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Mitigating Iron Toxicity by Using Rock Phosphate to Improve Rice Productivity

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Abstract

Iron toxicity is a major constraint to rice production, particularly in highly weathered soils of inland valleys in Sub-Saharan Africa where the rice growing area is rapidly expanding. This study aimed to improve the productiveness of iron toxicity sensitive's rice fields as well as in the unsensitive fields by using local phosphate fertilizers. Eighteen (18) rice genotypes were been assessed in a split plot design in two areas: without iron toxicity and with iron toxicity. NPK, NK, Rock Phosphate, Triple super phosphate, Calcined phosphate and Acidulated phosphate were used as fertilizers. Data collection was focused on agronomic traits and yield (g/m^2). The best fertilizers in the area without iron toxicity were NPK (820.2 g/m^2) and triple super phosphate (751.7 g/m^2). In the iron toxicity area, the best yields were performed by NPK (785.5 g/m^2) and raw calcined phosphate (698.3 g/m^2). Yet, the Accessions 15, Accessions 225, Accessions 226 and Accessions 270 were rainfed rice genotypes while CC109 A, HB 46 and HB 62 were low-land/irrigated rice genotypes. NPK, NK and acidulated phosphate fertilizers alleviate the best, iron toxicity in both sensitive and unsensitive rice fields.

Keywords

Oryza NPK, NK Rock Phosphate, Rice

1. Introduction

Iron toxicity is an important constraint for rice productivity and rice field sustainability in tropical region. Iron toxicity occurring could be linked to the deficiency of phosphorus, zinc as well as to the acidity and low chemical fertility in the soil (Sagna *et al.,* 2019). In addition to leave symptoms, it decreases rice plant growth and reduces it tillering which definitely impact the yield [1] [2] [3]. Therefore, yield lost can occur at 16% - 78% [4] and reach 100% in West Africa. In Burkina Faso, in 1986, around 300 hectares were abandoned in the Valley of Kou due to iron toxicity [5]. The same stress persists in many developed fields in certain regions of the country, as Hauts-Bassins, Cascades, etc.). Iron toxicity is then, the most important yield limiting factor, especially in low-land where it inhibits roots development and plants growing. Solutions could be found by creating tolerant rice genotypes and using suitable cultural practices, fertilizers, water managing and so on. To sum up, it is important to bring a nutritional balance to rice plants by approaches that reduce iron absorption and/or increase phosphorus availability.

[6] reported that the available phosphorus of soils was one of the main rice's yields limiting factor, in rice fields of Africa in the southern Sahara. Yet, it's known that acid soils lack organic matter in phosphorus favorize iron and phosphoric acid combination and produce insoluble and unassimilable ferrous phosphates [7], which therefore, reduce iron toxicity. However, in the country rock phosphate fertilizer coating effect level on iron toxicity reducing is not determined. The hypothesis stating that the use of rice genotypes associated with phosphate fertilizers could result in different capacity of tolerance to iron toxicity, is then emitted. This study aims to promote the use of rice genotypes associate with phosphate fertilizers to face iron toxicity tolerance on the rice fields. The main aim is to increasing rice productivity in iron toxicity condition by using the combination of tolerant rice genotypes with phosphate fertilizer.

2. Material and Methods

2.1. Presentation of the Study Area

The trial has been set on rice perimeter at the Kou Valley, situate around 30 km from Bobo Dioulasso on the road Bobo Dioulasso-Faramana-Mali border. It geographical coordinates are 11˚22' on the North latitude and 04˚22' on the West longitude with an altitude of 300 m. A total of 1083.3 mm of rainwater has been recorded in 67 days from March to October in the year 2021. The best raining month was August which recorded 368.8 mm of water in 19 days [8].

2.2. Vegetal Material and Fertilizers

The genotypes used for the trial was composed by ten (10) selected genotypes, four (4) check control and four (4) new rice genotypes named KBR (KamBoinsé Riz) (KBR 2, KBR 4, KBR 6 et KBR 8) (**Table 1**).

- ✓ Five (5) tolerant genotypes + two (2) tolerant control (Orylux 6 et Azucena);
- ✓ Five (5) sensitive genotypes + two (2) sensitive control (IR64 et Bouaké 189).

2.3. Treatments

Six (6) types of fertilizers were used as treatments in this study (**Table 2**). The rice plant develops in three steps. The vegetative step: from germination to panicle initiation; the reproductive step: from panicle initiation to flowering; and the maturation step: from flowering to full maturity. For rice fertilization, all fertilizers, called bottom fertilizers, were applied in a single dose during transplanting except urea. Urea (46%), know cover fertilizer was brought to plants during tillering beginning and heading steps at the dose of 1/2 and 1/2 of the whole dose respectively

Table 1. List of the 18 genotypes use for the trial.

Génotype	Espèce	Type variétal
Acc_225	*Oryza glaberrima*	
CC 109A	*Oryza glaberrima*	
FKR 76	*Oryza glaberrima*	
HB 46	*Oryza glaberrima*	
HBG-2	*Oryza glaberrima*	
Acc_15	*Oryza glaberrima*	
Acc_68	*Oryza glaberrima*	
Acc_262	*Oryza glaberrima*	
Acc270	*Oryza glaberrima*	
FKR 56N	*Nerica*	
KBR 2	*Oryza sativa*	*Intraspecifique*
KBR 4	*Oryza sativa*	*Intraspecifique*
KBR 6	*Oryza sativa*	*Intraspecifique*
KBR 8	*Oryza sativa*	*Intraspecifique*
Azucena	*Oryza sativa*	*Japonica*
Orylux 6	*Oryza sativa*	*Indica*
IR 64	*Oryza sativa*	*Indica*
Bouaké 189	*Oryza sativa*	*Indica*

Acc_: Accession.

