Vol-11, Issue-3 PP. 22-27 ISSN: 2394-5788

GLOBAL JOURNAL OF ADVANCED RESEARCH
(Scholarly Peer Review Publishing System)

IDENTIFICATION OF YIELD-LIMITING NUTRIENTS FOR UPLAND RICE (ORAYZA SATIVA L) YIELD, NUTRIENT UPTAKE AND USE EFFICIENCY IN ETHIOPIA.

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Abstract
A study was undertaken to examine the nutrients that limit yield by conducting a nutrient omission trial on the yield and yield components of upland rice in the Fogera district of Northwestern Ethiopia. The treatments included Control, PKSBZn, NKSBZn, NPSBZn, NPKZnB, NPKSZn, NPKSB, recommended NP, and NPSKBZn. Prior to applying the treatments, a composite soil sample was taken from a depth of 0–20 cm for the analysis of the soil's physicochemical properties. Samples of rice straw and grain were collected to assess the uptake of Nitrogen and Phosphorus as well as agronomic efficiency. The data was analyzed using SAS software. The analysis revealed that NPKSZnB application led to a significantly higher grain yield, in contrast to the control and nitrogen-deprived plots which had the lowest yields. Notably, plots lacking Nitrogen fertilizer exhibited a notable decrease in yield compared to the other plots. Moreover, there was no significant difference in yield between the prescribed NP plots and plots where potassium, sulfur, boron, or zinc were omitted. These findings underscore the importance of Nitrogen and Phosphorus in enhancing both the yield and yield components of rice.

Keywords: Nutrient; uptake; vertisols; agronomic efficiency and omission.

1. INTRODUCTION
Nutrient uptake by rice has been calculated from the data of nutrient concentration and crop yield. Total uptake of a nutrient is the sum of grain and straw uptake of that nutrient. Good fertilizer management can increase rice yield and nutrient uptake. Practice of proper management strategies like adequate rate and timing of fertilizer application can increase rice yield and uptake of nutrient. There are many factors that influence the nutrient absorption including cultivar, soil type, fertilizer type, fertilization technology, and environmental factors. Imbalanced fertilizer application can affect soil productivity [1] .

Africa is commonly characterized by significant variability in fertility and its responsiveness to external inputs. The depletion of soil nutrients and the resulting degradation are widely recognized as major threats to agricultural productivity, leading to reduced crop yields and per capita food production in Sub-Saharan Africa (SSA) [1]. According to a report by the World Bank, the growth rate of cereal yields in Africa has been alarmingly low at 0.7% over the years, in stark contrast to the growth rates observed in other developing regions ranging from 1.2% to 2.3%.

The importance of proper soil conservation practices becomes increasingly apparent when addressing the issue of enhancing soil fertility in SSA. This is underscored by the fact that a significant portion of the region's population relies directly on agriculture and agriculture-related industries for their livelihoods. The concept of sustainable agricultural production emphasizes the utilization of natural resources to boost agricultural productivity and income without compromising the integrity of the resource base [2]. By implementing effective soil management strategies, it is possible to safeguard nutrient levels in soils and facilitate the gradual restoration of degraded lands in Sub-Saharan Africa in the long run.

Rice has become a commodity of strategic rapidly growing source of food across many African countries [3]. The total milled rice grain production in sub-Saharan Africa increased from 2 million tons in 1961 to 16 million tons in 2009. About 80% of rice in Africa is produced by small–scale farmers for their own utilization and local market.

Rice has emerged as a commodity of strategic importance, rapidly gaining significance as a food source in numerous African nations [3]. The total production of milled rice grains in sub-Saharan Africa surged from 2 million tons in 1961 to 16 million tons in 2009. A substantial 80% of rice production in Africa is attributed to small-scale farmers, catering to their own consumption and local markets.

The introduction of rice to Ethiopia dates back to the 1970s, with cultivation initially limited to specific regions of the country [4]. Despite not being a traditional staple in Ethiopia, rice has been swiftly embraced by farmers, who are now diversifying its culinary applications. Presently, Ethiopia is swiftly establishing itself as a key player in rice production within sub-Saharan Africa [5]. Regions such as Gambella, Pawe, Fogera, Metema, and Oromia Zone in eastern Amhara National Regional State have been identified as conducive for rice cultivation [6]. In 2008, Amhara regional state accounted for 40% of the national rice production, Tigray region 1.14%, Benshangul-Gumz 0.41%, Oromia 7.23%, Gambella 1.55%, Somalia 13.33%, and Southern region 27.18% [7]. However, the national average rice productivity in Ethiopia remains low at approximately 2.8t ha–1 [8].

