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Yield and Iron Toxicity Response of Rice Cultivars to Nitrogen and Phosphorus Application Rates in Lowland Ecology of Moist Savanna of Northern Nigeria

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Abstract

Evaluation of ameliorative effect of nitrogen and phosphorus rates on iron toxicity of lowland rice was examined. Trials were conducted in the Research Farm of National Cereal Research Institute, 2006 and 2007 wet season. The experiment was laid out in a randomized complete block design (RCBD) in split-split-plot arrangement replicated three times. The main blocked consisted of three levels of phosphorus (0, 30 and 60 P_20_5 kg ha^{-1}); the sub-block four levels of nitrogen (0, 30, 60 and 120 N kg ha^{-1}) and the sub-sub-block ten rice varieties (five lowland NERICAs (NERICA L-19, 20, 41, 42 and 60), four improved *sativa* (FKR 19, TOX 4004, BW 348-1and WITA 4) and one local variety (Ebagichi). Significant interactions (P <0.05) of phosphorus × nitrogen × variety at 42 and 63 DAT were observed on iron toxicity score with significant depression at 30 kg P_20_5 ha^{-1} of lower nitrogen rates in all varieties except NERICA L-60. Increasing application rates of nitrogen resulted in increase in grain yield, while maximum grain yield was observed at 30 kg P_20_5 ha^{-1}. WITA 4 at lower N application rates and 30 kg P_20_5 ha^{-1} remained the most promising in terms of grain yield and iron toxicity tolerance in the moist Savanna of northern Nigeria.

Keywords: Iron toxicity, Lowland, NERICA

1. Introduction

Iron toxicity is a predominant nutritional disorder found in the lowland ecology of rice production (Dobermann and Fairhurst, 2000). The problem is even more severe in the valley bottom soil (Sahrawat and Diatta, 1995). The increasing human population density and attendant nutritional requirements is placing much pressure on available arable land, thus necessitating the need to explore and utilise other ecologies, especially the lowland ecologies for rice production. Rice is a staple crop for most of the developing countries of the world. Increase in crop productivity could be achieved through the utilisation of lowland ecologies. The cultivated area for lowland rice is estimated to be around 128 million hectare of irrigated and rainfed lowland (Maclean *et al.,* 2002). Further exploration of lowland ecology is constrained by iron toxicity (Dobermann and Fairhurst, 2000). Available literature indicated that in West Africa, rice yield reduced by as much as 12-100 % as a result of iron toxicity (Abifarin, 1988; Sahrawat *et al*., 1996; Sahrawat, 2004). Various factors are responsible for iron toxicity in the lowland; namely anoxic condition coupled with edaphic factors. Humid tropical region is mostly affected due to the intensity of precipitation in the presence of low soil pH and cation exchange capacity, sandy textural class; increased soil bulk density with reduced porosity, contributing to reduced oxidation front. Becker and Asch, (2005) opined that microbial reduction of iron, could accentuate reduction of insoluble iron to soluble form in the soil.

The physiological implication of iron toxicity in crops is reflected on reduced growth and yield (Abifarin, 1988; Sahrawat *et al*., 1996; Sahrawat, 2004; Mehraban *et al*., 2008). Fageria *et al*., (2008), reported that iron toxicity resulted in reduced plant height and tillering, while loss of chlorophyll, leaf discolouration and reduced root growth was reported by Vechenevetskaia and Roy (1999). One possible explanation for this is the antagonistic effect of iron uptake on the availability of other essential nutrients like potassium, zinc and manganese, which could cause nutritional disorder. The other effect is the elicitation of reactive oxygen radical and the accumulation of oxidised polyphenol, with their cytotoxic effect on macro molecules, such as peroxidation of lipids, denaturation of proteins and DNA (da silveira *et al*., 2007), leading to a disruption in the cellular structural organisation.

Further use of lowland valley for rice production would demand integrated cultural practices addressing soil, water and crop management in order to ameliorate the adverse effect of iron on crop yield. Severity of iron toxicity is influenced by the genotype and the phenology of the crop (Tanaka *et al*., 1968; Yoshida, 1981; Genon *et al*; 1994; Sahrawat, 2004; Fageria *et al*., 2008). Van Breeman and Moormann, (1978) reported that maximum iron toxicity was observed in rice at maximum tillering period and heading stage. However, it was observed that there was compatibility between iron tolerance and yield in some selected varieties (Audebert and Sahrawat, 2000; da Silveira *et al*., 2007). The use of tolerant varieties with nutrition management techniques could ameliorate the negative productive effect of iron toxicity in rice. Sahrawat and Sika, (2002) reported that *Oryza glabberima* are more tolerant of iron toxicity than *Oryza sativa*. The use of interspecific varieties could give a promising perspective and insight towards reducing the effect of iron toxicity in rice.

The objective of the this study was to investigate the effect of the application rates of inorganic phosphorus and nitrogen fertilisers at different growth stages on iron toxicity in lowland rice of moist Savanna of northern Nigeria.

2. Materials and Methods

2.1 Location and Site Characterisation

Field experiments were conducted at the West Africa Rice Development Association (WARDA) fields situated at the Research farm of National Cereals Research Institute (NCRI), Edozhigi, Bida, Niger State, Nigeria. NCRI is located at 09^{o}45'N, 06^{o}7'E, 70.5 m above sea level, in the moist Savanna agroecology of northern Nigeria, 2006 and 2007 wet seasons.

