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Effects of Iron on the Productivity of Lowland Rice (*O. sativa* L.) in Segregating Populations

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Abstract: Rice plants have the tendency of taking up iron in the form of Fe^{2+}, which is prevalent in paddy fields under flooded environments. But its deficiency or in excess of Fe^{2+} in the soil affect several physiological functions of the plant. The objective of the study was to evaluates the effect of three ferrous sulphate concentration levels on the yield and yield components of lowland segregating rice populations. Three experiments were established in screenhouse concurrently in randomized complete block design in three replications in pots. Treatment comprised of 6 breeding lines each from two rice populations of F2 and F3 generations and two popular checks. Experiment one is the control without $FeSO_4$ treatment, while experiment two and three are F2 and F3 populations, respectively treated with $FeSO_4$ solution. Three concentration levels of $FeSO_4$ solution (600mg/kg of soil, 1200mg/kg of soil, and 1800mg/kg of soil,) were applied into each pots a week before transplanting in the treated experiments. Remarkable reduction in effective tiller number at 1800mg of Fe stress relative to the control was observed of 42.6% and 42.9% in F2 and F3 population, respectively. Significant reduction in grain yield of 33.5% and 36.4% at 1800mg of Fe compared to the control in F2 and F3 populations, respectively. The study showed that at 1200mg of Fe could be optimal for rice crop performance and at 1800mg of Fe becomes toxic to the plant as observed significant reduction in all agronomic traits especially in total grain yield. In F2 and F3 population, UPN 59, UPIA 2 and UPN 95 where the most stable genotypes across iron concentration levels. These genotypes could be used in population development for iron breeding programme.

Keywords: Genotypes, Populations, Iron, GGE Biplot, Stability, Rice

1. Introduction

Rice could be regarded as a global crop for human consumption. Rice (Oryza sativa) is the most widely grown and is the staple food for an estimated 3.5 billion people worldwide [1, 2]. The tremendous growth of the human population worldwide has increased the demand for rice and its current production needs to be doubled by the year 2025 [3] This is a task for the rice breeders to embark on cutting-edge research to mitigate all constraints to rice production.

Rice is grown both in lowland and irrigated ecologies, rice could yield up to 12t/ha in these ecologies. One of the major constraints for rice in attaining its maximum yield potential in these ecologies is iron toxicity. In many Africa countries, lowland rice ecologies represent about 53% of the total rice area in the region, iron toxicity is a serious problem for smallholder rice farmers [4]. Iron is a trace element is very important for rice plants for growth and development, especially for grain yield production through efficiency of photosynthesis by maintaining high chlorophyll production. However, when in excess, it becomes a highly toxic element [5, 6]. Rice yield loss due to iron toxicity ranges from 10% to 100%, depending on the severity of the toxicity and the tolerance of rice varieties. The loss could be greater when toxicity is accompanied by nutrient deficiencies [4, 7].

Rice genotypes greatly vary in their response to iron toxicity and the use of tolerant cultivars is one of the effective strategies for preventing yield loss, especially for farmers with low income [8]. The severity of Fe toxicity in rice is related to

a number of soil factors such as potassium, phosphorus, calcium, magnesium, zinc and H_2S [9, 10, 11]. Rice plants under Fe toxicity stress display a wide range of responses as part of their strategies to overcome the stress. These strategies include both avoidance and tolerance mechanisms and their efficiency may vary with the type of Fe toxicity occurring in the growth environment, its duration and intensity [10, 12]. The appearance of iron toxicity in plants is related to high Fe^{2+} uptake by roots and its transportation to the leaves through transpiration stream. Fe^{2+} excess causes free radical production that impairs cellular structure irreversibly and damages membranes, DNA and proteins [13, 14].

It is also commendable the efforts of molecular breeding in iron toxicity breeding research. Several quantitative traits Loci (QTLs) have been identified for iron toxicity bronzing. The report [15] using a double haploid population derived from IR64 and Azucena identified three QTLs for leaf bronzing score and relative decrease in shoot dry weight with phenotypic contributions ranging from 10 to 32%, this information assisted the breeder in iron toxicity breeding programme. Four genomic regions, which are high QTLs density have been reported [16a,]. The rice species *O. glaberrima* has good agronomic traits [17], Fe toxicity tolerance QTLs has been identified from *O. glaberrima* using an interspecific backcross population [18b], these could be used in rice population development for good agronomic traits. The work on iron toxicity tolerance QTL analysis has been found to be limited with 203 QTLs from 16 mapping populations. The work also reported that these 203 QTLs were found to be distributed mainly on seven chromosomes 1, 2, 3, 4, 5, 7, and 11 [19]. Identifying stable QTLs with a large effect, which control complex traits under Fe toxicity conditions, remains a challenge [20]. All approaches that could identify Fe toxicity tolerant genotypes of high stability and enduring in Fe stressed environments could be welcome in this circumstance. The objective of the study was to evaluates the effect of three ferrous sulphate concentration levels on the yield and yield components of lowland rice segregating populations.