Cereal grain yield in the northern highlands of Ethiopia is hampered by inadequate essential nutrients in the soil. Typically, fertilizer application in Ethiopia lacks precision, with blanket recommendations for rates instead of site-specific soil and tissue analysis. Nitrogen (N) and phosphorus (P) dominate fertilizer usage in Ethiopia, while other crucial nutrients like sulfur (S) receive minimal attention [9].

Suboptimal soil fertility and ineffective nutrient management significantly influence rice yield levels. A balanced nutrient approach is vital for enhancing productivity, maintaining soil health, and fostering sustainable agricultural practices. Maximizing genotype yield potential and utilizing chemical fertilizers play crucial roles in enhancing rice productivity. In Ethiopia, poor soil fertility remains a key constraint to rice production, necessitating the application of nitrogen, phosphorus, and potassium fertilizers in substantial quantities to prevent nutrient deficiencies and yield reductions [10].

Quantification of soil capacity to supply major nutrients N, P, K, etc. are the pre-requisite for increasing yield and nutrient use efficiency. A large variability in soil nutrient supplying capacity exists among and recommended doses of fertilizer may not be suitable in all fields [11].

Soil analyses and site-specific studies indicated that elements such as K, S, Ca, Mg, and micronutrients were becoming depleted and deficiency symptoms were observed in major crops in different parts of Ethiopian soil [12]. The status of micronutrients in central highlands of Ethiopia, the available Zn in Nitosols, Luvisols and Cambisols soils in Bale area were low.

The application of site-specific nutrient management (SSNM) is designed to empower farmers in making dynamic adjustments in fertilizer utilization to effectively bridge the gap between the nutrient requirements of a high-yielding crop and the nutrient availability from naturally existing indigenous sources like soil, organic amendments, crop residues, manures, and irrigation water. Its primary objective is to administer nutrients at optimal levels and timings to attain maximum yield and enhanced nutrient utilization efficiency in rice cultivation, ultimately resulting in increased economic returns per unit of fertilizer input.

Enhancing the genetic yield potential and the application of chemical fertilizers play crucial roles in enhancing agricultural productivity. As indicated by Ethiosis [13] soils in Ethiopia commonly demonstrate deficiencies in multiple nutrients. This deficiency could be attributed to inadequate soil fertility management practices, prolonged history of continuous cropping without replenishing the nutrients extracted by the crops, inadequate incorporation of crop residues, and limited addition of organic matter to the soil.

2. MATERIALS AND METHODS

2.1 Location

The experiment was conducted on vertisol of Fogera district, South Gondor, Amhara. The district is bounded with Farta woreda in the east, Dera woreda in the south, Lake Tana in the west and Libokemkem woreda in the north.

2.2 Experimental Design and Procedures

The experiment was conducted in Fogera District at an altitude of 1815 m above sea level with an average maximum temperature of 27.7 °C. A total of nine treatments were assessed following a Randomized Complete Block Design (RCBD) with three replications. Each plot had dimensions of 5m* 5m and the rice was planted in drill rows with a spacing of 20cm and a seed rate of 100 kg/ha. The net plot was created by excluding three rows from both the top and bottom sides, while the spacing between Blocks and plots was maintained at 1m and 0.5m respectively.

Various sources of nutrients such as N (urea), P (TSP), K (KCl), S (CaSO4), Zn (ZnO), and B (Borax) were utilized during planting, with the exception of Nitrogen. The specific rates employed were 138N kg ha-1, 46 P2O5 kg ha-1, 60 K2O kg ha-1, 30 S kg ha-1, 5 Zn kg ha-1, and 2 B kg ha-1. It was recommended to apply 138 kg ha-1 of N and 46 kg ha-1 of P in the study area. The experimental treatments were designed by excluding one of the nutrients, and in cases where N (Urea) was used, it was applied in three separate splits: 1/3 at planting, 1/3 at tillering, and 1/3 at panicle initiation. Based on the study conducted by Tilahun Tadesse et al. [14] the application of nitrogen and phosphorus fertilizers at rates of 138 N and 46 P2O5 kg ha-1 proved to be the most suitable for rainfed upland rice production in fogera and similar agro-ecologies. According to Hagos Brhane et al. (2017), the results demonstrated that higher biological yield (straw + grain) and grain yields of wheat were achieved with increased K rates. However, the analysis of partial budget indicated that 60 K2O kg/ha is the economically viable rate for Vertisols.

