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Effect of Kaolin on Rice Production in Ferrous Toxicity Condition

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Abstract **Original Research Article**

Tropical lowland rice cropping is often facing with iron toxicity ([Fe^{2+}] soil> 300ppm) constraint. This edaphic constraint is commonly observed in West African lowlands. It can cause yield reduction in a range of 10 to 100% depending on the concentration of iron in the soil solution and the cultivar used. Applying fertilizers and amendments have been recommended, including silica use. However, the high cost of the industrial silica limits its application. Hence the initiative to explore the potential of kaolin (54.7% SiO2) as a natural source of silica. Two pot experimentations were conducted during two successive rice cultivation cycles when applying 900 ppm of Fe^{2+}. Five kaolin treatments were tested (T_0 = 0 kg kaolin ha^{-1}, T_1 = 366 kg kaolin ha^{-1}, T_2 = 735 kg kaolin ha^{-1}, T_3 = 1097 kg kaolin $ha^{-1}$and T_4 = 1465 kg kaolin ha^{-1}) in a randomized complete blocks with 5 repetitions for each experiment. Twenty one days old plants were transplanted into a pot (treatment). After transplanting, only plants from T_1, T_2, T_3 and T_4 survived until yielding. The dose of 366 kg ha^{-1} was sufficient to inhibit the toxic effect of iron on the development of the rice plant. The results show that kaolin input improved grain yield of rice (0 t ha^{-1}- 1.08 t ha^{-1}). The dose of 1465 kg kaolin ha^{-1} gave the higher grain yield (1.08 t $ha^{-1)}$. Response of rice to kaolin doses was more linear (RDG = 0.98 × Dose) than quadratic, indicating 1391.75 t ha^{-1} of kaolin as the optimal dose (1.054 ± 0.07 t ha^{-1}) under iron toxicity condition of 900 ppm Fe^{2+}.

Keywords: Kaolin/ iron toxicity/ rice cultivation/ response curve/ Côte d'Ivoire.

INTRODUCTION

Rice (Oryza sativa L.) is the staple food or even the main food of more than half of the world's population [1]. In West and Central Africa, rice demand is one of the highest in the world [2]. However, its production faces numerous constraints, among which iron toxicity remains among the most virulent [3-6]. It can cause a yield reduction in a range of 10 to 100% depending on the iron concentration in the soil solution and the cultivar used. To manage this constraint, fertilizers and amendments have been recommended. For this purpose, the potentialities of silica (Si) to enhance plant tolerance to biotic and abiotic stresses have been explored [7-9]. In this recommendation, the effectiveness of silica is shown because of the power of silica to increase the oxidizing in the rhizosphere of rice [10] and its ability to reduce the effect of numerous toxicities of edaphic origin [11, 12]. However, access to industrial silica is difficult for African farmers because of its high cost. Hence this study was initiated to explore the potential of Bingerville kaolin (54.7% SiO_2) as a natural source of silicon for rice cultivation.

Kaolin is a silico-aluminous clay rock whose characteristic mineral is kaolinite. It is used particularly in ceramics, paper industry, manufacture of rubber, pesticides, cosmetics and medicine [13-15]. But in Côte d'Ivoire, it is used in body painting and traditional medicine [16].

In Côte d'Ivoire, the rice annual deficit amounts to 616,329 tonnes of milled rice [17, 18], whereas good practice in the lowlands could increase yields about 200% (1, 5 t ha^{-1} - 4 t ha^{-1}). Therefore, it is important to control the most common constraint; iron toxicity in lowland. Audebert's work has tested the effect of N, P, K and Zn fertilizers on rice plant tolerance to iron toxicity in the Korhogo lawland [19] and Sanogo and collaborators in the lowlands of Gagnoa on the capacity of mineral fertilization to improve rice production [20]. However, these results remain little adopted probably because of the high costs of these inputs. Given the recognized effectiveness of silica (Si), the use of kaolin would be a good alternative given its rapid dissolution in water [21].

There are kaolin deposits throughout Côte d'Ivoire, with the Bingerville deposit in southern Côte d'Ivoire remaining the largest [16]. This Bingerville kaolin (54.7% SiO_2) can serve as a natural source of silicon for rice growing. The oxidizing power of Si in the rhizosphere of rice should result in the conversion of Fe^{2+} to Fe^{3+}. It is for this purpose that pot study was realised to analyse the effect of kaolin on rice yield parameters and to determine the optimal kaolin dose for a better rice response in iron toxicity condition.