2. Materials and Methods

The study was a screenhouse experiments using soil collected from the experimental farm of the International Institute of Tropical Agriculture (IITA) Onne, (longitude 7°95′28″E and latitude 4°43′78″N) in the Humid forest ecological zone of Nigeria. Mean annual rainfall in the zone is 2310.9 mm and it falls mainly within the months of February to November with peak rainfall received in September. It is a pot experiment and Soil was collected from the research station field at 0 – 15 cm depth, sterilized and filled into 4kg pot to minimize uneven distribution of $FeSO_4$ in the pots [21].

Three experiments were established concurrently in randomized complete block design in three replications in pots. Treatment comprised of 6 breeding lines each from two rice populations of F2 and F3 generations and two popular checks (Table 1.). Experiment one is the control without $FeSO_4$ treatment, while experiment two and three are F2 and F3 populations, respectively treated with $FeSO_4$ solution. Three concentration levels of $FeSO_4$ solution (600mg/kg of soil, 1200mg/kg of soil, and 1800mg/kg of soil,) were applied into each pots a week before transplanting in the treated experiments. The rice seeds were raised in the normal seedling nursery beds with untreated soil. The seedlings were transplanted at 21 days after sowing into treated pots with $FeSO_4$, two seedlings per pot [22].

Table 1. *Genetic material used for the experiment.*

S/N	Genetic materials	Pedigree	Source
1	UPN 59	323845/FARO 44	Uniport Germplasm Uniport
2	UPN 82	323861/UPIA 3	Uniport Germplasm Uniport
3	UPN 86	323865/UPIA 2	Uniport Germplasm Uniport
4	UPN 95	323876/FARO 52	Uniport Germplasm Uniport
5	UPN 103	323879/FARO 44	Uniport Germplasm Uniport
6	UPN 107	323892/FARO57	Uniport Germplasm Uniport
	Checks		Uniport Germplasm Uniport
7	FARO 44		Uniport Germplasm Uniport
8	UPIA 2		Uniport Germplasm Uniport

2.1. Data Collection

Data was collected at appropriate stage of the crop development. The agronomic characters were measured at weekly intervals. The 'Standard Evaluation System (SES) for Rice' reference manual [23] was used for all trait measurements except where stated otherwise.

2.2. Statistical Analysis

Analysis of variance (ANOVA) was performed separately on the individual experiments using the PROC GLM of SAS [24]. The means of the combined analysis were used for simple linear correlation and regression analysis. Simple linear correlation was performed using the PROC CORR program of SAS and the F3 population means were regressed on their F2 parent values for each trait to determine heritability estimates. Biplot analysis was employed to investigate the cultivar-by-environment interaction (site regression model) [25]. Biplot construction was based on the first two principal components (PC1 and PC2). The PC1 and PC2 are referred to as primary and secondary effects, respectively, and were derived from singular-value decomposition (SVD) of the environment-centred data [25]. The environment-centred data were subjected to SVD for the construction of the biplots. This resulted in three component

matrices: singular value (SV) matrix, the cultivar eigenvector matrix, and the environment eigenvector matrix. Thus, the biplot was constructed based on the following model [26].

$$Yij-G-Ej = \sum \lambda n\, \varepsilon in\, \eta in + \varepsilon ij$$

where Yij = the measured mean trait of cultivar i in environment j; G = the grand mean; Ej = the mean effect of environment j; (G + Ej) being the mean trait in environment j; λn = the SVD of nth principal component (PC), the square of which is the sum of square explained by PCn; εin = the eigenvector of cultivar i for PCn; ηjn = the eigenvector of environment j for PCn; and εij = the residual variation associated with genotype i in environment j.

3. Results

3.1. Agronomic Performance of the Tested Genotypes

Significant difference (($P \leq 0.01$) was observed among the test genotypes across all $FeSO_4$ treatment levels and the control (Table 2). Plant height generally increased with increase in iron concentration but declined at 1800mg of Fe. It was observed that genotypes from F2 populations were taller than those from F3 population. Based on the grand mean, genotypes are taller for both populations at 1200mg of Fe and UPN 103 in F2 population was the tallest at 128.5 cm (Table 2).