3. RESULTS AND DISCUSSION

3.1 Effect of NOT on Rice Nutrient Uptake

Agricultural output and efficiency are intrinsically connected to the availability and absorption of nutrients. The provision of nutrients is essential to maintain high crop yields. The uptake or accumulation of nutrients is determined by the concentration and dry weight of plant tissues. The accessibility of nutrients to plants involves various processes within the soil-plant system before a plant can absorb or use the nutrients. These processes encompass the application of nutrients to the soil or the presence of nutrients in the soil, their movement from the soil to the plant roots, absorption by the roots, transportation to the aerial parts of the plant, and ultimately, utilization by the plant. These processes are influenced by climatic conditions, soil properties, plant characteristics, and their interplay. Adequate and balanced uptake of nutrients by crops is crucial for achieving higher yields. Likewise, the allocation of absorbed or accumulated nutrients in the grain and straw plays a role in enhancing yield. Nutrient uptake in plants is typically assessed through tissue analysis and quantified in terms of concentration or accumulation, commonly expressed as kilograms per hectare for macronutrients and grams per hectare for micronutrients in field experiments. It is also imperative to determine the proportion of accumulated nutrients that are translocated to the grain and straw. In the current investigation, the total uptake of nitrogen, phosphorus, potassium, sulfur, zinc, and boron by rice plants was significantly impacted by nutrient deprivation ($P < 0.01$). A gradual and noteworthy rise in nutrient uptake was observed with an increasing supply of balanced nutrients.

3.1.1 Absorption of nitrogen by rice plants

Nitrogen is identified as one of the primary nutrients that restrict crop yield potential globally. It is recognized as the most extensively applied nutrient element for the majority of annual crops. The adequate uptake of nutrients by crop plants, in appropriate quantities and ratios, holds significant importance in the quest for achieving elevated yields. Moreover, the efficient distribution of assimilated or accumulated nutrients within the shoot and grain, particularly higher nitrogen content in the grain, is closely linked to enhancements in yield productivity. The information presented in Table 1 demonstrates a notable impact on nitrogen uptake by rice due to the application of various treatments involving the omission of specific nutrients.

The exclusion of nitrogen and phosphorus in Vertisols located in the Fogera district led to a substantial reduction in nitrogen uptake by rice when compared to plots where all essential nutrients were provided. The plots receiving NPKSZnB, NPKSB, and NP respectively exhibited the highest grain nitrogen uptake values of 71.63, 71.53, and 68.95 Kg-1. Conversely, the plots with the lowest nitrogen uptake in the grain were those in the control group and those with nitrogen omission, recording values of 20.33 and 36.38 Kg-1 respectively, followed by phosphorus omission. The removal of nitrogen and phosphorus from the fertilizer regimen resulted in a decrease in grain nitrogen uptake compared to treatment T3 by 49% and 22% respectively, with phosphorus omission following suit. The absence of nitrogen and phosphorus significantly reduced nitrogen uptake in comparison to sulfur and potassium. Regarding treatments involving micronutrients and secondary nutrients, the exclusion of sulfur, potassium, or boron led to a respective decrease in nitrogen uptake by 13%, 11%, and 9% compared to treatment T3.

Table 1. Rice grain, straw and Total nutrient uptake

Treatments	N-Uptake (Kg ha^{-1})			P-Uptake (Kg ha^{-1})			Grain Uptake Reduction %	
	Grain	Straw	Total	Grain	Straw	Total	N	P
Control	20.33e	11.25d	31.59f	2.21e	3.66d	5.87e	72	84
Rec. NP	68.95ab	34.99ab	103.94ab	11.07ab	13.68ab	24.75ab	18	41
NPKSZnB	71.53a	38.54a	110.07a	13.76a	16.04a	29.80a	-	0
PKSZnB -N	36.38d	20.67cd	57.05e	4.79de	6.09cd	10.89d	49	65
NKSZnB -P	55.61c	28.31abc	83.92d	6.31cd	8.55cd	14.86cd	22	54
NPSZnB -K	63.69b	33.89ab	97.58bc	11.07ab	9.55bc	20.63b	11	20
NPKZnB -S	61.96bc	26.55bc	88.52cd	9.19bc	9.05bc	18.24bc	13	33
NPKSB -Zn	71.63a	30.38abc	102.01ab	8.79bc	9.78b	18.17bc	-	36
NPKSZn -B	65.72ab	27.82abc	93.54bcd	8.03bcd	9.65bc	17.68bc	9	42
Mean	56.20	28.05	84.25	8.02	9.19	17.14		
LSD (0.05)	7.54	10.95	10.79	3.62	3.56	4.5		
Sig.level	**	**	**	**	**	**		
CV (%)	7.76	22.56	7.40	26.06	22.53	15.16		

*Where, ** = significant at $P < 0.01$, *= significant at $P < 0.05$, ns = non-significant.*