Table 2. The different fertilizers of the trial.

N° of fertilizer	Fertilizer	Fertilizer quantity (kg/ha)	Fertilizer dose quantity by plot (g/m^2)	Urea 46% (g/m^2)
T1	NPK	200	20	10
T2	NK (Nitrate potassium)	90	9	10
T3	Rock Phosphate (PR),	135	13.5	10
T4	Triple Super phosphate (TSP)	300	30	10
T5	calcined phosphate	135	13.5	10
T6	Acidulated phosphore	105	10.5	10

3. Methods

3.1. Experimental Design

A split plot design was set up in two areas: area without iron toxicity (Stox) and iron toxicity area (Tox). In both areas, two randomized factors repeated three times were applied. The first randomized factorial level was the factor rice genotype with 18 modalities. The second factor was determined by fertilizers coating (NPK, NK, Rock phosphate, Triple Super phosphate, Calcined phosphate, Acidulated phosphate).

3.2. Trial Setting

The elementary plot was composed by 1 m^2 (1 m × 1 m). Transplanting was done by distancing plants with 0.20 m once on and between lines. Two treatments were separated by 1meter and in the same treatment elementary plot was separated by 0.5 m. Both blocs and sub-blos were set particularly to the gradient.

3.3. Data Collection

Data were collected on five (5) central plants prior selected and marked. It concerned agronomical parameters such as: tillers' height and number at 30, 60 and 85 days after sowing (DAS), panicles length, total number of grains per panicle, filled grains rate, 1000-grain weight and plot yield (g/m^2). Qualitative parameters such as culms' strength, panicles thresh ability, lodging, panicle exsertion and maturity cycle were recorded.

3.4. Data Setting and Analysis

An analysis of variance test (ANOVA) was performed by GenStat Release 12.1 software. For any significant difference of the average values between the fertilizers and rice genotypes the Newman-Keuls (SNK) test was performed for means comparison. Graphics were generated with Microsoft Office Excel table 2010.

4. Results

4.1. Fertilizers Effect on Rice Yield (g/m^2) and Agromorphological Traits in Area Stox

In area without iron toxicity (Stox), results shown a very highly significant difference ($P < 0.001$) for the average amount of tillers/plant on the 60^{th} day after sowing (DAS) (Tall_60) Cv (%) = 20.4, average height of plants on the 60^{th} DAS Cv (%) = 9.6 and the 85^{th} DAS Cv (%) = 9.6. The coefficient of variance (Cv) of the average yield performed by fertilizers was: Cv (%) = 34.3. A very high significant difference has been revealed for 50% heading cycle, to maturity (Cv (%) = 1.4. Yet, no significant difference was revealed at limit of 5% by the analysis for the parameters rate of filled grains per panicle (%GP/Pan) and 1000-grain weight (g). However, a very highly significant difference was shown by the analysis of variance of the interaction between fertilizers treatments and rice genotypes for the parameter yield (Table 3). The best yields were performed by the fertilizers treatment NPK (T1) (820.2 g/m^2) and STP (T4) (751.7 g/m^2). In the Stox area, the fertilizers treatments STP and NPK had respectively recorded 13 and 14 rice genotypes whom performed higher yield values than the average yield 706.8 g/m^2 (Table 4). Concerning the effect of fertilizers treatments on rice

Table 3. Fertilizers' effect on rice yield (g/m^2) and some agromorphological traits in both areas: iron toxicity area (Tox) and without iron toxicity (Stox).

		Till_60	PH_60	PH_85	HC	MC	Gr/pan	%FG/Pan	GW	Yield (g/m^2)
Area with iron toxicity										
Treatments										
T1 (NPK)		10.848d	75.09e	98.61c	88.80bcd	108.2a	172.8b	86.85	24.8	820.2b
T2 (NK)		8.459bc	67.39b	95.18b	87.72a	109.2b	165.9ab	85.12	24.09	626.3a
T3 (P/PR)		7.819ab	65.60a	93.10a	89.09cd	110.2c	159.0ab	86.01	24.21	652.0a
T4 (STP)		8.974c	71.19d	95.99b	88.04ab	109.4b	157.0ab	85.84	24.54	751.7ab
T5 (Cal/P)		7.637a	69.69c	96.83b	89.69d	109.3b	171.2b	86.26	24.59	707.9a
T6 (Aci/P)		8.567bc	70.40cd	96.26b	88.17abc	108.7ab	154.5a	86.2	24.6	682.5a
Source of variation		**Fpr.**	**Fpr.**	**Fpr.**	**Fpr.**	**Fpr.**	**Fpr.**	**Fpr.**	**Fpr.**	**Fpr.**
	Treatments	***	***	***	***	***	**	ns	ns	***
Signification	Genotype	***	***	***	***	***	***	***	***	***
	Treatments *genotypes	ns	***	***	ns	***	***	***	***	**
Cv (%)		20.4	9.6	9.6	2.4	1.4	18.9	6.8	5.8	34.3
Iron toxicity area										
T1 (NPK)		9.715c	63.21d	90.92e	94.02a	115.8a	199.8	80.16b	23.23	785.5b
T2 (NK)		6.744a	55.34b	81.35abc	94.83a	118.1b	186.1	77.81b	22.52	588.3a
T3 (P/PR)		6.219a	53.51a	79.60a	97.43bc	118.3b	194.3	71.86a	22.65	608.6a
T4 (STP)		8.107b	58.62c	85.75bd	94.85a	117.0ab	189.4	78.98b	23.14	656.2ab
T5 (Cal/P)		6.781a	55.31b	81.24ab	97.93c	118.2b	185	77.31b	22.67	698.3ab
T6 (Aci/P)		8.048b	58.91c	83.87abcd	95.96ab	117.0ab	189.9	72.77a	22.98	640.8ab
Source of variation		**Fpr.**	**Fpr.**	**Fpr.**	**Fpr.**	**Fpr.**	**Fpr.**	**Fpr.**	**Fpr.**	**Fpr.**
	Treatments t	***	***	***	***	***	ns	***	ns	***
Signification	Genotype	***	***	***	***	***	***	***	***	***
	Treatments *genotype	ns	***	**	***	***	ns	**	ns	**
Cv (%)		28.6	11.4	24.5	4.1	2.2	29.7	13.2	7.4	46.4