It was observed during the growing seasons that the minimum amount of rainfall was recorded in March (< 50 mm), while maximum amount was observed in August for both years (345 mm and 310 for years 2006 and 2007 respectively). However, rainfall was higher in 2007 compared to 2006 only at April, June and September.

The textural class of the site was determined using the USDA textural triangle. Soil particle size distribution was determined using the hydrometer method (Bouyoucus, 1962). The organic content of the samples was determined using wet – oxidation method. Walkey-Black Method, modify by Allison (1965). The pH was determined (1: 1 soil: water) using a pH meter (glass electrode) (Mclean, 1982).Total nitrogen was determined using modified micro Kjeldahl digestion technique (Jackson, 1962). Available phosphorus was determined using Bray-1 (Bray and Kurtz, 1945) and evaluated colometrically using the method of Murphy and Riley (1962). K^+ in the extract was determined by flame photometry while Ca^{2+} and Mg^{2+} was determined using Atomic Absorption Spectrophotometer (AAS). The physico-chemical properties of the site in both years indicated that pH in 2006 was very strongly acidic (4.4) compared to slightly acidic status of 2007 (6.5). Percentage of organic carbon was low in both years; 0.81 and 0.83 % in 2006 and 2007 respectively. Similar pattern was observed for total Nitrogen in both years (0.08%). The amount of available phosphorus on the experimental site in both years was moderate; 12.48 ppm and 12.62 ppm in 2006 and 2007 years respectively. The amount of exchangeable Potassium, Magnesium and Calcium in both years was very low with a high concentration of soluble iron on the site for both years; 27.39 ppm and 27.59 ppm in 2006 and 2007 years respectively. The textural class for the site in both years was sandy loam.

2.2 Experimental Design and Treatments

The experiment was laid out in a randomised complete block design (RCBD) in split-split-plot arrangement and replicated three times. The main plot size was 21. 5 m × 33 m consisted of three application rates of phosphorus (0, 30 and 60 kg P_20_5 ha^{-1}) using triple super phosphate (46 % P_2O_5) at land preparation just before transplanting and a blanket application of 30 kg K_2O ha^{-1} as muriate of potash (60 % K_2O). The sub-plot size was 5 m × 33 m consisted of four application rates of nitrogen (0,30, 60 and 120 kg N ha^{-1}) using Urea (46 % N) in two split doses of $^1/_3$ at tillering and $^2/_3$ at panicle initiation stages and applied by broadcasting on the rice plots. The sub-sub-plot size was 5 m × 3 m, with ten rice varieties (five lowland NERICAs (NERICA L-19, 20, 41, 42 and 60), four improved *sativa* (FKR 19, TOX 4004, BW 348-1and WITA 4) and one local variety (Ebagichi). The net plot size was 3 m × 2 m (6 m^2). Planting materials were sourced from Africa Rice Centre, Ibadan substation. Total treatment combination was 120 (3 × 4 × 10) in three replicates.

2.3 Land Preparation and Transplanting

The experimental site was ploughed manually, thereafter the soil was loosened and field marked out to size and number of plots required with a pathway of 1.0 m between replicates and 0.3 m between plots of 5 m × 3 m each. Rice seedlings were transplanted at the rate of two seedlings per hill four weeks after seeding on 13th August, 2006 and 24th July, 2007 during the cropping seasons with spacing of 20 cm × 20 cm. Missing hills were replenished to ensure optimum plant population. There were 15 rows of 25 hills of rice in each plot of 5 m × 3 m (15 m^2) and 10 rows of 15 hills of rice were in each net plot of 3 m × 2 m (6 m^2). Weeding was done manually; thrice during the growing season to keep the field weed free.

2.4 Data Collection

Ten hills were randomly sampled per plot from which measurements was taken at 50 % flowering and at harvest maturity. Iron toxicity score was taken per plot by visual judgment using a scale of 1-9 according to IRRI standard evaluation system for iron toxicity score (IRRI, 1980).

Straw yield was obtained through straw dry weight sampled per plot and then converted to Mg ha^{-1}. Grain yield obtained per plot was weighed and then extrapolated to give grain yield in Mg ha^{-1}.

2.5 Data Analysis

Data collected were subjected to analysis of variance using the mixed model procedure with the restricted maximum likelihood method (REML) for variance estimates over years (SAS Institute, 2001). Significant mean were separated using the SAS LSMEANS test (probability of difference [PDIFF]) at $P < 0.05$. LSMEANS and standard error of means (SE) are presented.

3. Results

3.1 Iron toxicity score at 42 and 63 DAT

Nitrogen and variety had significant effect (P <0.05) on iron toxicity score at 42 and 63 DAT. (Table 1). Increasing inorganic nitrogen application rates lead to a significant reduction in iron toxicity score at both periods of observation. In both cases the least significant iron toxicity score was observed when 120 kg N ha^{-1} was applied, however, a lower iron toxicity score was observed at 42 DAT (1.88) than 63 DAT (4.21). At 42 DAT NERICAs L - 19, NERICA L-20, NERICA L-42 and FKR 19 had significantly the least iron toxicity score compared to others. At 63 DAT, NERICA L-42 had significantly the least iron toxicity score (4.36). However, higher iron toxicity score was observed at a later growth stages than earlier. Year and phosphorus application rates had no significant effect (P > 0.05) on iron toxicity score at both growth stages.

