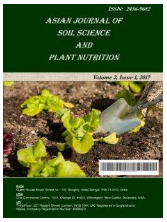

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Impact of Nitrogen Forms and Levels on Yield and Quality of Rice in Kirinyaga and Kisumu Counties Kenya

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Authors' contributions

Author NW designed the experiment, corrected data analyzed and developed the first manuscript draft. Author JPGO reviewed the experimental design, guided on collection of the study variables and reviewed all the manuscripts drafts. Both authors read and approved the final manuscript.

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ABSTRACT

Nitrogen is one of the most limiting elements in crop production. The lack of nitrogen is even more pronounced in Sub-Saharan African as farmers are poor and cannot afford the required amount for crop production. Depending on form, nitrogen is known to affect the uptake of other nutrient elements. It is therefore important to understand strategies that can enhance the availability of N as well as other element. The N content is also a putative precursor for protein, an important component of rice quality.

An experiment was therefore carried out to evaluate the effects of nitrogen forms and levels on yield and quality of rice grain in Ahero Kisumu county and Mwea Kirinyaga county.

The trial took place during the main growing seasons of July to December. The Experiments were laid out in Randomized Complete Block Design (RCBD) in a factorial arrangement with three replicates giving a total of 36 plots, with each plot measuring 3 m by 4 m. Two nitrogen forms, including urea and ammonium sulphate were applied in three levels (0, 25 and 50kgha^{-1} respectively).

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The results showed a positive relationship between levels of nitrogen and the measured parameters. There were observed increase in yield, grain crude protein, as well as more zinc and iron accumulations. Ammonium sulphate supplied at 50kgha^{-1} recorded an increase in grain zinc concentration of 163.8 mgkg^{-1} and 195.5 mgkg^{-1} in Ahero and Mwea respectively. A similar trend was observed in both crude protein and iron accumulation in the rice grain. The unfertilised plots had the lowest accumulation and uptake of the two elements and lower quality of tested aspects. Proper application of nitrogen with the recommended rates has the potential of eliminating the challenges of hidden hunger, hence enhancing food insecurity and reducing malnutrition through increased yield and quality of rice.

Keywords: Cation competition; hidden hunger; iron; protein content; protein; Zinc.

1. INTRODUCTION

Nitrogen nutrition in rice crop is a major requirement in plant growth and development. It is a limiting factors in plant and development and has also been reported to affect uptake of other micro-nutrients that are essential for human nutrition [1]. In Kenya, rice is the third most important cereal crop that contributes a greater percentage toward curbing the issue of food insecurity in the country [2]. Of essence, the micronutrients play great role in promoting growth and development of the rice plants. Incidentally, zinc is one of the micro-nutrients essential in growth and reproduction of rice and is useful in the synthesis of substrates and enzyme that enhance transcription. It has been documented to be one of the elements leading to the greatest plant growth and developmental disorders and limits growth and production in rice especially in lowland countries [3]. Zinc's major function is to also promote physiological metabolisms of the rice plants. Its deficiency has also been viewed as one of the major challenges limiting rice production and its contribution to the maximum nutritional quality upon consumption. When a substantial amount of the Zn is accumulated in the tissues, it is later remobilised and stored in the grain. The amounts of micronutrients that accumulated in the grain are affected by proper nitrogen nutrition [4].

Iron on the other hand, is an element essential for oxidation and transportation of the electro elements. It also maintains the structure and function of the chloroplasts. Several reports have denoted that there is low accumulation of Zinc and Fe in the grain of rice hence leading to low quality of nutritional needs [5,6]. Low concentration of zinc and iron in the grain of rice has been associated to be the leading factors in increased rates of malnutrition the in world [7]. Crude protein provides another measure of quality in grain as it determines its nutritional content [8]. The protein content in the grain is also a representation of nitrogen harvest index which depends on the ability of the plants to uptake the available and supplied Nitrogen into potential yield [9]. Therefore, this implies that there is a gap that needs to be addressed to give more insights to crude protein content, zinc and iron concentration in the grain to ensure that the required nutritional quality is achieved. Nitrogen fertilisation has been marked as one of the strategies that can enhance the improved quality of the grain [10, 11]. Therefore, the current study was carried out to evaluate the effects of N fertilisation under different levels and forms on yield, crude protein content, zinc and Fe concentration in rice grain.