There was a significant difference ($P \leq 0.01$) among all the tested genotypes for maximum tillering ability except at 1800mg of Fe in F3 population. (Table 3). Contrary to plant height observation, F3 population produced more tillers than the F2 population in all concentration levels and the control. Tillering ability of the genotypes increased with increase in iron concentration but declined at 1800mg of Fe and genotype UPN 86 (17.75) had the highest tiller number at 1200mg of Fe in F2 population (Table 3).

Table 2. *Effect of Iron concentration on plant height (cm) of genotypes within F2 and F3 populations.*

Genotype	Control		600mg of Fe		1200mg of Fe		1800mg of Fe	
	F2	F3	F2	F3	F2	F3	F2	F3
UPN 59	72.50c	69.75de	80.50e	78.00e	90.75d	87.50d	65.00c	62.75d
UPN 82	70.25c	66.00f	85.25d	81.50cde	99.50b	94.25cb	61.50c	60.25d
UPN 86	73.75c	71.25d	86.25d	81.75cd	92.50cd	91.50cd	67.25c	61.00d
UPN 95	72.25c	68.25ef	83.50de	80.25ed	95.50bcd	90.00cd	63.75c	59.50d
UPN 103	87.25b	77.25c	114.00a	107.50a	128.50a	120.00a	74.25b	72.25b
UPN 107	96.25a	94.00a	104.75b	96.50b	125.75a	115.50a	84.75a	83.50a
UPIA 2	82.50b	85.25b	94.50c	95.25b	98.50bc	98.75b	66.75c	67.75c
FARO 44	74.75c	776.50c	84.00de	84.25c	85.00d	89.75cd	66.75c	68.25c
Mean	78.69	76.03	91.59	88.13	102.56	98.41	68.75	66.91
Coefficient of variation	3.58	1.49	2.03	1.65	2.38	2.66	3.32	2.48
Level of Significance	**	**	**	**	**	**	**	**

**=significant at the 1%.

Table 3. *Effect of Iron concentration on Maximum number of tillers of genotypes within F2 and F3 populations.*

Genotype	Control		600mg of Fe		1200mg of Fe		1800mg of Fe	
	F2	F3	F2	F3	F2	F3	F2	F3
UPN 59	9.00abc	9.75cde	12.25d	12.75b	15.00b	16.50b	6.00bc	7.00a
UPN 82	8.50bc	9.25e	11.00e	12.50bc	14.25bc	15.25c	6.50ab	8.00a
UPN 86	9.50ab	10.00bcd	13.00bc	14.00a	17.25a	17.75a	6.5ab	7.25a
UPN 95	9.50ab	10.25abc	13.50ab	14.00a	16.25a	17.00ab	6.75a	8.25a
UPN 103	8.00c	9.50de	11.25e	12.75b	14.75b	15.25c	5.50c	6.75a
UPN 107	6.25d	7.75f	9.75f	11.50c	13.50c	13.50d	4.00d	8.50a
UPIA 2	10.25a	10.50ab	14.00a	14.00a	16.75a	16.75ab	6.25ab	6.25a
FARRO 44	10.25a	10.75a	12.75cd	12.75b	14.50bc	14.75c	6.00bc	6.25a
Mean	8.91	9.72	12.19	13.03	15.28	15.84	5.94	7.28
Coefficient of variation	6.34	3.04	2.19	3.38	3.26	3.14	4.5	27.77
Level of Significance	**	**	**	**	**	**	**	ns

Ns= not significant, **=significant at the 1%.

3.2. Performance of Post-harvest Traits of the Tested Genotypes

The results in Table 4 shows the effect of iron concentration on panicle length of the tested genotypes within F2 and F 3 populations. There were significant differences among the genotypes in all levels of $FeSO_4$ solution. Panicle length was relatively higher at 1200mg of Fe based on the grand mean than other treatments and the F3 population had relatively long panicle length than F2 population (Table 4).

Table 4. *Effect of Iron concentration on panicle length of genotypes within F2 and F3 populations.*

Line	Control		600mg of Fe		1200mg of Fe		1800mg of Fe	
	F2	F3	F2	F3	F2	F3	F2	F3
UPN 59	**22.25d**	**25.00ab**	**25.00b**	**25.50abc**	**25.50bc**	**25.50b**	**19.75e**	**24.50bc**
UPN 82	20.75e	24.00c	22.50d	24.50d	23.25d	24.75b	19.50e	23.25d
UPN 86	22.50cd	24.50bc	23.75c	25.00cd	24.50c	25.00b	23.00c	24.00cd
UPN 95	21.75de	25.00ab	23.50c	24.75cd	23.25d	25.00b	21.75d	24.00cd
UPN 103	24.25b	25.50a	25.00b	25.25bcd	26.00ab	26.75a	23.50c	23.50cd
UPN 107	24.50ab	25.50a	25.75a	26.00ab	26.50ab	26.75a	24.00bc	25.50a
UPIA 2	25.75a	25.75a	26.25a	26.25a	27.00a	27.00a	25.75a	25.75a
FARO 44	23.75c	23.75c	26.00a	26.00ab	26.75a	26.75a	25.00ab	25.00ab
Mean	23.19	24.88	24.72	24.41	25.34	25.94	22.78	24.41
Coefficient of Variation	2.41	1.26	0.92	1.48	1.74	1.41	1.93	0.94
Level of Significance	**	**	**	*	**	**	**	**

*= significant at the 5%, **=significant at the 1%.