Table 1: Effect of year, phosphorus and nitrogen application rates on iron toxicity score of rice varieties at flowering and maturity growth stages in 2006 and 2007 seasons.

	Iron toxicity score	
Sources of variation	(42 DAT)	(63 DAT)
Year		
2006	2.10	4.91
2007	2.33	4.88
SE$\pm$ (df4)	Ns	Ns
Phosphorus (main plot) kg P_2O_5 ha^{-1}		
0	2.33	4.73
30	2.15	4.70
60	2.04	5.25
SE $\pm$ (df 8)	Ns	Ns
Nitrogen (sub plot) Kg N ha^{-1}		
0	2.75a	5.56a
30	2.18b	5.00b
60	2.04c	4.81c
120	1.88d	4.21d
SE $\pm$ (df 36)	0.12**	0.16**
Varieties (sub-sub plot)		
NERICA L -19	2.03c	4.61d
NERICA L -20	2.08c	4.61d

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NERICA L -41	2.21b	4.94c
NE RICA L -42	2.02c	4.36e
NERICA L -60	2.88a	6.36a
FKR 19	2.09c	5.00c
TOX 4004	2.20b	4.69d
BW 348-1	2.24b	5.31b
WITA 4	2.19b	4.52d
EBAGICHI (FV)	2.19b	4.53d
SE ± (df 432)	0.10**	0.17**

Means with the same letter (s) in a treatment column are not significantly different using standard error of means (SE) at 1 % probability level **.df – degree of freedom, DAT-days after transplanting.

3.2 Phosphorus application rates × variety on Iron Toxicity Score at 42 DAT

Increasing application rates of phosphorus, especially at 30 kg P_20_5 ha^{-1} resulted in a significant decrease in iron toxicity score for most varieties, except NERICA L-60 that remained stable. The least significant iron toxicity score was observed in NERICAs L- 42 (1.63), NERICA L- 19 (1.79) and BW 348-1 (1.75) at 30 kg P_20_5 ha^{-1}, while application of 60 kg P_20_5 ha^{-1} recorded no visible effect on iron toxicity score in most varieties (Table 2).

Table 2: Phosphorus application rates × rice varieties on iron toxicity score at flowering (42 DAT).

Phosphorus rates (kg P_2O_5 ha^{-1})			
Rice varieties	0	30	60
NERICA L-19	2.04cd	1.79de	2.25d
NERICA L-20	1.96cd	1.83d	2.46bc
NERICA L-41	2.13c	2.33b	2.17d
NERICA L-42	1.96cd	1.63e	2.50bc
NERICA L-60	2.63a	3.08a	2.92a
FKR 19	1.88d	2.00c	2.74cd
TOX 4004	2.33b	2.04c	2.25d
BW 348-1	2.54a	1.75de	2.42cd
WITA 4	2.00cd	1.96cd	2.63b
EBAGICHI (FV)	2.08c	2.04c	2.46bc
SE± (df 432)	0.18**		

Means with the same letter (s) within a set of a treatment column and between rows are not significantly different using standard error of means (SE) at 1 % probability level **.df – degree of freedom, DAT-days after transplanting.

3.3 Nitrogen application rates × rice variety on Iron Toxicity Score at 42 And 63 DAT

At 42 and 63 DAT (Table3) most varieties recorded significantly lower iron toxicity score with increasing application rates of nitrogen except NERICA L- 60. At 42 DAT, at application rate of 120 kg N ha^{-1} NERICA L-20 had the least significant iron toxicity score (1.67). At 63 DAT NERICA L-19 (4.11), NERICA L-20 (4.33), NERICA L-42 (4.55) , WITA 4 (4.33) and Egbagichi (4.44) had significantly lower iron toxicity score at 60 kg N ha^{-1} than other varieties. Increasing application rates of inorganic nitrogen however, did not result in any significant reduction in iron toxicity score of those earlier mentioned varieties. Other varieties did not indicate any particular trend in iron toxicity score at increasing application rates of inorganic nitrogen.

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Table 3. Nitrogen application rates × rice varieties on iron toxicity score at flowering (42 DAT) and physiological maturity (63 DAT).

Iron toxicity								
(42 DAT)		**Nitrogen rates kg N ha^{-1}**			(63 DAT)			
Rice varieties	0	30	60	120	0	30	60	120
NERICA L-19	2.67cd	1.94d	1.61d	1.89bc	5.22c	5.00c	4.11f	4.11c
NERICA L-20	2.83c	1.94d	1.89cd	1.67d	5.67b	4.56de	4.33ef	3.89d
NERICA L-41	2.39ef	2.28b	2.28b	1.89bc	5.67b	5.11c	4.67cd	4.33b
NERICA L-42	2.56de	2.00cd	1.78d	1.78bcd	4.89d	4.33ef	4.55cde	3.67de
NERICA L-60	3.56a	3.17a	2.56a	2.22a	6.67a	7.11a	6.11a	5.56a
FKR 19	2.33f	2.17bc	1.94cd	1.94b	5.11cd	5.22bc	5.33b	4.33b
TOX 4004	2.61d	2.22b	2.06c	1.94b	5.00cd	4.78d	4.78c	4.22c
BW 348-1	2.61d	2.17bc	2.22b	1.94b	5.78ab	5.44b	5.44b	4.56b
WITA 4	3.06b	2.00cd	200c	1.72cd	5.78ab	4.11f	4.33ef	3.89d
EBAGICHI (FV)	2.89b	1.94d	2.11bc	1.83bcd	5.78ab	4.33ef	4.44de	3.56e
SE± (df 432)	0.18**				0.27**			

Means with the same letter (s) within a set of a treatment column and between rows are not significantly different using standard error of means (SE) at 1 % probability level **.df – degree of freedom, DAT-days after transplanting.