2. MATERIALS AND METHODS

2.1 Description of the Study Site

The study was carried out in two locations; Ahero in Kisumu county and National Research Irrigation Board research station and in Mea Kirinyaga county at Kirogo farm research station. Kisumu county receives rainfall almost throughout the year and thus does not have a true dry season. It lies between latitude of 0^0 10' to 0^0 60"N and a longitude of 34° 54' E and 59.99" W. The average temperature is 22.9 ^{0}C and an annual rainfall of between 1200 mm and 1300 mm in various locations. Mwea, Kirinyaga county on the hand is located in central parts of country. It lies between 1158 m and 5380 m above the sea level and Latitude (05^0 and 04^0 S) and Longitude (37^0 and 38^0 E) with temperatures ranging between 12 ^{0}C and 26 ^{0}C [12]. It has both tropical climate and the equatorial rainfall patterns, annual rainfall ranges between 800-2200 mm and this is influenced by its position along the equator and on the windward side of Mt. Kenya. The experiment was carried out during the main growing season of rice in Kenya from July to December 2017.

2.2 Experimental Design and Data Collection

The experiment was laid out as Randomized Complete Block Design (RCBD) in a factorial arrangement and replicated three times. The treatments included; two forms of nitrogenous fertilisers which were: Sulphate of Ammonia (SA) and Urea at different levels (0, 25 and 50kgha^{-1}). There were two methods of applications; full dose and two splits. The plot sizes measured 3 m by 4 m. The seeds were sourced from the National Irrigation Board. Three weeks' old seedlings were transplanted at a spacing of 25 x 15 cm in the 36 plots. The fields were kept weed-free through manual weeding at different stages. Watering was done regularly and any incidences of pests and diseases were managed. Birds were managed through physical scaring while the fungal diseases were controlled using fungicides.

At maturity, the rice grains were harvested, and dried up to 14 % moisture content. They were ground and analysis of zinc and iron done through the use of the ash solution using an ICP spectrophotometer in a procedure described by Jones and Case [13]. Nitrogen content was determined following the Micro Kjeldahl method described in AOAC of 2007 [14]. The grain crude protein content was determined through multiplication of N content (this was determined by Kjeldahl method according to [14, 15] with a standard value of 6.25.

2.3 Data Analysis

The collected data on yield, Fe, Zn and crude proteins were managed in the excel spread sheet and subjected for analysis (ANOVA) using GenStat statistical software version 15.1. Separation of means was done at 5% level of significance using Fischer's Protected Least Significance Difference. Associations between the collected variables were determined by regression analyses.

3 RESULTS AND DISCUSSION

3.1 Influence of Nitrogen Forms and Levels on Grain Yield

From the regression analyses shown in Fig. 1, it was revealed that yield increased with N rates and the response assumed polynomial function, particularly at Mwea site where the R^2 values were 0.63 and 0.70 for urea and ammonium sulphate respectively. The trends were however very different at Ahero site with R^2 values being quite low and hence meant that yield increase could barely be explained by increasing N rates. For instance, nitrogen rates could only explain 47 percent of yield when N was applied as ammonium sulphate at Ahero site (Fig. 2 b) while the remaining 53 percent of yield were due to other factors other than N. It was also clear that rice yield still responded to additional N supply at Ahero (irrespective of N source). This was not reported in Mwea site which showed an optimal rate at about 45 kg N ha^{-1}.