Till: Tillers number; PH_: Plant Height at…days after sowing; HC: Heading Cycle days; MC: Maturity Cycle days; Gr/Pan: Grains number/panicle, AWG: 1000-Grains Weight; ns: none significant; *significant ($P < 0.05$); **Highly significant ($P < 0.01$); ***Very highly significant ($P < 0.005$); **** Very very highly significant ($P < 0.001$); CV: Coefficient of variation.

Table 4. Rice genotypes that performed the best yields with the best fertilizers treatment in the area without iron toxicity (Stox).

NPK fertilizer treatment				STP fertilizer treatment			
Genotype	**Yield (g/m²)**	**Geno**	**Yield (g/m²)**	**Genotype**	**Yield (g/m²)**	**Geno**	**Yield (g/m²)**
CC 109A	1036.22	KBR 6	917.90	HBG-2	713.30	FKR 76	837.87
KBR 2	1016.81	Orylux 6	846.36	KBR 4	718.34	KBR 6	838.03
Acc_68	991.94	IR 64	846.14	IR 64	746.63	HB-46	852.72
HB-46	975.06	Bouaké 189	840.94	CC 109A	762.03	KBR 2	902.20
FKR 56N	966.37	FKR 76	818.79	Orylux 6	772.09	Acc_68	925.38
KBR 4	929.81	HBG-2	810.84	Bouaké 189	775.65	Azucena	965.36
Azucena	926.74	KBR 8	745.76	FKR 56N	820.26		

STP: triple super phosphate; NPK: composed fertilizer NPK.

genotypes, results presented a very highly significant difference at parameters. The fertilizer NPK (14-23-14) revealed to be improving rice yield (820.2 g/m^2) and its agromorphological traits. It is followed by the fertilizer STP (751.7 g/m^2). Means separation performed by Student Newman Keuls test clustered fertilizers in three groups. Group 1 represented by treatment T1 (NPK) (820.2 g/m^2); the group 2, by treatment T4 (STP) (751.7g/m^2) and the group 3 composed by T2 (NK) (626.3 g/m^2), T3 (P/PR) (652.0 g/m^2), T5 (Cal/P) (707.9 g/m^2) and treatment T6 (Aci/P) (682.5 g/m^2). However, the analysis had not shown any significant difference based on the interaction of rice genotypes and fertilizers treatments for parameters plants' height on the 60th DAS and the 50 % heading cycle.

4.2. Fertilizers Effect on Rice Yield (g/m²) and Agromorphological Traits in Area Tox

In iron toxicity area (Tox), based on the interaction of fertilizers treatment and rice genotypes, data analysis revealed a significant difference at probability limit of 5% for the parameters plant height on the 60th DAS (PH_60) (Cv (%) = 14.4), PH_85 ((Cv (%) = 24.5); 50% heading cycle (HC) (Cv (%) = 4.1); 50% maturity cycle (MC) (Cv (%) = 2.2), as well as the yield (Cv (%) = 46.4 (Table 3). A none significant difference was observed based on the parameters: tiller number at 60 DAS, total number of grains/panicle (Gr/pan) and 1000-grain weight. However, a very highly significant difference was revealed by analysis, based on the effect of the differents fertilizers on ricegenotypes at parameters. The interaction between fertilizers treatment and rice genotypes shown a highly significant difference ($P < 0.001$) for yield performed, whether with fertilizers treatments and rice genotypes. Therefore, the best fertilizer treatments are: T1 (NPK) (785.5 g/m^2) and T5 (Cal/P) (698.3 g/m^2). Respectively fourteen (14) accessions with the fertilizers NPK and seven (07) with the Cal/P fertilizer performed yield value slightly higher than the varietal average yield 662.96 g/m^2 (Table 5).

Table 5. Rice genotypes that performed the best yields with the best fertilizers treatment in the iron toxicity area (Tox).

NPK fertilizer treatment				Cal/P fertilizer treatment			
Genotype	**Yield (g/m²)**	**Geno**	**Yield (g/m²)**	**Genotype**	**Yield (g/m²)**	**Geno**	**Yield (g/m²)**
HB-46	290.93	Azucena	857.72	FKR 56N	1098.23	KBR 6	848.9
KBR 6	1224.58	Bouaké189	835.99	KBR 4	1030.16	FKR 76	840.86
FKR 76	1004.51	Acc_68	810.96	Acc_68	987.67	KBR 2	840.45
KBR 8	994.07	IR 64	786.95	KBR 8	902.52		
Orylux 6	975.21	Acc_262	784.25				
KBR 4	972.2	HBG-2	707.04				
FKR 56N	907.51	KBR 2	858.09				

Cal/P: Calcined rock Phosphate and NPK: composed fertilizer NPK.