MATERIAL AND METHODS

Experimentation Site

The study was realized from May to December 2017 at the Scientific Pole of Technological Innovation of the University Felix Houphouet Boigny of Cocody located in Bingerville at 05 ° 21'25.6"N 03 ° 54'11.5"W, 2 m in the southern part of Côte d'Ivoire, during two successive rice growing cycles. This site is located in the district of Abidjan with a temperature ranging between 23.9 and 28.2° C and a mean annual rainfall of 2008.8 mm [22].

Experimentation Pot and Substrate of Culture

The experiment was conducted in a greenhouse in plastic pots which the surface at aperture was 706.5 cm^2 with 20 cm for the bottom diameter, 30 cm at upper and 40 cm high.

The growing substrate was sand (quartz grains) colluviated by rainwater runoff. This sand has been sieved to remove other elements, including organic debris and coarse particles including ferruginous concretions. Then, it was washed with tap water several times until a clear supernatant was obtained before being dried in an oven at a temperature of 120 ° C for 24 hours. Then 5 kg of this sand were weighed using a commercial scale of 20 kg graduation 100 g to fill the pots.

Plant Material

WITA 9 (WARA-IITA 9) was used as a rice variety to test because of its susceptibility to iron toxicity. It has a 120 day cycle, an average yield of 6 t ha^{-1} with a potential of 10 t ha^{-1}. The average height of the plants is 92 cm with 205 tillers on average per square meter. Her genetic parents are IR2042-178 × CT19.

Fertilizers and Source of Iron

One hundred and thirty grams (130 g) of Bingerville kaolin (5 ° 20'47"N 3 ° 52'59"W 15 m) were dried at 120° C during 24 hours as source of silicon.

13,66 g of monohydrate iron sulfate ($FeSO_4$ H_2O) were used to create the iron toxicity condition at 900 ppm per pot. One hundred and fourteen grams (114 g) of triple superphosphate ($Ca (H_2PO_4), 2H_2O$), 50g of potassium chloride (K_2OCl) and 61 g of urea ($(CO (NH_2)_2)$) were used as fertilizer at the rate of 60 kg P ha^{-1}, 60 kg K ha^{-1} and 80 kg N ha^{-1} respectively.

Kaolin

Kaolin is a clay rock, silico-aluminous which the characteristic mineral is of the kaolinite. Other minerals such as quartz, micas, feldspars, titanium oxides, oxides and hydroxides of iron and manganese are his secondary minerals [23]. It is a soil formation dominated by kaolinite that belongs to the family of phyllosilicates with a 1: 1 as structure and equidistance around 7Å. The kaolin used in this study is from Bingerville, extracted from an artisanal quarry of 10 hectares in area with a exploitable layer of 40 m thick, located at East of Bingerville city (5 ° 20'47 '' N 3° 52'59'W 15 m). It has a light pink colour (7.5 YR8/7) with 61% of diameter < 2µm. His main oxides are SiO_2, Al_2O_3, Fe_2O_3, MgO, MnO, K_2O, CaO, TiO_2, P_2O_3 and Na_2O [24].

Calculation of the quantity of silicate (SiO_2) and of iron

The kaolin of Bingerville contains 54.7% silicate (SiO_2). According to Lawrence and Fabrício, 200 kg ha^{-1} of SiO_2 are necessary to treat deficiency and disease problems in rice [25]. Based on this assertion the silicon doses were adjusted in this study to 0, 200 kg ha^{-1}, 400 kg ha^{-1}, 600 kg ha^{-1} and 800 kg ha^{-1} supposedly 0, 366, 736, 1097 and 1465 kg kaolin ha^{-1}. The pots used in this study have a surface of 1413 cm^2. The rate of kaolin and iron sulphate was calculated according to the following formulas:

Q kaolin = (surface x dose) / coefficient of conversion [26]

The surface expressed in m^2 and the dose in kg ha^{-1}.