In the two sites, there was a corresponding increase in the grain yield with increase in nitrogen rates irrespective of the source (urea or ammonium) in the two sites. These may imply that the plants were responding to the increase of the nitrogen nutrition and an additional amount would probably lead to more yield. This may be a pointer that the doses used by the farmers are well below the plant's needs, which partially agree with the high NUE in these sites [9]. The low R^2 value in regression between yield and N rates had earlier reported by the above author in Kirinyaga county with Nerica 4 and Nerica 10. But just like in Mwea site in Kirinyaga county results in our current work (Fig. 1 c and d), there were no further yield response to N with Nerica 4, an indication that other factors other than N led to poor response. Similar arguments had been advanced by Njinju et al. [12] who ascribed the low yield to unfilled grains when more N was supplied.

The results of this study are in disagreement with those of Moro et al. [16] in Ghana who reported an increment in grain yield in rain fed rice up to 90 kgha^{-1} and thereafter declined beyond this level. The disagreement could probably be due to the different environment conditions since in rain fed conditions the rate of emission and leaching are minimal compared to low land rice hence leading to high efficiency that maximise yield. The findings of this study are however in agreement with those of Ahemed et al. [17] who reported an increase in the yield of barley in response to an increase in nitrogen levels. In another study done in India, it was also reported that the wheat grain yield increased with an increase of N levels [18]. The results are also in agreement with other repots [19] that showed an increase in yield of japonica soft super rice with an increment with nitrogen levels in Nainjing in China. A similar trend was also observed in a study done by Wekha et al. [20] who reported a similar trend finger millet when supplied with different levels of phosphorous.

3.2 Effects of Nitrogen Form and Levels on Grain Iron (Fe) Uptake

The iron uptake in rice grain was significantly ($p≤0.05$) different in respect to levels and forms /sources of N in both experimental sites. Ammonium sulphate applied at 50 $kgha^{-1}$ elicited an increased uptake of iron in the grain in both sites with 163.8 $mgkg^{-1}$ and 195 $mgkg^{-1}$ in Ahero and Mwea respectively, this was followed by urea 50 $kgha^{-1}$ while the control (unfertilised plots had the lowest concentration of 119.5 $mgkg^{-1}$ in Ahero and 139 mgkg-1 in Mwea (Table 1).