The fertilizer NPK (14-23-14) improve more rice yield (785.5 g/m^2 and it agromorphological traits. It is followed by the calcined rock phosphate (698.3 g/m^2). Nevertheless, the analysis of variance of the interaction between rice genotype and fertilizer did not show any significant difference for the parameter tillers' number at 60 DAS, total number of grains per panicle (Gr/pan) and 1000-grain weight. Means comparison test clustered fertilizers treatment in three groups based on the average yield performed. The group 1 is represented by T1 (NPK) (785.5 g/m^2). Group 2 is composed by T4 (STP) (656.2 $/m^2$), T5 (Cal/P) (698.3 g/m^2) and T6 (Aci/P) (640.8 g/m^2). Finally, the group 3 gathers the treatments T2 (NK) (588.3 g/m^2) and T3 (P/PR) (608.6 g/m^2).

4.3. Rice Genotypes' Yields Based on Fertilizers Treatments in Area without Iron Toxicity (Stox)

The results of variance analysis for yield of rice genotypes in area Stox are reported in the Table 6. Only the fertilizer treatment T1 (NPK) revealed a significant difference at the probability limit of 5% ($P < 0.05$; Cv (%) = 31.75) between rice genotypes average yield with an average yield value of 820.21 g/m^2. Results had not shown any significant difference ($P > 0.05$) with the others fertilizers treatment T2 (NK); T3 (P/PR); T4 (STP); T5 (Cal/P) and T6 (Aci/P). Their average yield values are: NK (626.31 g/m^2); Rock phosphate (652.01 g/m^2); STP (751.66 g/m^2); Calcined Phosphate (707.95 g/m^2); acidulated phosphate (682.5 g/m^2). The downgrade ranking of fertilizers treatment based on the average yield performed is: T1 (NPK) 820.21 g/m^2 > T4 (STP) 751.66 g/m^2 > T5 (Cal/P) 707.95 g/m^2 > T6 (Aci/P) 682.5 g/m^2 > T3 (P/PR) 652.01 g/m^2 > T2 (NK) 626.31 g/m^2).

4.4. Rice Genotypes' Yield According to Fertilizers Treatment in Iron Toxicity Area (Tox)

The analysis of variance results according to rice genotypes yield (g/m^2) in the iron toxicity area are reported in the Table 7. Highly significant (HS) differences were observed between rice genotype average yield with the raw rock phosphate T3 (P/PR) ($P < 0.01$, Cv (%) = 40.96) and the acidulated phosphate T6 (P/Aci) ($P < 0.01$, Cv (%) = 57.59), performing the average yield of 608.65 g/m^2 and 640.77

g/m^2 respectively. Newman-keuls (SNK) means comparison based on rice genotypes average yield performed by the raw rock phosphate fertilizer (T3) (P/PR), revealed 2 groups: the group a represented by KBR 2 and the group b gathering Acc_68; KBR 4; FKR 76; FKR 56; KBR 6; Bouaké 189; Acc_225; HB-62; KBR 8; Azucena; HB-46; CC 109A; Orylux 6; IR 64; Acc_262; Acc_270 and Acc_15. However, the test revealed 3 groups with the treatment T6 (Aci/P): the group a (KBR 6), group ab (Acc_68; FKR 56; KBR 2 and FKR 76) and the group b (KBR 8; IR 64; HB-62; CC 109A; Azucena; Acc_270; Acc_225; Orylux 6; HB-46; KBR 4; Acc_262 and Acc_15). In contrast, any significant difference had been revealed with the fertilizers treatment T1 (NPK) ; T2 (NK); T4 (STP) and T5 (cal/P) that performed respectively the average yield value of 785.53 g/m^2; 588.27 g/m^2; 656.24 g/m^2 and 698.29 g/m^2. The downgrade ranking of fertilizers treatment based on the average yield performed is: T1 (NPK) 785.53 g/m^2 > T5 (Cal/P) 698.29 g/m^2 > T4 (STP) 656.24 g/m^2 > T6 (Aci/P) 640.77 g/m^2 > T3 (P/PR) 608.65 g/m^2 > T2 (NK) 588.27 g/m^2.

Table 6. Yield variance and rice genotypes ranking based on fertilizers treatment in the area without iron toxicity.