The highest straw nitrogen uptake, amounting to 38.54 Kg-1, was observed in the NPKSZnB treatment, which received a complete nutrient supply, and this value did not show any statistical difference from the Rec. NP and NPSZnB treatments. Conversely, the plots with the lowest nitrogen uptake, 11.25 and 20.63 Kg-1, were those in the control group and those with nitrogen omission respectively. The provision of all essential nutrients, including nitrogen in the "All" treatment, resulted in increased grain and straw yields, as well as nitrogen concentrations, consequently promoting higher nitrogen uptake (Syed et al., 2006). The nitrogen uptake was minimal in the control group and in cases of nitrogen omission, showcasing nitrogen as the primary limiting nutrient that led to diminished yields and nitrogen uptake levels. Comparable outcomes were also documented by Mishra et al., [15].

3.1.2 Absorption of phosphorus by rice plants

Phosphorus is an essential major nutrient necessary for biosynthesis of nucleotides, proteins, bio membranes, and energy metabolism such as the provision of ATP. P is highly sorbed to soil particles and is therefore considered to be an immobile nutrient in soils. Phosphorus uptake was significantly affected with application of different missing nutrient treatments. Phosphorus Omission of N, P, Zn and S in Vertisols of Fogera district significantly reduced the total P uptake by rice as compared to treatment where all the nutrients were supplied (Table 2).

Table 2. Agronomic efficiency of nutrients in kg grain kg^{-1} applied Nutrients

Treatment	N	P
Control	-	-
Rec. NP	29.9abc	86.9b
NPKSZnB	36.2a	108.5a
PKSZnB -N	-	36.3c
NKSZnB -P	27.0c	-
NPSZnB -K	31.4abc	94.3ab
NPKZnB -S	30.4abc	91.2ab
NPKSB -Zn	34.6ab	103.8ab
NPKSZn -B	33.2ab	99.6ab
Mean	24.6	68.9
LSD (0.05)	5.8	18.2
Sig.level	**	**
CV (%)	13.8	15.2

*** = significant at P < 0.01, *= significant at P < 0.05, ns = non-significant.*

The grain and straw P uptake was significantly (P < 0.01) affected with nutrient omission trials. Phosphorus uptake varied between 2.21 – 13.76 kg ha^{-1} in grain and 3.66 – 16.04 kg ha^{-1} in straw and total uptake 5.87- 29.80 kg ha^{-1}. Grain P uptake 13.76 kg ha^{-1} was recorded in application of 138 + 46 + 60 + 30 + 5 + 2 kg ha^{-1} NPKSZnB which have no significant difference in Rec. NP and K omitted one. In Contrast, the lowest P uptake of grain was 2.21 and 4.79 Kg^{-1} was recorded in the plots of control and N omitted respectively followed by omission of P.

The highest straw P uptake 16.04 Kg^{-1} was recorded from NPKSZnB which received all the nutrients. While the lowest P uptake 3.66, 6.09 and 8.55 Kg^{-1} was recorded in the plots of control, N and P omitted respectively. The data depicted that a significantly higher amount of phosphorus was taken up by the treatment with all nutrients in sufficient amounts and at par with Zn omitted treatment, while the P omitted treatment had the lowest uptake of P. This might be because of low P availability in the soil. In absence of P application the grain uptake was reduced by 54% over treatment T3 in which all nutrients applied.

In absence of N and S application the uptake was reduced by 65 and 33 % respectively. Zinc plays an important role in absorption of P by rice. In absence of this nutrient the uptake was reduced by 36% over T3. Reductions in P uptakes with omission of N, P and S have also been reported by Mishra et al. [15] for rice crop and reductions in P concentration with omission of P have been reported by Din et al. (2001). Supply of P in “All” treatment increased the soil solution P causing higher absorption of P resulting in higher grain and straw yields as well more uptake of P because P was the next most yield limiting nutrient after N, which resulted in lower yields and lower P uptake.

3.2 Rice Agronomic Efficiency

Agronomic use efficiency measures the increase in yield per unit of nutrient applied, providing a direct reflection of the impact of fertilizer application on production and its economic returns. To calculate AE accurately, one needs to know the yield without nutrient input, which is only possible when research plots with zero nutrient input are established on the farm. The study revealed a significant (P < 0.01) difference in agronomic efficiency influenced by nutrient omission in rice cultivation. While the full combined application of 138+46+60+30+5+2 kg ha-1 of NPKSZnB resulted in the highest numerical agronomic efficiency for rice, this difference was not statistically significant when compared to the application of NP and other micronutrient combinations.