Q iron sulphate = (M iron sulphate x total dose per pot) / M_{Fe}

The rate of iron sulphate applied to reach 900 ppm is 13.66 g. This quantity was calculated taking into account that the molar mass of iron sulphate is 170 g mol^{-1} and the molar mass of iron 56 g mol^{-1}. 1 ppm equals 1 mg kg^{-1} so for a pot containing 5 kg of sand, 4500 mg of Fe is needed for the dose of 900 ppm.

$$Q_{900ppm} = (170 \times 4500.10^{-3})/56 = 13.66 \text{ g}$$

Table-1: Different doses of SiO_2 and corresponding rate of kaolin used in the experimental pot

Doses of SiO_2 (kg ha^{-1})	Quantity of kaolin (g)	Dose of kaolin (kg ha^{-1})
200	5.16	366
400	10.33	736
600	15.49	1097
800	20.66	1465

Treatments

The pot experimentation (5 kg of sand) considered five (5) treatments established as fallows to control the effect of 13.66 g of iron sulphate (900 ppm Fe).

The experimentation considered five (5) treatments established as follows:

- $T_{0\ (witness)}$: 0 g of kaolin
- T_1 : 5.16 g of kaolin
- T_2 : 10.33 g of kaolin
- T_3 : 15.49 g of kaolin
- T_4 : 20.66 g of kaolin

The experiment design is a complete randomized block consisting of five treatments with five repetitions. The different quantities of kaolin corresponded the doses of 0, 366, 1097 and 1465 kg kaolin ha^{-1}

Experimental Design

The WITA 9 rice variety has been used as a plant material, it is a variety sensitive to iron toxicity. After drying, the sand was mixed with iron sulphate at a rate of 900 ppm, supposedly 13.66 g of iron sulphate per 5 kg of substrate. Plants of twenty-one (21) days were transplanted into pots at a rate of one plant per pot placed in the center of each pot. Five treatments of kaolin were applied they are, 0, 366, 736, 1097 and 1465 kg kaolin ha^{-1}. The fertilization was done at the rate of 60 kg P ha^{-1} (2.3 g TSP) 60 kg K ha^{-1} (1g K_2OCl) and 80 N kg ha^{-1} (0. 5 g of urea). The nitrogen supply was fractionated, thus two urea additions were made for 0.5 g at tillering and 0.5 g at the panicular stage, reducing the urea dose to 80 kg N ha^{-1}. The fertilizer, iron sulphate and kaolin combination were thoroughly mixed with the sand before the semi. Then, all the pots were kept flooded with a water height of about 3 cm above the surface of the substrate until the end of the test to create an anoxic environment favourable to iron toxicity condition.

Data Collection

At 30 days after transplanting, a scoring of the iron toxicity was made. This consisted of determining the number of yellowed or browned plants, determining the height of the plants, the number of tillers / pot, the mortality rate by treatment, the iron toxicity severity score on the plant and the foliar severity according to the standard rice evaluation method of the International Rice Research Institute [27]. This operation was repeated at heading at 75 days, at flowering 90 days after transplanting and at maturity at 120 days. Finally, at maturity, the number of panicle, the average panicle length, the average number of full and empty seeds per panicle was determined per pot. After harvest, grain yield and straw yield were determined per pot and for each treatment.

The determining of kaolin effect on the rice root, a test established according to the same protocol was prepared for this purpose. At 30 and 60 days after sowing, rice plant was dug out from each pot and the Hue, Value and Chroma of the roots were determined using a Munsell code.

STATISTICS ANALYSIS

The analyses of variance, of correlation of Pearson and the rice response curve to kaolin doses were made with SAS software. The average mean comparison by the smallest significate difference on the threshold of $\alpha = 0.05$, as same as the acceptation of the probability.

RESULTS

Effect of Treatments on Agronomic Parameters

The results in Table-2 show the means values of the yield parameters per treatment. The analysis of the results shows that the panicle length remains practically identical to the level of all the treatments. However, the number of grains per panicle varies. The largest number of grains (210 grains) was obtained in the treatment T_3. The largest number of empty grains per (20 grains) is obtained with the treatment T_1 of the test 1. The grain yield of 1.08 t ha^{-1} is obtained with the treatment T_4 in the tests 1 and 2.