3.4 Year × rice variety on Iron Toxicity Score at 42 DAT

Most varieties had similar iron toxicity score in both years, except NERICA L-60 with stable iron toxicity score in both years (Table 4.).

Table 4: Year × rice varieties on iron toxicity score at flowering (42 DAT).

Rice varieties	2006	2007
NERICA L-19	2.03bc	2.03d
NERICA L-20	2.06bc	2.11cd
NERICA L-41	2.17b	2.25bc
NERICA L-42	1.92c	2.14cd
NERICA L-60	2.47a	3.28a
FKR 19	1.97c	2.22bc
TOX 4004	2.08bc	2.33b
BW 348-1	2.14b	2.33b
WITA 4	2.03bc	2.36b
EBAGICHI (FV)	2.14b	2.25bc
	0.15**	

Means with the same letter (s) within a set of a treatment column and between rows are not significantly different using standard error of means (SE) at 1 % probability level **.df – degree of freedom, DAT-days after transplanting.

3.5 Phosphorus × nitrogen × rice variety on iron toxicity at 42 DAT

At 0 kg P_20_5 ha^{-1}, it was observed that most varieties had significantly lower iron toxicity score at lower inorganic nitrogen application rates (0 kg N ha^{-1} and 30 kg N ha^{-1}) than other rates , with NERICA L-41 having significantly the least iron toxicity score (1.67) at 0 kg N ha^{-1}. At 30 kg P_20_5 ha^{-1} similar trend was observed with NERICA L-42 (2.00) and BW 348-1 (2.17) having significantly the least iron toxicity score at 0 kg N ha^{-1}. Sixty (60 kg P_20_5 ha^{-1}) did not lead to a

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drastic reduction in the iron toxicity score, with similar trend as observed in the earlier application rates of inorganic nitrogen. However, FKR 19(2.33) and TOX 4004 (2.50) had significantly the least iron toxicity score at 0 kg N ha^{-1}, with a higher iron toxicity score than 0 application rates of inorganic phosphorus and nitrogen. Application of all rates of phosphorus and nitrogen to NERICA L-60 had significantly the highest iron toxicity scores with a significant depression (1.83) at application rates of 0 kg P_20_5 ha^{-1} and 120 kg N ha^{-1} (Table 5).

Table 5. Phosphorus × nitrogen × rice varieties on iron toxicity score atflowering (42 DAT).

Iron toxicity												
Nitrogen kg N ha^{-1}												
	0 kg P_2O_5 ha^{-1}				30 kg P_2O_5 ha^{-1}				60 kg P_2O_5 ha^{-1}			
Rice varieties	0	30	60	120	0	30	60	120	0	30	60	120
NERICA L-19	2.67bc	2.17c	1.50cd	1.83b	2.33cd	1.83c	1.33d	1.67b	3.00c	1.83d	2.00c	2.17a
NERICA L-20	2.00e	1.67e	2.33a	1.83b	2.83b	1.83c	1.33d	1.33c	3.67b	2.33b	2.00c	1.23b
NERICA L-41	1.67f	2.67b	2.33a	1.83b	2.83b	2.17b	2.67a	1.67b	2.67de	2.00cd	1.83c	2.17a
NERICA L-42	2.17de	2.17c	1.67c	1.83b	2.00e	1.50d	1.67c	1.33c	3.50b	2.33b	2.00c	2.17a
NERICA L-60	3.17a	3.17a	2.33a	1.83b	3.50a	3.50a	2.83a	2.50a	4.00a	2.83a	2.50a	2.33a
FKR 19	2.33d	2.00cd	1.50cd	1.67b	2.33cd	1.83c	2.00b	1.83b	2.33f	2.67a	2.33b	2.33a
TOX 4004	2.50cd	2.83b	2.17b	1.83b	2.83b	1.83c	1.67c	1.83b	2.50ef	2.00cd	2.33b	2.17a
BW 348-1	2.83b	2.67b	2.50a	2.17a	2.17de	1.67cd	1.67c	1.50c	2.83d	2.17c	2.50a	2.17a
WITA 4	3.17a	1.83d	1.33d	1.67b	2.83b	1.67cd	2.00b	1.33c	3.17c	2.50b	2.67a	2.17a
EBAGICHI (FV)	2.17de	2.17c	2.33a	1.67b	2.83b	1.67cd	2.00b	1.67b	3.67b	2.00cd	2.00c	2.17a
SE± (df 432)	0.31**											

Means with the same letter (s) within a set of a treatment column and between rows are not significantly different using standard error of means (SE) at 1 % probability level **.df – degree of freedom, DAT-days after transplanting.