Effective tiller is the harvestable tillers produced at the time of harvest; this is an important index for high total grain yield of a genotype. There was significant difference among all the genotypes both in F2 and F3 populations in all the $FeSO_4$ concentration levels (Table 5). The effective tiller number increases with increasing iron concentration up till 1200mg of Fe beyond, which the effective tiller number declined. Generally, the F3 population produced more tillers than the F2 population in all concentration levels. Significant reduction in the effective tiller number of 42.6% and 42.9% at 1800mg of Fe compared to the control in F2 and F3 populations, respectively were observed and UPN 95 (5.25) had the highest effective tiller number (Table 5).

Table 5. *Effect of Iron concentration on effective tillers of genotypes within F2 and F3 populations.*

Genotype	Control		600mg of Fe		1200mg of Fe		1800mg of Fe	
	F2	F3	F2	F3	F2	F3	F2	F3
UPN 59	6.25bc	7.50ab	9.50c	9.75cde	12.75cd	13.50ab	3.00d	4.00bc
UPN 82	6.50abc	7.50ab	9.00cd	9.50de	12.00de	13.00b	3.50cd	4.25ab
UPN 86	6.25bc	7.75ab	10.75b	11.25ab	14.25a	14.00ab	3.50cd	4.00bc
UPN 95	7.25ab	7.50ab	10.50b	10.50bcd	13.75abc	14.50a	3.75bc	5.25a
UPN 103	5.50cd	6.75b	9.25cd	9.75cde	13.00bcd	13.50ab	3.50cd	3.75bc
UPN 107	4.00d	4.75c	8.75d	9.25e	11.00e	11.25c	3.25cd	3.00c
UPIA 2	7.75ab	8.00ab	11.75a	11.75a	14.00ab	14.00ab	4.75a	4.75ab
FARO 44	8.00a	8.50a	10.75b	10.75abc	12.75cd	13.00b	4.25ab	4.25ab
Mean	6.43	7.28	10.03	10.31	12.94	13.34	3.69	4.16
Coefficient of variation	10.58	6.84	2.94	4.76	3.5	3.59	6.78	10.6
Level of Significance	**	**	**	*	**	**	**	*

*= significant at the 5%, **=significant at the 1%.

Significant difference was observed in F2 and F3at 1800mg of Fe among the genotypes and at F3 in control experiment (Table 5). There is no obvious difference in 1000 grain weight in iron treatments and control, as1000 grain weight is more of genetic dependent than any external factors (Table 6).

Table 6. *Effect of Iron concentration on 1000 grain weight of genotypes within F2 and F3 populations.*

Genotype	Control		600mg of Fe		1200mg of Fe		1800mg of Fe	
	F2	F3	F2	F3	F2	F3	F2	F3
UPN 59	22.50a	22.00ab	23.25a	17.25a	24.00ab	23.00ab	23.00c	21.25c
UPN 82	22.25a	21.25b	23.50a	23.00a	23.75b	23.25ab	23.00c	22.00bc
UPN 86	22.25a	21.50b	23.75a	22.75a	24.25ab	23.25ab	23.50b	22.00bc
UPN 95	22.75a	22.00ab	23.50a	22.25a	23.75b	23.25ab	23.00c	21.25c
UPN 103	23.00a	21.50b	23.75a	22.25a	24.25ab	22.75b	24.00a	21.50c
UPN 107	22.75a	21.50b	23.50a	22.75a	24.50a	23.00ab	23.00c	21.75c
UPIA 2	23.00a	22.75a	23.50a	23.50a	24.00ab	24.00a	22.75c	22.75ab
FARRO 44	22.50a	22.50a	23.25a	23.25a	24.00ab	24.00a	23.00c	23.00a
Mean	22.63	21.88	23.5	22.13	24.06	23.31	23.16	21.94
Coefficient of variation	1.87	1.49	1.06	11.74	1.11	1.81	0.54	1.72
Level of Significance	ns	*	Ns	Ns	ns	ns	**	*

ns= not significant, *= significant at the 5%, **=significant at the 1%.