Table-2: Means values of the yield parameters by treatment in the test 1 and 2

Test	Parameters	T_0	T_1	T_2	T_3	T_4
1	Panicle length (cm)	-	26,4±0,7	28,7±0,7	27,9±0,7	26,5±0,7
	Number of grain per panicle	-	152±9,1	197±9,1	210±9,1	193±9,1
	Number of empty grain / panicle	-	18±0,6	15±0,6	9±0,6	11±0,6
	Number of panicle / pot	-	17±0,3	13±0,3	15±0,3	21±0,3
	Straw yield/ pot (t ha^{-1})	-	1,40±0,02	1,37±0,02	3,31±0,02	3,45±0,02
	Grain Yield / pot (t ha^{-1})	-	0,2±0,01	0,51±0,01	1,02±0,01	1,08±0,01
2	Panicle length (cm)	-	25,3±0,7	24,7±0,7	28,6±0,7	26,9±0,7
	Number of grain per panicle	-	148±9,2	162±9,2	198±9,2	187±9,2
	Number of empty grain / panicle	-	20±0,6	14±0,6	11±0,6	10±0,6
	Number of panicle / pot	-	19±0,3	14±0,3	16±0,3	17±0,3
	Straw yield/ pot (t ha^{-1})	-	1,20±0,02	1,44±0,02	3,60±0,02	3,42±0,02
	Grain Yield / pot (t ha^{-1})	-	0,18±0,01	0,53±0,01	0,63±0,01	1,08±0,01

Determination of the Optimal Dose of Kaolin

The characteristics of rice response to kaolin doses are shown in Tables 3 and 4 and in Figure-1. It is noted that the rice response has a highly significant linear appearance ($p < 0.0001$) with $R^2 = 0, 68$, while its quadratic shape is significant only at 0.03, for a lower value of $R^2 = 0.06$. Figure-1 illustrates this linear trend of rice response to kaolin doses. However, analysis of the surface of the response curve reveals no significant difference between yields the doses of 1391.75 kg ha^{-1} (1.054 ± 0.07 t ha^{-1}) and 1465 kg ha^{-1} (1.056 ± 0.09 t ha^{-1}). This revelation makes it possible to adjust the optimal dose to 1456.47 kg ha^{-1} as noted in Table-4.

The equation of the rice response curve for increasing doses of kaolin is as follows:

Yield = 0.98 × X (Figure-1).

The equation obtained for response of rice to kaolin doses in test 2 is Yield = 1.4 × X.

As in the first trial, a linear appearance of rice response to kaolin doses is shown (Figure-1).

Tables 3 and 4 reveal that the linear pattern of the rice response is highly significant ($p = 0.005$ and $R^2 = 0.79$) as well as the quadratic rate ($p = 0.004$) but with a low value of $R^2 = 0.06$ (Table-4).

The response curve shows no significant difference between the dose yields of 1391.75 kg ha^{-1} (1.12 ± 0.06 t ha^{-1}) and 1465 kg ha^{-1} (1.12 ± 0.07 t ha^{-1}). This makes it possible to adjust the optimum dose to 1496.99 kg ha^{-1} of kaolin as noted in Table-4.

Table-3: Characteristic of linear regression of grain yields following kaolin doses in experiment 1 and 2

	Regression	DDL	Some of square	R2	P>|r|
experiment 1	Linear	1	2,91	0,68	0,0001
	Quadratic	1	0,26	0,06	0,03
	product	0	0	0,00	-
	Total model	2	3,17	0,74	0,0001
Experiment 2	Linear	1	3,61	0,79	0,005
	Quadratic	1	0,29	0,06	0,004
	product	0	0	0,00	-
	Total model	2	3,90	0,74	0,0001

Table-4: Quadratic regression of yield in experiment 1 and 2

	Parameter	DDL	Coefficient	P>|r|
experiment 1	Constant	1	0,09	0,33
	Dose	1	0,0003	0,00002
	$Dose^2$	1	-4,55.10-7	0,03
	Critical value	0,98		
	Optimal dose (kg ha^{-1})	1456,47		
Experiment 2	Constante	1	0,05	0,47
	Dose	1	0,001	0,0001
	Dose2	1	-4,80.10-7	0,004
	Valeur critique	1,04		
	Dose optimale (kg ha^{-1})	1496,99		