3.6 Phosphorus × nitrogen × rice variety on iron toxicity score at 63 DAT

At 63 DAT NERICA L-60 recorded significantly the highest iron toxicity scores across different application rates of inorganic phosphorus and nitrogen (Table 6). The trend reported at 42 DAT was also observed at 63 DAT, where significantly lower toxicity was recorded at the lowest application rates of inorganic nitrogen and phosphorus than other applied rates. NERICA L-42 had significantly lower iron toxicity scores within a range of (3.67-5.00) and (4.67 – 3.67) at 0 and 30 kg P_20_5 ha^{-1} respectively than other varieties. At 60 kg P_20_5 ha^{-1} most varieties had significantly higher iron toxicity score within the range of (7.00 -3.67) at different rates of nitrogen application than earlier observed at lower application rates of inorganic nitrogen and phosphorus.

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Table 6. Phosphorus × nitrogen × rice varieties on iron toxicity at physiological maturity (63 DAT).

Iron toxicity												
	Nitrogen kg N ha^{-1}											
	0 kg P_2O_5 ha^{-1}				30 kg P_2O_5 ha^{-1}				60 kg P_2O_5 ha^{-1}			
Rice varieties	0	30	60	120	0	30	60	120	0	30	60	120
NERICA L-19	5.00c	5.67b	4.33c	3.67c	5.00c	5.00c	3.67e	4.33b	5.67c	4.33d	4.33d	4.33c
NERICA L-20	5.00c	3.67e	5.00b	4.33b	5.67b	4.33d	3.67e	3.67c	6.33b	5.67b	4.33d	3.67d
NERICA L-41	4.33d	5.67b	4.33c	4.33b	6.33a	4.67cd	4.67cd	4.33b	6.33b	5.00c	5.00c	4.33c
NERICA L-42	3.67e	5.00c	5.00b	3.67c	4.67d	3.67e	4.33d	3.67cd	6.33b	4.33d	4.33d	3.67d
NERICA L-60	6.33a	7.67a	5.67a	5.00a	6.67a	6.67a	6.33a	5.00a	7.00a	7.00a	6.33a	6.67a
FKR 19	4.67cd	4.33d	5.00b	3.67c	5.00c	5.67b	5.67b	4.33b	5.67c	5.67b	5.33bc	5.00bc
TOX 4004	4.33d	5.00c	5.00b	3.67c	5.00c	4.33d	4.33d	3.67c	5.67c	5.00c	5.00c	5.33b
BW 348-1	5.67b	5.00c	5.67a	5.00a	5.33bc	5.67b	5.00c	4.00bc	6.33b	5.67b	5.67b	4.67c
WITA 4	6.33a	3.07e	4.33c	3.67c	5.33bc	3.67e	3.67e	3.67cd	5.67c	5.00c	5.00c	4.33c
EBAGICHI (FV)	5.00c	4.33d	4.00c	3.67c	5.33bc	3.67e	5.00c	3.33d	7.00a	5.00c	4.33d	3.67d
SE$\pm$ (df 432)	0.47**											

Means with the same letter (s) within a set of a treatment column and between rows are not significantly different using standard error of means (SE) at 1 % probability level **.df – degree of freedom, DAT-days after transplanting.

3.7 Grain and Straw Yield

Year and inorganic nitrogen application rates had (Table 7) a significant effect ($P < 0.05$) on straw yield. Phosphorus and variety had no significant effect ($P > 0.05$) on straw yield. Straw yield was significantly higher in 2007 (9.11 Mg ha^{-1}) than 2006 (6.98 Mg ha^{-1}). Increasing application rates of inorganic nitrogen resulted in significant increase in straw yield. All treatments had significant effect ($P < 0.05$) on the grain yield. Grain yield was significantly higher in 2007 (2.68 Mg ha^{-1}) than 2006 (1.76 Mg ha^{-1}). A significant curvilinear response was observed with increasing application rates of inorganic phosphorus. A significant increase in grain yield was observed with increasing application rates of inorganic nitrogen. WITA 4 had a significantly higher grain yield (2.56 Mg ha^{-1}) than other varieties, which was not significantly different from Ebagichi (2.45 Mg ha^{-1}) and BW 348-1 (2.47 Mg ha^{-1}). NERICA L-60, however, had the least significant grain yield (1.58 Mg ha^{-1}).

Table 7: Effect of year, phosphorus and nitrogen application rates on straw and grain yield of rice varieties in 2006 and 2007 seasons.

Source	Straw yield (Mg ha^{-1})	Grain yield (Mg ha^{-1})
Year		
2006	6.98b	1.76b
2007	9.11a	2.68a
SE$\pm$ (df 4)	0.49**	160.53*
Phosphorus (main plot) kg P_2O_5 ha^{-1}		
0	8.03	2.0b
30	8.80	2.5a
60	7.31	2.06b
SE $\pm$ (df 8)	ns	137.68*
Nitrogen (sub plot) Kg N ha^{-1}		
0	6.81c	1.89c
30	8.00b	2.14b
60	8.13b	2.23b
120	9.24a	2.42a
SE $\pm$ (df 36)	0.50**	133.51**
Varieties (sub-sub plot)		
NERICA L -19	8.68	1.98d
NERICA L -20	7.42	1.93d
NERICA L -41	7.39	2.23c
NERICA L -42	7.91	2.31bc
NERICA L -60	7.33	1.58f
FKR 19	7.55	1.78e
TOX 4004	8.26	2.39b
BW 348-1	8.29	2.47ab
WITA 4	9.03	2.56a
EBAGICHI (FV)	8.35	2.45ab
SE $\pm$ (df 432)	ns	134.85**

Means with the same letter (s) in a treatment column are not significantly different using standard error of means (SE) at 1 % probability level **.df – degree of freedom, DAT-days after transplanting.