Treatments	T1 (NPK)		T2 (NK)		T3 (P/PR)		T4 (STP)		T5 (Cal/P)		T6 (Aci/P)	
	Geno	**Yield**	**Geno**	**Yield**	**Geno**	**Yield**	**Geno**	**Yield**	**Geno**	**Yield**	**Geno**	**Yield**
Rice genotypes ranking based on yield (g/m^2)	CC 109A	1036.2	CC 109A	908.3	Azucena	969	Azucena	965.4	HB-46	1121	HBG-2	931.4
	KBR 2	1016.8	Acc_68	801.3	HBG-2	815.3	Acc_68	925.4	CC 109A	951.9	HB-46	877.4
	Acc_68	991.9	KBR 2	764.6	CC 109A	774.7	KBR 2	902.2	HBG-2	936	Acc_68	850.8
	HB-46	975.1	KBR 8	761.7	Acc_68	740	HB-46	852.7	Acc_68	883.8	Azucena	808.5
	FKR 56 N	966.4	HB-46	741	Orylux6	724	KBR 6	838	FKR 76	873.9	FKR 76	776.5
	KBR 4	929.8	HBG-2	740.4	Acc_225	710.8	FKR 76	837.9	Acc_262	809.2	CC 109A	776.3
	Azucena	926.7	IR 64	689.9	KBR 6	693.1	FKR 56N	820.3	Azucena	759.3	KBR 2	708.7
	KBR 6	917.9	KBR 4	688.9	Bouaké 189	681.2	Bouaké 189	775.7	Acc_225	718.8	KBR 4	704.6
	Orylux 6	846.4	KBR 6	673.9	FKR 76	670.3	Orylux 6	772.1	Bouaké 189	704.1	Orylux 6	689.9
	IR 64	846.1	FKR 76	669.4	IR 64	667.9	CC 109A	762	KBR 4	673.2	Acc_225	674.6
	Bouaké 189	840.9	FKR 56 N	650.6	KBR 4	653.7	IR 64	746.6	KBR 6	661.6	KBR 6	656.5
	FKR 76	818.8	Orylux 6	614.9	FKR 56N	645.6	KBR 4	718.3	IR 64	624.5	FKR 56	635.7
	HBG-2	810.8	Acc_225	553.9	KBR 2	620.7	HBG-2	713.3	FKR 56	608.7	KBR 8	618.2
	KBR 8	745.8	Azucena	539.7	Acc_262	615.5	KBR 8	702.5	KBR 2	596.1	Bouaké 189	613.5
	Acc_225	628.2	Bouaké 189	518.7	HB-46	604.3	Acc_225	668.4	Orylux 6	561.4	IR 64	593.8
	Acc_270	509.2	Acc_262	514.2	KBR 8	512.4	Acc_262	633.6	KBR 8	455.8	Acc_262	575.7
	Acc_262	507.9	Acc_270	253.9	Acc_270	357.5	Acc_270	495.5	Acc_15	404.9	Acc_270	507.1
	Acc_15	448.7	Acc_15	188.2	Acc_15	280.2	Acc_15	400	Acc_270	398.8	Acc_15	285.7
Average	**820.21**		**626.31**		**652.01**		**751.66**		**707.95**		**682.5**	
Signification	*		ns		ns		ns		ns		ns	
CV (%)	**31.75**		**43.9**		**35.9**		**24.7**		**40.7**		**33.4**	
LSD	**35.44**		**39.15**		**33.48**		**28.22**		**41.62**		**32.47**	

Geno: Genotypes; T1 (NPK): composed fertilizer NPK; T2 (NK): Nitrate of potassium; T3 (P/PR): Raw rock phosphate; T4 (STP): triple super phosphate; T5 (Cal/P): Calcined rock Phosphate; T6 (Aci/P): Acidulated phosphate; ns: none significant; *Significant ($P < 0.05$); Geno: rice genotypes; CV: Coefficient of variation; LSD: Less Significant Difference.

Table 7. Yield variance and accessions classification in each in the le area of iron toxicity.

Treatments	T1 (NPK)		T2 (NK)		T3 (P/PR)		T4 (STP)		T5 (Cal/P)		T6 (Aci/P)	
	Geno	Yield	Geno	Yield	Geno	Yield	Geno	Yield	Geno	Yield	Geno	Yield
Rice genotypes ranking based on yield (g/m²)	KBR 6	1224.6	KBR 8	963.5	KBR 2	1351.2a	KBR 2	1037.2	FKR 56	1098.2	KBR 6	1585.8a
	FKR 76	1004.5	KBR 2	780.2	Acc_68	829.2b	KBR 6	1026.9	KBR 4	1030.2	Acc_68	1086.8ab
	KBR 8	994.1	Bouaké 189	706.6	KBR 4	732.3b	KBR 4	1018.2	Acc_68	987.7	KBR 8	825.5b
	Orylux 6	975.2	Orylux 6	697.6	FKR 76	710.3b	Bouaké 189	803.8	KBR 8	902.5	Bouaké 189	771.1b
	KBR 4	972.2	KBR 6	683.8	FKR 56	693.0b	KBR 8	794.9	KBR 6	848.9	FKR 56	767.1ab
	FKR 56 N	907.5	FKR 76	680.9	KBR 6	673.9b	Acc_68	683.3	FKR 76	840.9	KBR 2	714.6ab
	KBR 2	858.1	Azucena	656.8	Bouaké 189	657.6b	FKR 76	679.9	KBR 2	840.4	FKR 76	680.1ab
	Azucena	857.7	Acc_262	622.8	Acc_225	610.4b	Azucena	642.3	Bouaké 189	647.8	IR 64	642.7b
	Bouaké 189	836	FKR 56	607.4	HBG-2	599.1b	Acc_225	611.1	HBG-2	614.5	HBG-2	538.1b
	Acc_68	811	HBG-2	590.4	KBR 8	587.6b	FKR 56	573.6	Acc_262	609	CC 109A	535.6b
	IR 64	787	IR 64	560.5	Azucena	535.6b	Acc_270	568.8	CC 109A	588.1	Azucena	520.1b
	Acc_262	784.2	CC 109A	560.4	HB-46	511.7b	CC 109A	554.5	IR 64	585.7	Acc_270	518.0b
	HBG-2	707	Acc_68	450.5	CC 109A	497.6b	Orylux 6	546.4	Acc_225	581.8	Acc_225	479.1b
	Acc_225	587	Acc_15	413.5	Orylux 6	459.0b	HBG-2	511.2	Acc_270	574	Orylux 6	453.0b
	Acc_270	584.6	KBR 4	410	IR 64	442.0b	IR 64	507.2	Orylux 6	538.6	HB-46	442.2b
	CC 109A	571.9	Acc_225	403.1	Acc_262	439.1b	Acc_262	480.4	HB-46	523.8	KBR 4	340.4b
	Acc_15	386	Acc_270	401.6	Acc_270	376.8b	HB-46	395.2	Azucena	466.6	Acc_262	338.8b
	HB-46	290.9	HB-46	399.3	Acc_15	249.4b	Acc_15	377.3	Acc_15	290.6	Acc_15	295.0b
Average	785.53		588.27		608.65		656.24		698.29		640.77	
Signification	ns		ns		**		ns		ns		**	
CV (%)	40		40.79		38.9		55.1		45.9		56	
LSD	46.97		32.65		40.96		48.92		46.22		57.59	

Geno: Genotypes; T1 (NPK): composed fertilizer NPK; T2 (NK): Nitrate of potassium; T3 (P/PR): Raw rock phosphate; T4 (STP): triple super phosphate; T5 (Cal/P): Calcined rock Phosphate; T6 (Aci/P): Acidulated phosphate: ns: none significant; ** Highly significant ($P < 0.01$); CV: Coefficient of variation; LSD: Less Significant Difference.