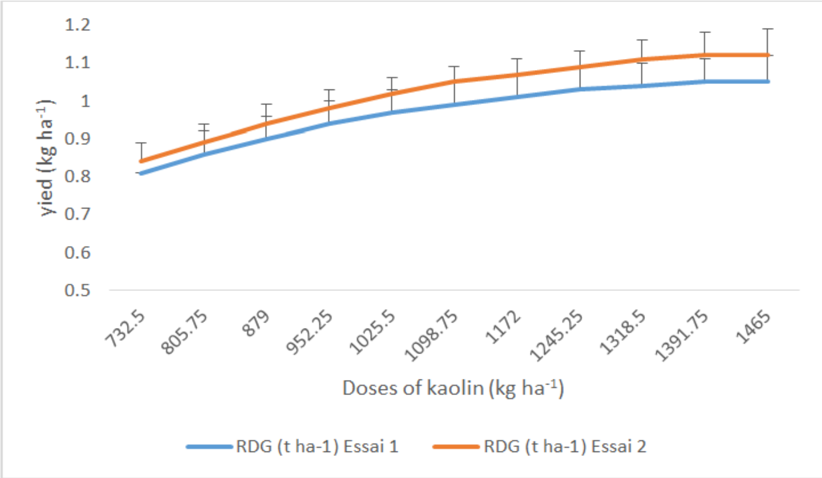

Fig-1: Regression curve of the rice response surface at increasing doses of kaolin in experiment 1 and 2

Effect of kaolin on the roots of the rice plant

Table-5 shows the colour of the root of the rice plant at 30 and 60 days after germination and the correlation of iron toxicity score with root colours chroma and value. In detail, there is a hue stability (5YR) in the treatments in absence or with kaolin. However, there is a variation in the purity (chroma) and clarity (value) of the hues. The purities observed range from 1 to 8 passing through 3 and 6. The brightness or luminance range from 5 to 8 passing through 6 and 7. On the other hand, the time did not affect the components (chroma and value) of the root colour. In addition, there is a reduction of the purity along with kaolin doses increasing resulting from darker colours in the gray and brown. We notice the yellowish red colour (5YR5 / 6) in T_4 whereas it evolves in the light in T0.

It is found that the colour of rice plant root varies with kaolin applying. From 5YR1 / 8 and 5YR8 / 6 the colours turn to 5YR8 / 7, 5YR6 / 7, 5YR3 / 8 5YR6 / 8, 30 and 60 days after sowing respectively with T_1, T_2, T_3 and T_4.

We also note that there is a strong positive correlation in the purity (chroma) of rice plant roots colour and the score of iron toxicity on the plant and leaves with R = 0.77 for a probability p <0 , 0001 for the score on the leaves.

Table-5: Effect of kaolin on rice root 30 and 60 days after sowing

Root after 30 days			
	Hue	Chroma	Value
T0	5YR	1	8
	5YR	8	6
T1	5YR	1	8
	5YR	8	7
T2	5YR	1	8
	5YR	6	7
T3	5YR	1	8
	5YR	3	8
T4	5YR	1	8
	5YR	6	5
Root after 60 days			
T0	5YR	1	8
	5YR	8	6
T1	5YR	1	8
	5YR	8	7
T2	5YR	1	8
	5YR	6	7
T3	5YR	1	8
	5YR	3	8
T4	5YR	1	8
	5YR	6	5

DISCUSSION

Potential Managing of Iron Toxicity

The results of the experiment showed that none of the pots plants that did not receive kaolin survived. While these pots received the same proportion as all other pots of the test, nitrogen, phosphorus and potassium at doses of 80, 60 and 60 kg ha^{-1} respectively (Table-2). This observation confirms the severity of iron toxicity for rice at a dose of 900 ppm Fe^{2+}, in particular, this underlines the sensitivity of WITA9. Indeed, some varieties of the TOX line can tolerate this constraint at 900 ppm of Fe^{2+} knowing that the critical threshold is 300 ppm [28]. This toxicity manifested despite the presence of nutrients (NPK) in the culture medium would explain that the action of iron would make unavailable to the rice plant nutrients essential for its development. Indeed, the symptoms of iron toxicity in rice are the result of P and K deficiency [29]. Zadi argued that K^+ cation is substituted by Fe^2 on cation exchange sites in the soil [30]. Also, the soil-reducing conditions that cause ferrous iron accumulation lead to increased nutrient requirements such as P and K needed to overcome stress [31, 32]. This deficiency resulted in wilting of the plants in the T_0 treatment pots. These results are in agreement with the observations made by Bode and collaborators [33].