4. Discussion

The severity of iron toxicity in lowland ecology is dependent on the variety, stage of crop growth and the soil nutrient status (Tanaka *et al*., 1966; Jayawardana *et al*., 1977). Integrated approach had always been favoured in the reducing the negative impact of iron toxicity in lowland rice production (Mathias and Folkard, 2005). A combination of resistant lowland rice with nutrient management had been reported as one of such ameliorative measures (WARDA, 1995; WARDA 2002; Mathias and Folkard, 2005). Reduced iron toxicity score with the increasing application rates of nitrogen, phosphorus and potassium fertiliser had earlier been reported (Sahrawat *et al*., 2001). It could be suggested that predominance of ammonium in a waterlogged condition due to reduced soil redox potential and the increasing denitrification of nitrogen due to the activities of denitrifying bacteria in the soil could have adversely accentuated the negative influence of iron with increased concentration of ammonium, which had been reported to be toxic to plant (Gerendas *et al*., 1997). The combined source of nitrogen in both forms was observed to have positively affected crop growth (Kirk and Kronzucker, 2005).

Resistant lowland rice varieties had been implicated in the reduction of negative impact of iron toxicity (Audebert and Sahrawat, 2000; Nozoe *et al*., 2008; da Silveira *et al*., 2007). Various mechanism had been reported for this resistance mechanism; avoidance/inclusion (compartmentalisation and exclusion of iron from the symplast) (Audebert and Sahrawat, 2000), avoidance/ exclusion (rhizospheric oxidation and root ion selectivity) (Kawase, 1981; Green and Etherington, 1977), tolerance/ inclusion (detoxification by enzymes and the activity of phytoferritin) (Hu *et al*., 199; Smith, 1984) in the maintenance of Fe^{2+} homeostasis. At both growth stages (flowering and maturity) of investigation NERICA L-60 was observed to be the susceptible variety, while other varieties investigated had significant resistant to iron toxicity, however, the mechanism responsible for the resistant varieties could not be ascertained in this study. The non-significant effect of year on the iron toxicity score would have suggested similarity in the physico-chemical properties of the soil in both years.

Phosphorus is one of the macronutrient reported to be unavailable to the plant (soil and growth medium, root surface and within the plant) under the condition of iron toxicity (Ward *et al*., 2008). In the soil and growth medium precipitation of phosphorus and its reduced availability had been observed (Von Vexhall and Mutert, 1998). The root plagues from iron in lowland rice was reported to act as a barrier to phosphorus uptake in Arabidiopsis (Zhang *et al*., 1999), while its translocation was impaired within the plant (Cumbus *et al*., 1977; Mathan and Auberger, 1977). This would have informed the increasing application rates of phosphorus. However, alone there was no significant effect of it on iron toxicity score in both growth stages. We propose that one of the reasons would be the concentration of zinc in the soil, though was not determined in this study, since zinc is antagonistic to the uptake of phosphorus. However, in combination with variety, for most varieties investigated its ameliorative measure was observed at increasing application rates, especially at 30 kg P_20_5 ha^{-1} except NERICA L-60.

Significant reduction in iron toxicity score with increasing application rates of nitrogen in varieties investigated, except NERICA L-60 would have suggested ameliorative measure of nitrogen. Iron toxicity impairs protein synthesis. Nitrogen on the other hand is a major macronutrient in protein synthesis. The enzymes that are responsible for scavenging reactive oxygen radicals and chlorophyll involved in the interception of radiant energy are made of protein. Ameliorative effect of phosphorus on varieties with increasing nitrogen application rates was more pronounced at 30 kg P_20_5 ha^{-1}. This could have suggested antagonistic interaction of phosphorus with other nutrients, probably zinc in the soil. Zinc is a major cofactor of Superoxide dismutase (Mousavi, 2011), suppression of its activities could have negative influence on oxidative stress. Variation in grain and straw yield over the years could not be explained based on edaphic factors alone, other factors could have been responsible for that that could not be ascertained in this study. Grain and straw yield per hectare was also more at 30 kg P_20_5 ha^{-1}, indicating it to the optimum for such agroecology zone as reflected above. Increase in grain yield per hectare with increasing application rates of nitrogen could have indicated not only its nutritional effect but also a decline in the phytotoxic effect of iron. Susceptible variety (NERICA L-60) had least significant grain yield indicating the negative impact of iron toxicity on it, while resistant varieties had better performance.