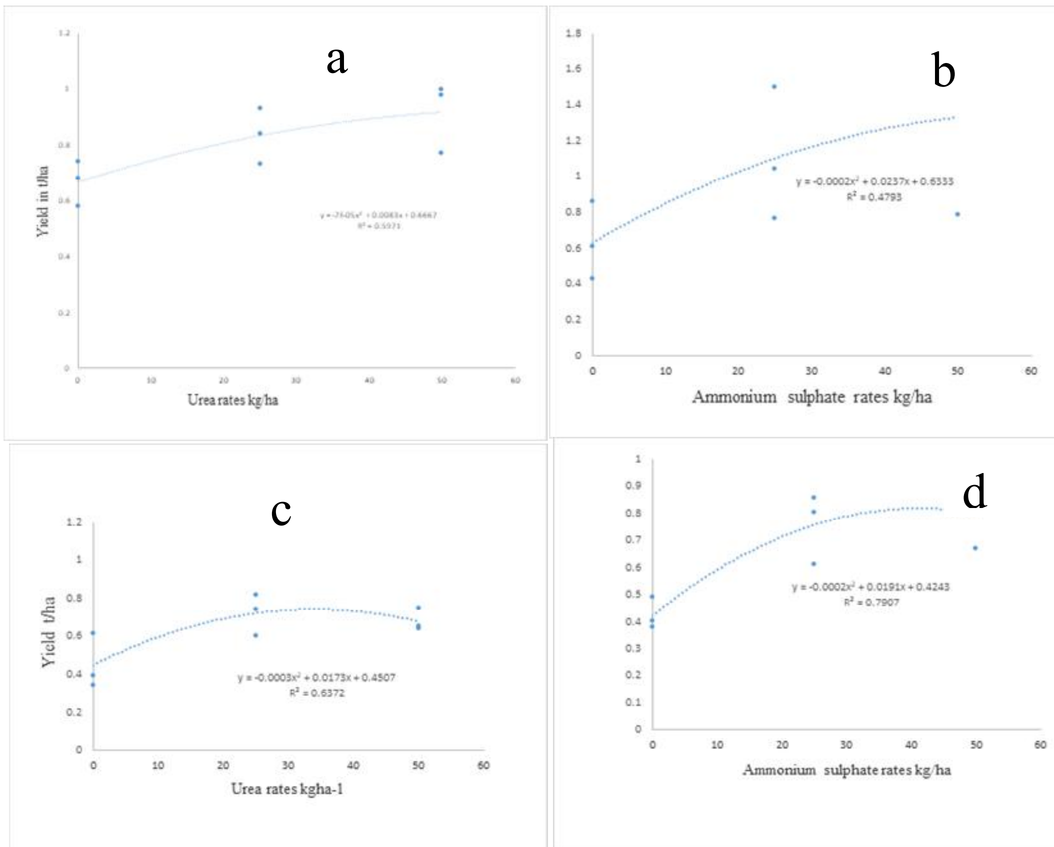

Fig. 1. Regression analysis between nitrogen and grain yields based on different nitrogen sources in Ahero study site (a and b) and Mwea study site (c and d)

Table 1. Crude protein and iron concentration in rice grain as affected by nitrogen forms and levels in Ahero and Mwea sites

	Ahero		Mwea	
	Crude protein Percent	**iron Fe mg kg^{-1}**	**Crude protein Percent**	**iron $mgkg^{-1}$**
N rates $kgha^{-1}$				
Control	10.25^c	119.5^b	15.41^c	139.2^c
As50	15.06^a	163.8^a	22.60^a	195.5^a
As25	12.51^b	144.8^a	19.02^b	172.0^{ab}
Ur50	14.72^a	155.3^a	22.15^a	188.0^a
Ur25	12.27^b	147.8^a	18.34^b	177.8^a
LSD	0.70	14.05	1.13	16.97

Means followed by the same letter within the same column are not significantly different ($p≤0.05$)

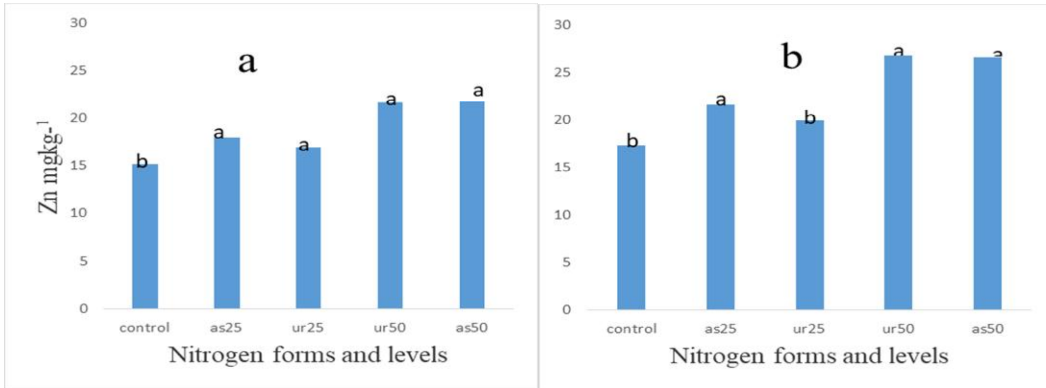

Fig. 2. Zinc concentration as affected by nitrogen levels and forms in Ahero (a) and Mwea study sites (b) respectively

The increase of N concentration in the grain in response to the increase in the levels of nitrogen could be due to synergistic relationship between nitrogen sources and iron translocated to the grain. The findings of this study are similar to those of Duhan and Singh [21], who reported a notable increase in iron concentration in the grain when nitrogenous fertilisers were applied in rice. Moreover, nitrogen is associated with potential to increase availability of micronutrient such as iron hence the high uptake in the grain following adequate fertilisation. The increase in biomass production of the rice grain due to nitrogen fertilisation is associated with high uptake of micronutrients like iron due to a high pool of translocation to the grain [22]. This argument is in concurrence with those of Barunawati et al. [23]. The results of this study thus suggests that nitrogen fertilisation is promising strategy can be used in natural biofortification process [24] hence proper management can help in eliminating the issue of malnutrition and hidden hunger among the world's population as result of Fe deficiency.