4.5. Yields Performed by Rice Genotypes and Fertilizers Treatment and Comparison of Rice Yield (g/m²) Based on Area, Fertilizers and Interaction Area*Genotype

Results did not show any significant difference ($P > 0.05$) between rice genotypes based on the average yields, the fertilizers treatment (Table 8) as well on the interaction area*genotype on both areas. However, a significant difference between rice genotypes was shown in both areas with the fertilizers treatment T1 (NPK) ($P < 0.009$*), T2 (NK) ($P < 0.045$) and highly significant (HS) ($P < 0.002$**) with the raw rock phosphate treatment (P/PR) T3. The analysis of variance of the average yields, shown a significant difference between both areas (Stox and Tox) for fertilizers treatment T5 (Cal/P) and T6 (Aci/P). In fact, the yield performed by the calcined phosphate fertilizer (T5) in the area without iron toxicity (Stox) was higher (707.9 g/m^2) than the one scored in the iron toxicity area (Tox) (698.3 g/m^2). The acidulated phosphate fertilizer (T6) had shown the same performance with yield values of 682.5 g/m^2 and 640.8 g/m^2 respectively in area Stox and area Tox (**Table 9**). Rice yields assessment in both areas (Stox et Tox) revealed that the rice genotype CC109A from *Oryza glaberrima* and KBR 6 performed respectively the best yield values 868.3 g/m^2 and 1007.3 g/m^2 (**Table 10**). However, the accession 15 performed the lowest yield value in area Stox (334.6 g/m^2) and in area Tox (335.3 g/m^2). The analysis of variance of average yield performed on each fertilizer in both areas (Stox and Tox) revealed a highly significant difference between several rice genotypes. It is the accession KBR 8, FKR 56N, KBR 2, KBR 6, FKR 76 and accession 68. The difference was highly significant between the rice genotypes IR64, Orylux 6, KBR 4, HB-62, Azucena, Bouaké189, HB-46 et CC 109 A and the accession 270, accession 262, accession 225. Accession 15 whom yield was not affected by area effect.

Table 8. Yield (g/m^2) comparison based on area and rice genotype and their interaction.

Treatments		**T1 (NPK)**		**T2 (NK)**		**T3 (P/PR)**		**T4 (STP)**		**T5 (Cal/P)**		T6 (P/Aci)	
Area		**Stox**	**Tox**	**Stox**	**Tox**	**Stox**	**Tox**	**Stox**	**Tox**	**Stox**	**Tox**	**Stox**	**Tox**
Average		820.21	785.53	626.31	588.27	652.01	608.65	751.66	656.24	707.95	698.29	682.5	640.77
Probability & Signification	**Area**	0.514^{ns}		0.433^{ns}		0.342^{ns}		0.089^{ns}		0.87^{ns}		0.473^{ns}	
	Geno	0.009*		0.045*		0.002**		0.104^{ns}		0.162^{ns}		0.011*	
	Area*Geno	0.277^{ns}		0.551^{ns}		0.086^{ns}		0.775^{ns}		0.169^{ns}		0.06^{ns}	
Cv (%)		34.2		41.3		37.4		40.8		43.3		45.4	

Geno: Rice genotype; Stox: area without iron toxicity; Tox: iron toxicity area; ns: none significant; *significant (P < 0.05); **Highly significant (P < 0.01); T1 (NPK): composed fertilizer NPK; T2 (NK): Nitrate of potassium; T3 (P/PR): Raw rock phosphate; T4 (STP): triple super phosphate; T5 (Cal/P): Calcined rock Phosphate; T6 (Aci/P): Acidulated phosphate; CV: Coefficient of variation.

Table 9. Variance analysis of the average yields of the areas without iron toxicity (Stox) and the area of iron toxicity (Tox) of the different fertilizer treatments.

Treatments	**Areas**			
	Stox		**Tox**	
T1 (NPK)	820.2	**b**	785.5	**b**
T2 (NK)	626.3	**a**	588.3	**a**
T3 (P/PR)	652	**a**	608.6	**a**
T4 (TSP)	751.7	**b**	656.2	**ab**
T5 (P/Cal)	707.9	**a**	698.3	**ab**
T6 (P/Aci)	682.5	**a**	640.8	**ab**
Probability	**<0.001**		**0.015**	
Signification	***		*	
Cv (%)	**34.3**		**46.4**	

Stox: area without iron toxicity; Tox: iron toxicity area; T1 (NPK): composed fertilizer NPK; T2 (NK): Nitrate of potassium; T3 (P/PR): Raw rock phosphate; T4 (STP): triple super phosphate; T5 (Cal/P): Calcined rock Phosphate; T6 (Aci/P): Acidulated phosphate; CV: Coefficient of variation. In each column, different letters mean significant differences.

Table 10. Variance of yield (g/m^2) within areas (Stox and Tox) and rice accession.