5. Conclusion

Increasing application rates of inorganic nitrogen fertiliser resulted in significant depression in iron toxicity score at both growth stages, especially at 120 kg N ha^{-1}. No significant effect was observed with the increasing application rates of phosphorus. Significant varietal differences were observed on iron toxicity score at both growth stages. At 63 DAT, NERICA L-42 had significantly the least iron toxicity score than other varieties. NERICA L-60 was the most susceptible variety at both growth stages. Most varieties recorded no significant differences in iron toxicity score on both years. Significant interactions (P <0.05) of phosphorus × nitrogen × variety at 42 and 63 DAT were observed on iron toxicity score with significant depression at 30 kg P_20_5 ha^{-1} of lower nitrogen rates in all varieties except NERICA L-60. Increasing application rates of nitrogen resulted in increase in grain yield, while maximum grain yield was observed at 30 kg P_20_5 ha^{-1}. WITA 4 at lower N application rates and at 30 kg P_20_5 ha^{-1} remained the most promising in terms of grain yield and iron toxicity tolerance in the moist Savanna of northern Nigeria.

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References

Abifarin, A. O. (1988). Grain yield loss due to iron toxicity. West African Rice Development Association (WARDA) Technical Newsletter 8, 1-2.

Audebert, A., & Sahrawat, K. L. (.2000). Mechanism for iron toxicity tolerance in lowland rice. *Journal of Plant Nutrition. 23*(11 &12), 1877-1885. http://dx.doi.org/10.1080/01904160009382150

Becker, M., & Asch, F. (2005). Iron toxicity in rice- condition and management concepts. *Journal of Plant Nutrition, Soil Science. 168*(4), 558-573. http://dx.doi.org/10.1002/jpln.200520504

Bouyoucus, G. J. (1962). Hydrometer method improved for making particle size analysis of soil. *Agronomy Journal. 54*, 464-465. http://dx.doi.org/10.2134/agronj1962.00021962005400050028x

Bray, R. H., & L. T. Kurtz. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil Science. 59*, 39-45. http://dx.doi.org/10.1097/00010694-194501000-00006

Cumbus, I. P., Horasey, D. J., & Robinson, L.W. (1977). The Influence of phosphorus, Zinc and Manganese on absorption and translocation of iron in watercress. *Plant Soil. 48*, 655-660. http://dx.doi.org/10.1007/BF00145775

da Silveira, V. C., Oliveira, A. P., Sperotto, R. A., Espindola, L. S., Amaral, L., Dias, J. F., Cunha, J. B., & Fett, J. P. (2007). Influence of iron on mineral status of two rice (Oryza sativa L.) cultivars. *Brazilian Journal of Plant Physiology. 19*(2), 127-139. http://dx.doi.org/10.1590/S1677-04202007000200005

Dalton, C. C., Iqbal, K., & Turner, D. A. (1983). Iron phosphate precipitation in Murashige and Skoog media. *Physiologia Plantarium. 57*(4), 472-476. http://dx.doi.org/10.1111/j.1399-3054.1983.tb02771.x

Dobermann, A., & Fairhust, T. H. (2000). Rice: Nutrient disorders and nutrient management. The international Rice Research Institute, Manilla, The Philippines: 191.

Fageria, N. K., Santos, A. B., Barbosa Filho, M. P., & Guimaraes, C. M. (2008). Iron toxicity in lowland rice. *Journal of Nutrition 31*, 1676-1697. http://dx.doi.org/10.1080/01904160802244902

Genon, J. C., de Hepcee, N., Delvaux, B., Duffey, J. E., & Hennebert, P. A. (1994). Redox conditions and iron chemistry in highland swamps of Burundi. *Plant and soil 166*, 165-171. http://dx.doi.org/10.1007/bf00008329

Gerendas, J., Zhu, Z., Bendixen, R., Ratcliffe, R. G., Sattelmacher, B. (1997). Physiological and Biochemical processes related to ammonium toxicity in higher plants. *Z. Pflanzenernaehr Bodenkd. 160*, 239-251. http://dx.doi.org/10.1002/jpln.19971600218

Green, M. S., & Etherington, J. R. (1977). Oxidation of ferrous iron by rice roots. A mechanism for waterlogging tolerance. *Journal of Experimental Botany. 28*, 678-690. http://dx.doi.org/10.1093/jxb/28.3.678

Hu, B., Wu, P., Liao, C. Y., Jing, W. Z., & Zhu, J. M. (1999). Effect of ascorbate-specific H202-scavanging on tolerance to iron toxicity in rice. *Acta Phytophysiology Sinia. 25*, 43-48.

International Rice Research Institute. (1980). Standard evaluation system for rice. 2nd Edition. International Rice Testing Programme. Manilla, Phillippines.

Jackson, M. L. (1962). Soil chemical analysis. New Delhi, Prentice Hall of India Pvt.Ltd, 498p.

Jayawardana, S. D. G., Watanabe, T., & Tanaka, A. (1977). Relation between oxidizing power and resistance to iron toxicity in rice. *Japan Society of Crop Science and Breeding. 22*, 38-47.

Kawase, M. (1981). Anatomical and morphological adaptation of plants to waterlogging. *Horticultural Science. 16*, 30-34.

Kirk, G. J. D., & Kronzucker, H. J. (2005). The potential for nitrification and nitrate uptake in the rhizosphere of wetland plants: A modelling study. *Annals of Botany. 96*(4), 639-646. http://dx.doi.org/10.1093/aob/mci216

Maclean, J. L, Dave, D. C, Hardy, B, & Hettel, G. P. (2002). Rice Almanac. Wallingford, UK. CABI Publishing, p 253.

