cereals [49]. A balanced macronutrient supply, especially potassium, was crucial for maintaining high HI in rice [36]. The application of organic matter and humic acids increased HI due to improved nutrient availability and enhanced stress tolerance.

Low crop productivity under macronutrient application in SSA has often been reported [20], and it has been suggested that deficiencies of secondary and micronutrients could be one of the causes of limited crop response to macronutrients [4]. L-Amino acids: Act as chelation agents, improve nutrient uptake, stimulate enzymatic activity, and enhance grain filling [53]. Zinc (Zn): Crucial for enzyme activation and auxin synthesis; Zn application improves grain size and 1000-grain weight [54,55]. Iron (Fe): Important in chlorophyll synthesis and respiration. Fe deficiency reduces photosynthesis and hence grain filling [56]. Manganese (Mn), Copper (Cu), and Boron (B): Involved in photosynthesis, enzyme activation, and cell wall synthesis, contributing to better seed development and weight [36]. Molybdenum (Mo): Important for nitrogen assimilation and enhances the effectiveness of N-fertilizers in grain development [57]. Humic and Fulvic acids: Enhance nutrient uptake, improve root growth, and increase chlorophyll content and photosynthetic efficiency, leading to improved grain filling and higher 1000-grain weight [58]. Nitrogen (N): Critical for protein synthesis and grain formation; optimizes grain weight and size when applied properly [56]. Phosphorus (P): Essential in energy transfer and root development. Adequate P increases tiller number and grain weight [49]. Potassium (K): Important for enzyme activation, carbohydrate metabolism, and water regulation, promotes grain filling and 1000-grain weight [39]. Organic matter improves soil health and enhances microbial activity, thereby increasing nutrient availability and promoting plant growth.

The system of rice intensification recorded a pronounced effect on grain and straw yield (Table 3). The higher yield under the system of rice intensification was due to an adequate supply of resources, which contributed to higher dry matter accumulation and better partitioning of photosynthesis, resulting in higher yield traits and ultimately, the yield. Better vegetative growth, which contributed to higher dry matter accumulation, resulted in significantly higher straw yields under the system of rice intensification (micronutrient application).

Significant improvements in yield attributes, i.e., effective tillers/m², panicle length, grains/panicle, panicle weight, and 1000-grain weight, were recorded under the system of rice intensification (Table 4). This may be attributed to the adequate availability and supply of resources under the system of rice intensification, as well as their translocation along with other nutrients to the sink. Khan et al. [59] also reported that changes in management under SRI could result in the formation of more photosynthetic organs, strengthen photosynthetic ability, produce higher dry matter, provide sufficient nutrients to support continuous sink development, make the seed plumper, increase 1000-grain weight, seed setting percentage,

and filled grains per panicle. Application of micronutrients and bio-stimulants significantly improves the 1000-grain weight of rice by promoting better nutrient uptake, chlorophyll content, and assimilate partitioning to grains [53, 55, 58].

The application of micronutrients resulted in significant improvements in plant height, number of tillers, straw yield, and harvest index for both rice varieties. The positive response to micronutrient application indicates that these nutrients play a critical role in enhancing crop productivity, particularly in areas with low response to macronutrients. The study highlights the need to incorporate secondary and micronutrients into fertilization strategies to achieve higher agricultural productivity in SSA.

5. Conclusions

Different treatments had varying effects on the studied rice varieties. Recommendations will be made accordingly to optimize nutrient management practices for improving rice yield and nutrient use efficiency in Sub-Saharan Africa.

Way forward

The recommended rates should be adopted for use at the research station to improve the growth and yield of rice in Ghana.

Abbreviations

SSA	Sub-Saharan Africa
RNA	Ribonucleic Acid
HI	Harvest index
Mn	Manganese
Cu	Copper
B	Boron
Mo	Molybdenum
N	Nitrogen
P	Phosphorus
K	Potassium

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Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest

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Biography



Charles Afriyie-Debrah is a Senior Research Scientist at the Council of Scientific and Industrial Research-Crops Research Institute (CSIR-CRI), Kumasi, Ghana. Charles is an Agronomist, Biosafety into Plant Biotechnologist, Environmentalist who has been involved in improving growth and yield in the cereals division (maize and Rice), environmental and safety issues at CSIR-CRI. His research interest includes studies on the positive responses of foliar fertilizer application (micronutrient) to rice varieties, soil fertility and drought studies. He has also done studies on awareness, adoption, agronomic and molecular characterization of maize varieties and other environmental studies on food, soil and water quality (heavy metals) on our market's places and in the mining areas in

Ghana. Dr. Afriyie-Debrah obtained a BSc (Chemistry) degree, M.Sc. (Environmental Science) and Ph.D. (Agronomy), all from the Kwame Nkrumah University of Science and Technology. He also had an MPhil (Biosafety into Plant Biotechnology) from Marche Polytechnic University, Ancona, Italy. Dr. Afriyie-Debrah has travelled and has attended several conferences, workshops and training programmes in many countries around the world. He has authored, co-authored, and reviewed over twenty (20) scientific publications, comprising refereed journal papers and conference papers, including publications in highly-rated international journals. Additionally, He has trained interns, students and supervised graduate students from the Universities.

Research Field

Charles Afriyie-Debrah: Agronomy, Environmentalist

Kirpal Agyemang Ofosu: Plant breeder

Daniel Dzorkpe Gamenyah: Plant breeder

Elizabeth Norkor Nartey: Plant breeder

Jacob Kporku: Agronomy

Kenneth Korfeator: Agronomy

Linda Bediako: Agronomy

Maxwell Darko Asante: Plant Breeder

Boampong Edward: Geography, Socio, and Rural Developer

Francisca Amoah Owusu: Geography, Socio, and Rural Developer