The effect of different iron concentration levels on grain yield in F2 and F3 populations showed significant difference among the tested genotypes. (Table 7). The grain yield increases with increase in iron concentration up till 1200mg

of Fe and beyond, drastic reduction in grain yield was observed in F2 and F3 populations. Grain yield decrease of 60.0% and 58.0% was recorded in F2 and F3 populations, respectively by comparing effect of iron concentration levels at 1200mg of Fe and 1800mg on grain yield. Similarly, significant reduction in grain yield of 33.5% and 36.4% at 1800mg of Fe compared to the control in F2 and F3 populations. Genotype UPN 86 had the highest yield of more than 7.0 t/ha at 1200mg of Fe in the two populations (Table 7).

Table 7. *Effect of Iron concentration on grain yield of genotypes (t/ha) within F2 and F3 populations.*

Genotypes	Control		600mg of Fe		1200mg of Fe		1800mg of Fe	
	F2	F3	F2	F3	F2	F3	F2	F3
UPN 59	4.19a	4.69a	5.66ab	5.76ab	6.05d	6.45bc	2.54bc	2.73bc
UPN 82	4.00ab	4.69a	5.27bc	5.57	6.05d	6.35bc	2.83a	2.83ab
UPN 86	4.00ab	4.49ab	6.15a	5.96a	7.32a	7.23a	2.25d	2.44d
UPN 95	4.29a	4.49ab	5.86ab	6.05a	6.54bc	6.64ab	2.83a	3.03a
UPN 103	3.42ab	3.81bc	4.88c	5.08cd	6.05d	6.05bc	2.25d	2.34d
UPN 107	3.13c	3.52c	4.88c	4.98d	5.76d	5.96c	2.44cd	2.54cd
UPIA 2	4.19a	4.39ab	5.86ab	5.96a	6.74b	6.64ab	2.73ab	2.83ab
FARRO 44	4.00ab	4.00abc	5.27bc	5.27bcd	6.15cd	6.25bc	2.93a	2.93ab
Mean	3.91	4.26	5.48	5.58	6.34	6.45	2.6	2.71
Coefficient of variation	6.55	6.35	5.21	3.73	2.72	4.09	3.95	3.85
Level of Significance	*	*	*	**	**	*	**	**

*= significant at the 5%, **=significant at the 1%.

3.3. Heritability Estimates

The F3 population means were regressed on their F2 parent values for each trait to determine heritability estimates. Significant heritability estimates (($P \leq 0.01$) was observed for all measured traits except tiller number (Table 8). Heritability estimates for 1000 GWT (0.97) was the highest followed by Number of Panicle per Plant (NPPP).

Table 8. *Heritability Estimates by parent offspring regression of F3 and F2 populations.*

Parameters	b-value	s. e
YLD	0.23**	±0.28
1000 GWT	0.97**	±1.54
NPPP	0.53**	±1.50
PAL	0.12**	±2.78
ET	0.17**	±0.34
NTI	0.03ns	±0.27
PHT	0.35**	±0.48

ns= not significant, **=significant at the 1%, PHT=Plant height, NTI=Number of tillers, ET=Effective tillers, PAL=Panicle Length, NPPP=Number of Panicle per Plant, 1000-GWT=1000 grain weight, YLD=Yield (t/ha).

3.4. Phenotypic Correlation Among Traits in the Populations

Total grain yield showed positive and significant correlation with all the measured traits. The total grain yield had high significant correlation ($P \leq 0.001$) with number of tillers, effective tillers and number of panicles per plant (Table 9). The 1000 grain weight was significantly correlated at (($P \leq 0.01$) for the traits except plant height at ($P \leq 0.05$) (Table 9).

Table 9. *Linear correlation coefficient of growth and yield parameters for F2 and F3 population (Iron environment).*

TRAITS	PHT_C2	NTI_C2	ET_C2	PAL_C2	NPPP_C2	1000-GWT_C2	YLD_C2
PHT_C3							
NTI_C3	0.64**						
ET_C3	0.65**	0.98***					
PAL_C3	0.66**	0.49*	0.54**				
NPPP_C3	0.65**	0.98***	0.99***	0.48*			
1000-GWT_C3	0.36*	0.54**	0.57**	0.48**	0.57**		
YLD_C3	0.62**	0.96***	0.96***	0.43*	0.95***	0.53**	

C2 and C3 at the end of variables represent F2 and F3 populations, respectively. *= significant at 5%, **=significant at 1%, ***=significant at 01%, PHT=Plant height, NTI=Number of tillers, ET=Effective tillers, PAL=Panicle Length, NPPP=Number of Panicle per Plant, 1000-GWT=1000 grain weight, YLD=Yield/ha.