The kaolin applying therefore allowed the survival of the rice plants under iron toxicity conditions. The normal development of the plant with however the symptoms of iron toxicity that are the reduction of the number of grains per panicle and grain yield, the panicle sterility was observed at 366 kg ha^{-1} of kaolin contrasting with plants from pots receiving 736, 1097 and 1465 kg ha-1 kaolin. This result is confirmed by analyzing the rice response to increasing kaolin doses from 366 kg ha^{-1} kaolin with a linear increase in rice grain yield. However, there is no significant difference between yields from 1,097 to 1465 kg ha^{-1} kaolin, hence the recommendation for the optimal dose of 1456.47 kg ha^{-1} kaolin in a controlled environment with iron content of 900 ppm for a grain yield of 1.05 t ha^{-1} or 242.43 kg Si ha^{-1}.

The applying of the optimum dose of 1456.47 kg ha^{-1} of kaolin to rice under the conditions of iron toxicity (900 ppm) allowed to obtain a grain yield of 0.98 t ha^{-1}. These results are similar to those obtained by Aboa and Dogbé [34] in their work on the effect of iron toxicity on rice yield in Togo. According to Mamadou, the application of a dose of 240 g of silica on rice under the conditions of iron toxicity makes it possible to increase p Mechanism of action of kaolin [35]. The rice plant root colour varies with the applying of increasing kaolin doses. Indeed, from 5YR 1/ 8 and 5YR8 / 6, it turn to 5YR8 / 7, 5YR6 / 7, 5YR3 / 8 5YR6 / 8 30 after sowing and this tendency was preserved until 60 days respectively with T_1, T_2, T_3 and T_4. The dark colour (gray) observed for the roots of control treatment occurs the necrosis of the root cells following wilting occurred in plants in this treatment. Therefore, the bright colours (yellow and red) observed on the roots from pots with adding kaolin testify their vitality. Indeed, the rice plant naturally develops mechanisms to control the excessive concentration of iron [36]. It inhibits the absorption of iron by its oxidation in the rhizospheric zone, which favours the passage from Fe^{2+} to Fe^{3+} in this zone, causing rust deposit on the roots under iron toxicity conditions [37, 19]. This is what Tadano described as iron exclusion on the root surface [38]. The transition from light gray to reddish yellow along with increasing doses of kaolin augurs an intensification of this mechanism during the current study. There would be an aptitude of Si to oxidize the root surface so as to provoke the reversibility of the iron. When these root barriers are breached, the plant uses mechanisms of adaptation or enzymatic inactivation of iron in plant tissues [39]. The resistance of these different barriers depends on several factors including the duration of stress. Indeed, more the stress period is long, less the barriers will resist [40]. The observation of the symptoms of iron toxicity in the T_0 treatment during this work confirms this statement. Kaolin applying inhibited the Fe^{2+} absorption by reinforcing the oxidative barrier of rice plant rhizosphere, which could be explained by the variation in the colour of the roots observed. Kaolin strengthens tolerance of rice plant to iron toxicity. The industrial silicon until there indicated as the means solution of iron toxicity problems lowland rice growing [8, 7, 9], by this result, we are able to say that kaolin is now proving to be a durable and cheaper means solution of iron toxicity which curbing lowland rice cultivation in many parts of Africa, which consequently increases deforestation. In addition to improve rice growing under iron toxicity condition, kaolin promotes the rice plant root development by the increasing rice plant root length. The action of kaolin on the roots will allow the plant to explore a large volume of soil which would positively affect its yield. Kaolin amendment against iron toxicity in lowland rice growing would be a way to fight against climate change because of the less deforestation in lowland [41].

CONCLUSION

This study revealed the ability of kaolin to inhibit the effect of iron toxicity at 900 ppm in a controlled environment. Analysis of the surface of the response curve adjusted the optimal dose of kaolin to 1456.47 kg ha^{-1} for a grain yield of 0.98 t ha^{-1}.

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