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 Fe²⁺, which is prevalent in paddy fields under flooded environments. But its deficiency or in excess of Fe²⁺ 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 FeSO₄ treatment, while experiment two and three are F2 and F3 populations, respectively treated with FeSO₄ solution. Three concentration levels of FeSO₄ 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 H₂S [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 Fe²⁺ uptake by roots and its transportation to the leaves through transpiration stream. Fe²⁺ 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 FeSO₄ 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 FeSO₄ treatment, while experiment two and three are F2 and F3 populations, respectively, treated with FeSO₄ solution. Three concentration levels of FeSO₄ 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 FeSO₄, 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/UPN 3 | Uniport Germplasm Uniport |
| 3   | UPN 86            | 323865/UPN 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/FARO 57 | Uniport Germplasm Uniport |
| 7   | Checks            |           | Uniport Germplasm Uniport |
| 8   | FARO 44           |           | Uniport Germplasm Uniport |
| 9   | UPN 107           |           | 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].

\[ Y_{ij} - G - E_j = \sum \lambda_n c_{in} \eta_n + e_{ij} \]

where \( Y_{ij} \) = the measured mean trait of cultivar \( i \) in environment \( j \); \( G \) = the grand mean; \( E_j \) = the mean effect of environment \( j \); \( (G + E_j) \) being the mean trait in environment \( j \); \( \lambda_n \) = the SVD of \( n \)th principal component (PC), the square of which is the sum of square explained by PCn; \( c_{in} \) = the eigenvector of cultivar \( i \) for PCn; \( \eta_n \) = the eigenvector of environment \( j \) for PCn; and \( e_{ij} \) = 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).

| Genotype | Control | 600mg of Fe | 1200mg of Fe | 1800mg of Fe |
|----------|---------|-------------|--------------|--------------|
| 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       | 81.50de      | 98.50b       | 94.25c       | 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      | 95.50cd      | 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  | 77.65c      | 84.00de      | 84.25e       | 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%.

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 F3 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).
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 4. Effect of Iron concentration on panicle length 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   | 6.25   | 6.90        | 10.75        | 14.25        | 14.00        | 13.75        | 13.00        | 12.00        |
| UPN 82   | 6.50   | 6.90        | 10.75        | 14.25        | 14.00        | 13.75        | 13.00        | 12.00        |
| UPN 86   | 6.25   | 7.50        | 10.75        | 14.25        | 14.00        | 13.75        | 13.00        | 12.00        |
| UPN 95   | 7.25   | 7.50        | 10.50        | 14.25        | 14.00        | 13.75        | 13.00        | 12.00        |
| UPN 103  | 5.00   | 6.75        | 9.25         | 13.00        | 13.00        | 13.75        | 13.00        | 12.00        |
| UPN 107  | 4.00   | 4.75        | 8.75         | 11.00        | 11.25        | 14.00        | 14.00        | 14.00        |
| UPN 59   | 6.43   | 7.28        | 10.03        | 13.00        | 13.34        | 6.78         | 10.6         |

### 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   | 23.50  | 22.00        | 23.50        | 17.25        | 24.00        | 23.00        | 23.00        | 21.25        |
| UPN 82   | 22.25  | 21.25        | 23.50        | 23.00        | 23.75        | 23.25        | 23.00        | 22.00        |
| UPN 86   | 22.25  | 21.50        | 23.75        | 22.75        | 24.25        | 23.25        | 23.50        | 22.00        |
| UPN 95   | 22.75  | 22.00        | 23.50        | 22.75        | 23.75        | 23.25        | 23.00        | 21.25        |
| UPN 103  | 23.00  | 21.50        | 23.75        | 22.25        | 24.25        | 22.75        | 24.00        | 21.50        |
| UPN 107  | 22.75  | 21.50        | 23.75        | 23.50        | 24.50        | 23.00        | 23.00        | 21.75        |
| UPN 59   | 23.00  | 22.75        | 23.50        | 23.50        | 24.00        | 24.00        | 22.75        | 22.75        |
| FARRO 44 | 22.50  | 22.50        | 23.25        | 23.25        | 24.00        | 24.00        | 23.00        | 23.00        |
| Mean     | 22.63  | 21.88        | 23.5         | 22.50        | 23.5         | 24.00        | 23.16        | 21.94        |

**= 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           |
| 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 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 \((P \leq 0.01)\) for the traits except plant height \((P \leq 0.05)\) (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       | 0.64** | 0.98***| 0.54**| 0.49** | 0.99*** | 0.48*       | 0.57** |
| NTI_C3       | 0.65** | 0.98***| 0.54**| 0.49** | 0.99*** | 0.48*       | 0.57** |
| ET_C3        | 0.65** | 0.98***| 0.54**| 0.49** | 0.99*** | 0.48*       | 0.57** |
| PAL_C3       | 0.36*  | 0.54** | 0.57**| 0.48** | 0.57**  | 0.53**      | 0.53** |
| NPPP_C3      | 0.62** | 0.96***| 0.96***| 0.43*  | 0.95*** | 0.53**      |        |
| 1000-GWT_C3  |        |        |       |        |         |             |        |
| YLD_C3       |        |        |       |        |         |             |        |

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 environments, respectively (Figure 1).

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 was the most unstable genotype in F2 population (Figure 2).

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 Fe2) 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 Fe in 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, tillering 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 towards 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 ≤ 0.001) with number of tillers, effective tillers and number of panicles per plant, 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 Fe²⁺, which is very important for healthy growth and development. But its deficiency or in excess of Fe²⁺ 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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