3.5. GGEbiplot Analyses

The first two principal components (PC1 and PC2) obtained by SVD of the centred data explained 94.8% of the total variation for grain yield in F2 population. The PC1

accounted for 62.7% of the total variation for grain yield in F2 population (Figures 1 and 2). By visual observation in Figure 1. Iron concentration Fe1 and Fe2 (600mg of Fe and 1200mg of Fe) shared similar environment, while the control (F0) and Fe3 (1800mg of Fe) exhibit different environment respectively in F2 population. The genotypes at the vertices of the pentagon had highest grain yield at that environment. In environment (Fe1 and Fe2), UPN 86 was the best performed genotype based on grain yield, while UPN 95 and FARO 44 the best performed genotypes for F0 and Fe3 enivronments, respectively (Figure 1).

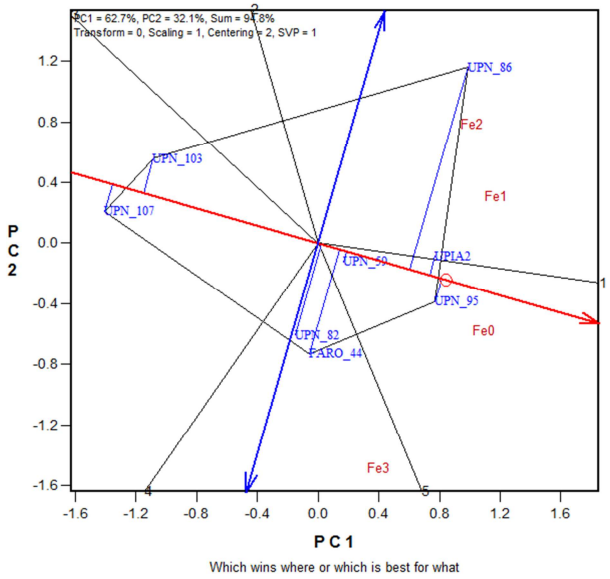

Figure 1. *F2 Fe which win where.*

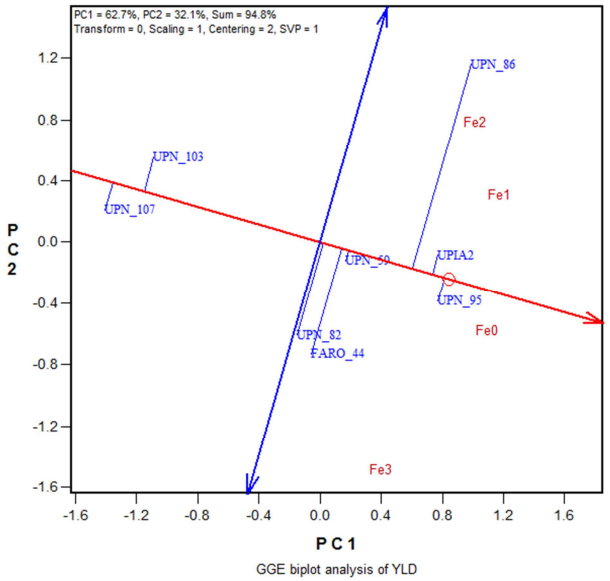

Figure 2. *F2 Fe virsual stability of genotypes.*

Genotypes were ranked in the direction indicated by the single-headed arrow (average tester coordinate) in ascending order of the mean grain yield of the experiments. Therefore, stability of genotypes was ranked on the basis of their projection from the average tester coordinate (axis) on the average environment main effect. The greater the length of the projection of a genotype, the more unstable that genotype (Figure 2). Genotypes UPN 59, UPN 95 and UPIA 2 were the most stable genotypes, while UPN 86 the most unstable genotype in F2 population (Figure 2).