Genotype	Areas				Signification
	Stox		Tox		
Acc_15	334.6	a	335.3	a	NS
Acc_270	420.3	a	504	abc	HS
Acc_262	609.4	b	545.7	abc	HS
KBR 8	632.7	b	844.7	cdef	THS
Acc_225	659.1	b	545.4	abc	HS
Bouaké 189	689	b	737.1	bcdef	HS
IR 64	694.8	b	587.5	abc	HS
Orylux 6	701.4	b	611.6	abcd	HS
FKR 56N	721.2	b	774.5	cdef	THS
KBR 4	728.1	b	750.5	bcdef	HS
KBR 6	740.2	b	1007.3	f	THS
KBR 2	768.2	b	930.3	df	THS
FKR 76	774.5	b	766.1	cdef	THS
HBG-2	824.6	b	593.4	abc	HS
Azucena	828.1	b	613.2	abcde	HS
HB-46	861.9	b	427.2	ab	HS
Acc_68	865.6	b	808.1	cdef	THS
CC 109A	868.3	b	551.4	abc	HS
Probability	<0.001		<0.001		
Signification	THS		THS		
Cv (%)	34.3		46.4		

Stox: area without iron toxicity; Tox: iron toxicity area; NS: None Significant; HS: Highly Significant ($P < 0.01$); VHS: Very Highly Significant ($P < 0.005$); CV: Coefficient of variation. In each column, different letters mean significant differences.

5. Discussion

In both areas, area without iron toxicity (Stox) and iron toxicity area (Tox), the fertilizer NPK performed the best performances for the whole parameters and the yield (g/m^2). It recorded therefore the shortest maturity date in comparison the others fertilizers. In fact, when a fertilizer is applied to the soil, which is the headquarter of an intense movement of diversified biological organism, it solubilized. Then, the resulting components are used in plant nutrition according to an osmotic balance with the humusy-argilleous complex.

The symbiotic bacteria linked to rice plant nutrition prepare the mineral components need by rice plant for its development. Through its enzymatic action, bacteria solubilize the nutritive components of the organic and mineral reserves of the soil, making them assimilable by plant as mineral ions in a balance rate and at the right period of its development.

The NPK fertilizer provided the three main nutritive components needed by rice plant such as nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O_5). Certains others showed that the absorption is influenced by the presence or the absence of another/others ones [9]. In fact, since 1988 studies concluded that: "iron toxicity occurring on rice plants due to an absorption of toxic iron, is more linked to unbalanced nutritional feeding caused by a lack of phosphorus and potassium than to a high concentration of soluble reduced iron" [10]. Which confirming Liebig's law sating that: "the performed yield's rate is determined by the nutritive component which quantity needed to ripe is relatively low than those ones of the others components" [11]. It would appear that providing the three components (nitrogen, phosphorus and potassium) simultaneously improves yield rate at 55% by increasing the unit of each fertilizer provided for plants [12] (**Table 3**). These results could explain the best productive performances scored by the NPK fertilizer in both areas (iron toxicity and area without iron toxicity) comparatively to others fertilizers: NK, rock phosphate, triple super phosphate, calcined phosphate and acidulated phosphate. Some founded that every treatment lacking P, K and N could not be sufficient enough to provide optimal growing and production for rice [13]. Phosphate fertilizers (rock phosphate, triple super phosphate, calcined phosphate and acidulated phosphate), seem to be more stored in the soil's phosphorus reserves instead of being directly used by rice plant. Others [14] affirmed that maintaining a convenient level of the phosphorus in soil solution depends on the quantity of labile phosphorus replacing the soil solution phosphorus absorbed by plant. Also, It stated that in a soil well provided in that mineral component, 5% to 10% of the phosphorus absorbed by plant come from the fertilizer while 90% to 95% are from the soil's reserve [11]. In addition, increasing the unit of fertilizers' components N, P and K, could easily covers plant nutritive needs and then induce the beginning of it reproductive step namely the panicle initiation and maturity cycle of 80%. The same situation is observed with the fertilizer NPK and plant growing (cm) as well the number of grains per panicle, comparatively to the others fertilizers. However, the negative cycle of a genotype could deeply be modified by edaphic and epigenetical conditions, the production area, fertilization, the season, etc. In addition at iron toxicity case, rice genotypes cycle along with the ferrous stress pression [1], which resulted into a cycle of 115.8 days and 108.2 days respectively in iron toxicity area (Tox) and the area without iron toxicity (**Table 3**). Moreover, the duration of cycle observed with treatments in both areas, could be explained by the unfulfillment of one or/all of the fertilization rules (compatibility, solubility and toxicity index) in those areas, according to [15]. Yet, the missing or the super fertilizing of one fertilizer component could cause an normal growing and a deficiency in another component. Those reasons could explain the decrement of the average yields in the area without iron toxicity with the values of 820.2 g/m^2 (NPK), 751.7 g/m^2 (STP), 707.9 g/m^2 (calcined phosphate), 682.5 g/m^2 (acidulated phosphate), 652.0 g/m^2 (rock phosphate) and 626.3 g/m^2 (nitrate of potassium) (**Table 3**).