Mahapatra, I. C., & Patrick Jr, W. H. (1969). Inorganic phosphate transformation in waterlogged soils. *Soil Science. 107*, 281-288. http://dx.doi.org/10.1097/00010694-196904000-00008

Mathan, K. K., & Auberger, A. (1977). Influence of iron on the uptake of phosphorus by maize. *Plant Soil. 46*, 413-422. http://dx.doi.org/10.1007/BF00010097

Mathias, B., & Folkard, A. (2005). Iron toxicity in rice-conditions and management concepts. *Journal of Plant Nutrition and Soil Science. 168*, 558-573. http://dx.doi.org/10.1002/jpln.200520504

Mehraban, P., Zadeh, A. A., & Sadeghipour, H. R. (2008). Iron toxicity in rice (Oryza sativa) under different Potassium nutrition. *Asian Journal of Plant Sciences*, 1682-3974.

Mousavi, S. R. (2011). Zinc in crop production and interaction with phosphorus. Australian *Journal of Basic and Applied Sciences. 5*(9), 1503-1509.

Murphy, J., & Riley, J. P. (1962). A modified single solution method for determimnation of phosphate in natural waters. *Analytical chemistry Acta. 27*, 31-36. http://dx.doi.org/10.1016/S0003-2670(00)88444-5

Nozoe, T., Agbisit, R., Fukuta, Y., Rodriguez, R., & Yanagihara, S. (2008). Characteristics of iron tolerant rice lines developed at IRRI under field conditions. *Japan Agricultural Research Quarterly .42*, 187-192. http://dx.doi.org/10.6090/jarq.42.187

Sahrawat, K. L. (2004). Iron toxicity in wetland rice and the role of other nutrients. *Journal of Plant Nutrition. 27*, 1471-1504. http://dx.doi.org/10.1081/PLN-200025869

Sahrawat, K. L, Mulbah, C. K., Diatta, S., De Laune, R. D., Patrick, W. H .Jr., Singh, B. N., & Jones, M. P. (1996). The role of tolerant genotypes and nutrients in the management of iron toxicity in lowland rice. *Journal of Agricultural Sciences Cambridge, 128*, 146-149. http://dx.doi.org/10.1017/S002185960007307X

Sahrawat, K. L., & Diatta, S. (1995). Nutrient management and season affect soil iron toxicity. Annual Report 1994. West Africa Rice Development Association, Bouake, Cote d'Ivoire: 34-35.

Sahrawat, K. L., Diatta, S., & Singh, B. N. (2001). Nutrient application reduces iron toxicity in lowland rice in West Africa. *International Rice Research Notes. 26*, 51-52.

Sahrawat, K. L., & Sika, M. (2002). Comparative tolerance of Oryza sativa and O. glaberrima rice cultivars for iron toxicity in West Africa. *International Rice Research Notes. 27*, 30-31.

SAS, Institute. (2001). Technical Report. SAS/STAT software: Changes and Enhancements. Release 8.02. SAS Institute, Cary. NC.

Smith, B. N. (1984). Iron in higher plant, storage and metabolic role. *Journal of Plant Nutrition. 7*, 759-766. http://dx.doi.org/10.1080/01904168409363239

Tanaka, A., Loe, R., & Navasero, S. A. (1966). Some mechanism involved in the development of iron toxicity symptoms in rice plant. *Soil Science and Plant Nutrition. 14*, 1-6. http://dx.doi.org/10.1080/00380768.1966.10431951

Tanaka, A., Mulleriyawa, R. P., & Yosu, T. (1968). Possibility of hydrogen sulphide induced iron toxicity of rice plant. *Soil Science and Plant Nutrition. 14*, 1-6. http://dx.doi.org/10.1080/00380768.1968.10432000

Vechnevetskaia, K. D, & Roy, D. N. (1999). Oxidative stress and antioxidative defence with emphasis on plant oxidants. *Environmental Review. 7*(1), 31-51. http://dx.doi.org/10.1139/a99-004

Von Vexhall, H. R., Mutert, E. (1998). Global extent, development and economic impact of acid soils. In: R.A. Date, N.J. Greendon, G.E. Rayment, Probert M.E. (eds). Plant-Soil Interactions at low pH. Principles and Management. Kluwer Academic Publishers. Dordrecgt, The Netherland. pp 5-19.

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining carbon in soils: Effect of variation in digestion conditions and of organic soil constituents. *Soil Science. 63*, 251-263. http://dx.doi.org/10.1097/00010694-194704000-00001

WARDA (West Africa Rice Development Association). (1995). Annual Report 1994. WARDA, Bouake, Cote d'Ivoie. pp.57-59.

WARDA (West Africa Rice Development Association). (2002). Annual Report 2001-2002. WARDA, Cote d'Ivoire.pp.25-37.

Yoshida S. 1981. Fundamentals of rice crop science. International Rice Research Institute, Manila, Philippines.p269.

Zhang, X., Zhang, F., 7 Mao, D. (1999). Effect of iron plague outside roots on nutrient uptake by rice (Oryza sativa L.): phosphorus uptake. *Plant Soil. 209*, 187-192. http://dx.doi.org/10.1023/A:1004505431879

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