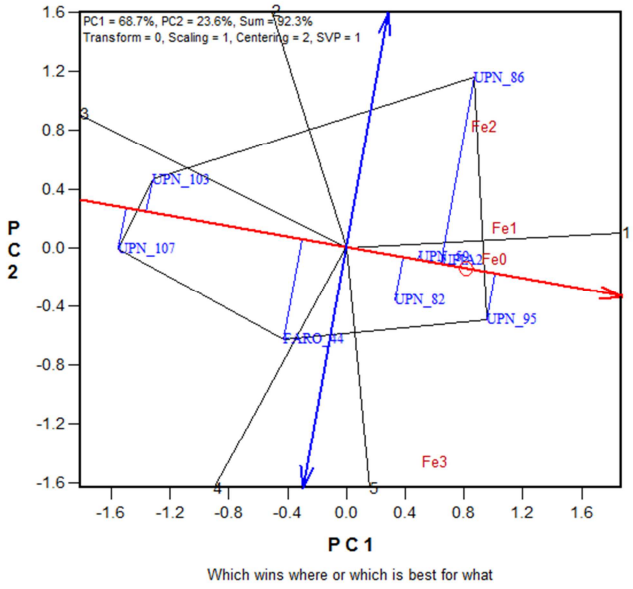

Figure 3. *F3 Fe which win where.*

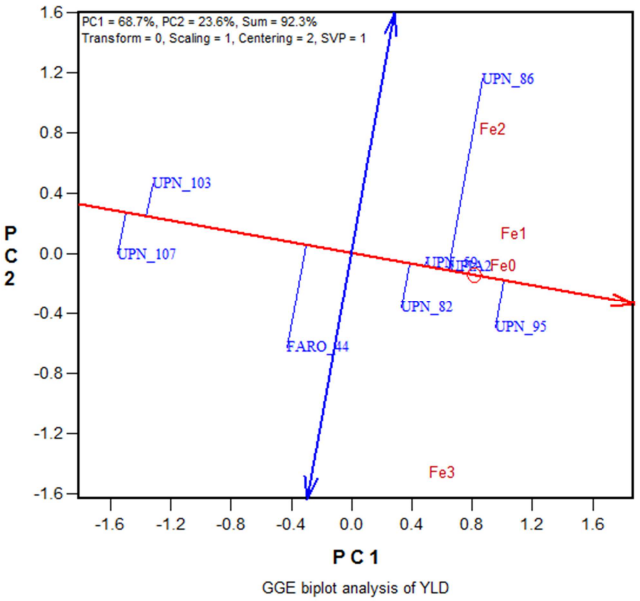

Figure 4. *F3 Fe virsual stability of genotypes.*

In F3 population, the first two principal components (PC1 and PC2) obtained by SVD of the centred data explained 92.3% of the total variation for grain yield. The PC1 accounted for 68.7% of the total variation for grain yield in F3 population (Figures 3 and 4). Two major environments were observed for F3 population. The first environment comprised (Fe0, Fe1 and Fe 2) of iron concentration the control, 600mg of Fe and 1200mg of Fe, respectively and Fe3 made the second environment of iron concentration at 1800mg of Fe. The genotypes at the vertices of the pentagon

had highest grain yield at that environment, genotype UPN 86 for the first environment and UPN 95 for the second environment (Figure 3).

The ranking of genotypes based on grain yield were in the direction indicated by the single-headed arrow (average tester coordinate) in ascending order of the mean grain yield of the experiments. Stability of genotypes was ranked on the basis of their projection from the average tester coordinate (axis) on the average environment main effect. The greater the length of the projection of a genotype, the more unstable that genotype (Figure 4). The most stable genotypes were UPN 59 and UPIA 2 and UPN 86 was the most unstable genotype in F3 population (Figure 4).

4. Discussion

4.1. Agronomic Performance of the Tested Genotypes

Iron is a micronutrient essential for the normal plant growth in normal concentration level in the soil. Iron shows an adverse effect on plant growth when it becomes excess in the soil often referred to as iron toxicity. The plant height recorded appreciable increase between 600mg of Fe and 1200mg of Fe in the soil, thus showed the optimal level of iron for good performance of rice, this may be attributed to the nitrogen fixation in plants this finding corroborates [27-29]. Iron toxicity during the vegetative stage has been reported [30] to reduce plant height and dry matter accumulation, this study showed reduction in plant height particularly at 1800mg of Fein the soil.

Tillering ability in rice is an important agronomy trait for grain production. Tillering plays an important role in determining rice grain yield since it is closely related to panicle number per unit ground area. In iron stressed environments, tilleing ability is reduced especially in severe Fe toxic condition. The symptoms of effected rice plant often associated with reduction in growth and tillering ability [8, 31]. Tillering number of the genotypes increased with increase in iron concentration but declined at 1800mg of Fe, this could depict more excess Fe^{2+} in the soil and becomes toxic to the plant. The high tiller number observed in F3 population as compared to F2 could be due to biased selections made at early stages of the crops.

4.2. Performance of Post-harvest Traits of the Tested Genotypes

Remarkable reduction in effective tiller number at 1800mg of Fe stress relative to the control was observed by 42.6% and 42.9% reduction in F2 and F3 population, respectively. The effective tiller was one of the most reliable characters in selecting genotypes of rice for higher yield. The effective tillers which, is the number of economic tillers harvestable at the time of harvest is an important trait that determines the total grain yield of genotype. Reduction in rice productivity has been reported to be directly proportional to concentration of Fe^{2+} in the soil and the tolerance of the cultivar type [32], therefore, genotype UPN 95 (5.25) had the highest effective tiller number in F3 population at 1800mg of Fe, which could be considered to be promising.