3.3 Grain Crude Protein as Affected by Nitrogen Forms and Levels

Significant differences ($p<0.05$) on crude protein content were observed between nitrogen rates and sources in the two study sites. There was a relative increase in the protein content in the grain with the increase in nitrogen fertilisation of different N forms/sources. Ammonium sulphate applied at the dosage of 50 $kgha^{-1}$ led to the highest crude protein content, with values of 15.06% and 22.60 % in Ahero and Mwea respectively (Table 1). Just like in case of Fe uptake, the control also had the lowest crude protein content of 10.25% in Ahero and 15.41% in Mwea sites respectively. The low levels of crude protein contents in the unfertilised plots is a clear indication that nitrogen fertiliser is key in enchasing quality of the rice grain. According to the report given by Silva et al. [25], nitrogen application at silking also increased kernel crude protein content of maize grain. This is could be due to increased uptake and high demand for nitrogen by the plants, specifically at reproductive stage. Moreover, this process is an added advantage at this stage since there are less nitrogen losses from the field hence reducing the farmers' production costs. In another research [26], it was found out that slow release fertilisers like urea led to a significant increase in grain protein content of cereals crops such as the wheat and rice. The slow release N fertilisers are effective in maintaining a balanced uptake of applied N that matches the needs of the crop at different growth stages. Therefore, due to increased nitrogen efficiency throughout the growing period, it implies a higher amount of crude protein in the grain, hence promoting the quality of the grain effective for human consumption. Similar findings [27] were reported, indicating that an increase in supply of nitrogen to rice plants had a corresponding increase in crude protein. This was associated with plant mechanisms to translocate absorbed nitrogen in high supply to essential storage organs such as the grain hence boosting the quality of the rice grains.

3.4 Grain Zinc Uptake as Affected by Nitrogen Forms and Levels

Zinc accumulation in the rice grain revealed significant differences ($p\leq0.05$) between nitrogen sources and rates in both Ahero and Mwea sites (Fig. 2). There was an increase in the concentration of Zn in the grains with an increased supply of N. Urea at 50 $kgha^{-1}$ was the most superior in both sites with 21.67 $mgkg^{-1}$ and 26.83 $mgkg^{-1}$ in Ahero and Mwea sites respectively.

The 50 $kgha^{-1}$ urea rate was followed by ammonium sulphate at 50 $kgha^{-1}$ in both study sites and the unfertilised treatments had the lowest zinc concentration in the grain. These findings agree with those of Kutman et al. [28] who reported an increase of Zn accumulation in wheat grain upon increase of N fertilisation. Importantly, they argued that the uptake of Zn to the grain is facilitated by the metal chelating compounds. In addition, increase of N supply enhanced remobilisation of Zn from pre-anthesis phase to the grain [29]. The improved uptake of Zn in the rice grain is an indication of improved remobilisation and transportation of microelements from the roots to the shoot and then to the grain during the grain filling stage [30]. Similar reasoning had previously been advanced in an excellent review by Cakmak [3].

4. CONCLUSION

Nitrogen fertilisation had a significant effect in yield and quality of rice grain. Increase in nitrogen levels regardless of the forms led to an increase in both yield and quality of the rice grain. Therefore, farmers can use both urea and ammonium sulphate at higher rates (50 kg ha^{-1}) for improved yield. The concentrations of micronutrients including, iron and zinc increased in rice grains in response to nitrogen levels in both study sites. Therefore, there is clear indication that supply of adequate nitrogen fertilisers to rice crop is a promising strategy to curb the issue of food insecurity as well malnutrition. Rice growers need to be advised on the optimal rates and N forms to be applied to enhance economic and health returns from their production systems.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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