In the iron toxicity area (Tox), the lowest yield value and the longest cycle were observed in the fertilizer NK treatment. Those results could be explained by the lack of phosphorus in this fertilizer (**Table 3**). Others reported that phosphorus permits a best growing of roots, a good development of grains [9], etc. It also stimulates flowering, precocity and grains' filling [16]. Still, [17] found that rice plant vegetation decreases and its flowering delayed as well, when it lacks of P_2O_5, decreasing then the yield at 50%. Yet, the mineral nutrition of rice plants is not specifically for a specie or a type of variety. In fact, the best rice genotypes that performed higher average yield values than the average yield of the whole genotypes (**Table 4**) are from both rice species: *O. sativa* (Accession 68) and *O. glaberrima* (CC 109A, HBG-2, HB-46). It also the same case for the type of variety: intraspecies (KBR 2, KBR 4, KBR6, KBR 8), interspecies (FKR 76, FKR 56N), *Japonica* (Azucena), *Indica* (IR64, Bouaké 189) with the treatments NPK and STP (Stox area) (**Table 4**), the treatments NPK and calcined phosphate (Tox area) (**Table 5**). This could be explaining that, once a good management of weeds, pests and diseases is operated, the mineral nutrition of rice plant only depends on water level, the soil moisture and pH, etc. Moreover, the difference between rice genotypes yields scored with NPK fertilizer (Stox area) (**Table 6**), with rock phosphate and acidulated phosphate (Tox area) (**Table 7**), could be explain by the varietal cycle duration which is a genetical and an ecological characteristic in plant breeding. That is why genotype production depends first on the ecology of the production area. Furthermore, the rice genotype diversity generally increases as long as the environment conditions vary. At Madagascar, concluded that rice genotypes from *Indica* group are cultivated in aquatic ecosystem (irrigated rice culture with water mastery, flooded rice culture, deep flood rice culture) in the tropical areas [18]. Then those from "temperate *Japonica*" group are cultivated in the aquatic ecosystem of temperate areas and the "tropical *Japonica*" rice genotypes cultivated in raining ecosystem (unflooded and drained soils' rice cultivation, especially based one rains' water) in the tropical area. Therefore, accession 15, accession 225, accession 226 and accession 270 should belong to the raining rice cultivation system genotypes and the genotypes CC 109 A, HB-46 and HBG-2 to the lowland/irrigated rice cultivation system (**Table 6** and **Table 7**). Also, revealed that the most morphological and physiological traits used to characterize the clustering of rice genetical diversity are the architectural traits (Tillering, leaves dimensions, culms and leaves leaning angle), the phenology (cycle duration, photo sensibility) [18] etc. In Burkina Faso, [19] [20] concluded the national average yield values in rice cultivation to 4 to 7 t/ha in irrigated system, 3 to 4 t/ha in lowland and 1 to 2 t/ha in raining system. They had recommends the *indica* rice type cultivation in low altitude ecology; the *japonica* rice in high altitude ecology for irrigated/lowland rice cultivation and the *japonica rice* in an "exclusive" raining rice cultivation system

[16].

Results shown a variability between rice genotypes based on yield performed in both study areas (**Table 8**). Variabilities observed with the fertilizers NPK (composed fertilizer), NK (nitrate of potassium), rock phosphate and acidulated phosphate. In fact, when the technical factors (transplanting young seedlings, good management of irrigation water, etc) are well set the only one determining factor remaining to a good productivity of the variety is to providing good nutrition of the soil and keep humusy-argilleous complex (HAC) and the cationic exchanging capacity (CEC) in good state.

Unfortunately, [21] stated that the acidity in the soil destroy links in the humusy-argilleous complex. Those statements could slightly explain the difference of yields performed in both areas Stox and Tox in one hand and within some fertilizer treatments (NPK, NK, rock phosphate and acidulated phosphate) in the other hand. Results at **Table 9** exactly revealed that any fertilizer treatment did not escape the ecology effect, which was most harshness in the iron toxicity area (Tox). Elsewhere, rice genotypes from *Japonica* type (Accessions 15, Accessions 262 and Accessions 270) seem to be less sensitive to fertilizers (treatments). In instance, they performed low yield values in both areas (**Table 10**). These results corroborate with of [18], who, in an *in-situ* study of rice structuration, eco-geographical distribution and management, found that rice accessions from *japonica* type had moderated tillering and average number of grains per panicle while those from the *indica* type had generally performed high number of tillers and grains per panicle. This last group in deed, gathers release in Burkina Faso (FKR 56N, FKR 76, Orylux 6, les KBR 2, KBR 4, KBR 6 and KBR 8) and the accessions CC 109A, HB-46, HB-62 (**Table 10**).

6. Conclusion

The objective in this study which consisted in increasing rice productiveness in iron toxicity condition by using the combination of tolerant rice genotypes with Burkina phosphate (BP) is reached. Increasing rice productiveness in such conditions goes through rice field ecosystem improvement. Moreover, fertilization' compounds used should improve rice yield components (tillers number/plant, panicles/plant grains number/panicle, etc.) as well as the yield in a unite of surface. Thereby, in the area without iron toxicity (Stox), the best fertilizers were the composed fertilizer NPK (820.2 g/m^2) and the triple super phosphate (751.7 g/m^2). In contrast the lowest yield value was performed by the nitrate of potassium (NK) (626.3 g/m^2). The five (05) productiveness genotype were CC 109A, Accession 68, HB46, Azucena and HBG-2. In the iron toxicity area(Tox), the best fertilizers were NPK (785.5 g/m^2) and the calcined phosphate (698.3 g/m^2). The five productiveness genotypes were KBR 6, KBR 2, Accession 68, KBR 8, FKR 56N and FKR 76. In that area also, the nitrate of potassium (NK) recorded again the lowest yield value (588.3 g/m^2). However, the accession 15, accession 225, accession 226 and accession 270 seem to belong to the rain rice cultivation system genotypes and the genotypes CC109 A, HB 46 and HBG-2 to the lowland/irrigated rice cultivation system. The most significative effect of the positive interaction between the phosphate ($H_2PO_4^-$; HPO_4^{2-}) and the potassium (K^+) ions induced the great impact of the treatments made of phosphorus (P) and potassium (K) (NPK, NK and acidulated phosphate) to the iron stress reduction.

Authors' Contributions

All the authors had contributed anyhow to the realization of this study realization.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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