Plant panicle length and 1000 grain weight were not adversely affected across the Fe concentration level, this could be that these traits are genetic and genotype dependent with little environmental influence. However, under Fe severe toxicity condition susceptible genotypes are adversely affected. When iron toxicity occurs during the late vegetative or early reproductive growth phases is associated with reduction in panicle number per plant [33].

Yield losses associated with iron toxicity commonly ranges from 30-70% [34]. However, in the case of severe toxicity at younger stage, complete crop failure can occur [35]. Higher grain yield of a variety indicates its tolerance capacity to iron toxic concentration [30]. Significant reduction in grain yield of 33.5% and 36.4% at 1800mg of Fe compared to the control in F2 and F3 populations, respectively. Genotype UPN 86 had the highest yield of more than 7.0 t/ha at 1200mg of Fe in the two populations. The study showed that at 1200mg of Fe could be optimal for rice crop performance and at 1800mg of Fe becomes toxic to the plant as observed significant reduction in agronomic traits especially in total grain yield.

4.3. Heritability Estimates

Knowledge of heritability of a trait is important because it determines the extent to which plant improvement through selection is possible. A parent-offspring regression gives heritability estimates and provides a measure of GCA (General Combining Ability) of parents for a trait [17]. The yield components of genotypes should have sufficient genetic variation and be highly heritable to ease selection process in population improvement. All the measured traits showed significance in heritability estimates as 1000 grain weight had (0.97**) followed by number of panicles per plant (0.53**) these traits are yield secondary traits, which could be used for yield improvement for genotypes. In an Fe stressed condition, narrow-sense heritability had a lower genetic variation than broad-sense heritability due to a lower proportion of additive variance, which could be explained by gene action in the inheritance traits [36, 37].

4.4. Phenotypic Correlation Among Traits in the Populations

A significant positive correlation was observed between total grain yield with all the traits measured in this study. Specifically, total grain yield had significant positive correlation ($P \leq 0.001$) with number of tillers, effective tillers and number of panicles per plan, therefore, these traits could be used for secondary selection for grain yield, this corroborate the report [38]. The existence of correlation may be attributed to the presence of linkage or pleiotropic effect of genes or physiological and development relationship or environmental effect or combination of all [39].

4.5. GGE Biplot Analyses

A GGE biplot displays the genotypic main effect (G) and genotype by environment interaction (GE) of a genotype-by-environment dataset [40]. GGE has been recognized as a useful tool to analyze and visualize the pattern of genotype x environment interaction of cultivar in multi environment and evaluation of different crops including cereals [41]. The study showed that the iron concentration levels exhibit varying effects on the F2 population and considered as different environments (Figure 1). In F2 population, UPN 86 was the best performed genotype based on grain yield in Fe1 and Fe2 environments, while UPN 95 and FARO 44 the best performed genotypes for environment Fe0 and Fe3, respectively. In the F3 population, the first environment comprised (Fe0, Fe1 and Fe2) of iron concentration the control, 600mg of Fe and 1200mg of Fe, respectively. This first mega environment will assist breeder in reducing research cost for iron screening experiment. The second environment Fe3 of iron concentration at 1800mg of Fe, genotypes experience high iron toxicity effects (Figure 3)

Stability of genotypes was ranked on the basis of their projection from the average tester coordinate (axis) on the average environment main effect. The greater the length of the projection of a genotype, the more unstable that genotype was (Figure 2 and 4). In F2 population, UPN 59, UPIA 2 and UPN 95 where the most stable genotypes across iron concentration levels, while UPN 86 is the most unstable genotype based on grain yield, similar trends were observed for F3 population. These genotypes could used for population development in iron toxicity breeding programme.

5. Conclusion

The soil is the primary source of Fe for plants and is available in the form of Fe^{2+}, which is very important for healthy growth and development. But its deficiency or in excess of Fe^{2+} in the soil affect several physiological functions of the plant. A significant positive correlation was observed between total grain yield with all the traits measured in this study. Specifically, total grain yield had significant positive correlation with number of tillers, effective tillers and number of panicles per plant. Plant panicle length and 1000 grain weight were not adversely affected across the Fe concentration level, this could be that these traits are genetic and genotype dependent with little environmental influence. In F2 and F3 population, UPN 59, UPIA 2 and UPN 95 where the most stable genotypes across iron concentration levels, while UPN 86 is the most unstable genotype based on grain yield. The study showed that at 1200mg of Fe could be optimal for rice crop performance and at 1800mg of Fe becomes toxic to the plant as observed significant reduction in agronomic traits especially in total grain yield.

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