Nitrogen agronomic efficiency was highly significant ($P < 0.01$) which was affected due to nutrient omission on rice. The maximum of 36.2 kg grain of kg^{-1} nutrient applied agronomic efficiency of nitrogen was obtained from application of 138+ 46 + 60 + 30 + 5 + 2 kg ha^{-1} NPKSZnB which was not statically different with application NP and other micro nutrient combinations. 1The minimum nitrogen agronomic efficiency of 27.0 kg kg^{-1} was recorded from application of 138+ 60 + 30 + 5 + 2 kg ha^{-1} NKSZnB (-P) which indicates that the combined application of N and P are very important nutrients for increasing nitrogen agronomic efficiency.

The results suggest that AE_N values for rice production could be increased by adjusting not only N, P, and K nutrient status but also other micro- and macro-nutrient deficiencies such as S, Si, and Zn and iron toxicity even under both irrigated and rainfed production systems [16]. Variability in crop response and nutrient use efficiencies to fertilizer application is quite common under varying soil and climatic conditions. The differing parameters between the agro-ecologies were related to difference in rainfall amount and not to soil factors. The findings of Kurwakumire et al. [17] also reported that the highest AEN was attributed to the synergetic effects of N with PKS and micronutrients. Grain yield response to N application and agronomic efficiencies of N were higher in high rainfall areas than for the moisture stress areas [18]. It is in line with Doberman [19]. Balanced application of K and micronutrients improves N use efficiency.

The phosphorus agronomic efficiency showed high significance ($P < 0.01$) and was notably affected by nutrient omission in rice cultivation. The highest phosphorus agronomic efficiency of 108.5 kg kg-1 was achieved through the application of 138+46+60+30+5+2 kg ha-1 of NPKSZnB, which was not statistically different from the application of NP and other micronutrient combinations. On the other hand, the lowest phosphorus agronomic efficiency of 36.3 kg kg-1 was observed with the application of 46+60+30+5+2 kg ha-1 of PKSZnB (-N), highlighting the importance of combined nitrogen and phosphorus application for enhancing nitrogen agronomic efficiency. It was found that the agronomic efficiencies of nitrogen and phosphorus were higher in high rainfall areas compared to moisture-stressed regions [18]. Adequate phosphorus application to wheat and rice showed high agronomic efficiencies under both aerobic and anaerobic conditions [20]. Additionally, the combined application of nitrogen, phosphorus, and zinc was found to enhance the agronomic efficiency of phosphorus [17].

Nitrogen uptake showed a strong and positive correlation with micro nutrient uptake and efficiency in grain, as observed by Bandita Jena and R.K. Nayak in [21] Their findings were consistent with the results of their study, which indicated that the combined application of micro nutrients and nitrogen resulted in the highest agronomic nitrogen efficiency and physiological efficiency. This aligns with the research of Shah Nawaz et al. in [22] who found that the agronomic efficiency of applying zinc and boron showed the highest effectiveness when boron was applied at a rate of 2 kg per hectare.Table 2. Agronomic efficiency of nutrients in kg grain kg^{-1} applied Nutrients [23,24].

4. CONCLUSION AND RECOMMENDA-TION

Based on the results of the study, it is possible to deduce that nitrogen is the most critical nutrient for optimizing upland rice yield. The combined use of nitrogen and phosphorus significantly enhanced the uptake of these nutrients by rice plants in the research area. The findings also demonstrated that omitting either nitrogen or phosphorus reduced the average agronomic efficiency of both nutrients.

In conclusion, the response of soil nutrients such as nitrogen, phosphorus, potassium, sulfur, boron, and zinc indicates that nitrogen and phosphorus are the primary limiting factors for enhancing grain yield in the vertisol of Fogera districts. Omitting other nutrients has a minor effect on the growth and yield of rice. The influence of potassium and micronutrients is less significant in comparison to nitrogen and phosphorus, as they have a lower impact on limiting rice growth. The response to fertilizer application, as demonstrated by grain yield, nutrient uptake, and agronomic efficiencies of nitrogen and phosphorus, was notably enhanced due to their combined application. Nevertheless, additional trials on nutrient omission need to be conducted in various agro-ecological zones and soil types to provide robust fertilizer recommendations for the study area.

DISCLOSURE STATEMENT

The paper is original. No part of the manuscript has been published before, nor is any part of it under consideration for publication in another journal. In addition, we affirm that all the authors have approved the manuscript for submission.

ACKNOWLEDGMENTS

The authors acknowledge the Ethiopian Institute of Agricultural Research (EIAR) for financing the research. We are grateful to Fogera National Rice Research and Training Center (FNRRTC) for the logistics support.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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