__Original Research Article__

Effect Of Kaolin On Rice Production Under Iron Toxicity Conditions: Determination Of The Effective Dose Of Kaolin Against Iron Toxicity In Irrigated Or Lowland Rice Cultivation

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ABSTRACT

In tropical areas, lowland rice cultivation with or without water control is often faced with the problem of iron toxicity. This edaphic constraint is commonly observed in the West African lowlands. It is a nutritional disorder associated with high concentrations of iron in the soil solution ([Fe^{2+}] soil > 300ppm). It can cause a drop in yield ranging from 10 to 100% depending on the concentration of iron in the soil solution and the cultivar used. To combat this constraint, fertilizers and amendments have been recommended, including industrial silicon. However, the high cost of industrial silicon limits its application by the farmers. Hence, the initiative to explore the potential of Kaolin (54.7% SiO_2) as a natural resource providing silicon. A pot test was carried out for two successive rice cultivation cycles by applying 900ppm of Fe^{2+}. Five kaolin treatments were analyzed (T0 = 0 kg kaolin ha^{-1}, T1 = 366 kg kaolin ha^{-1}, T2 = 735 kg kaolin ha^{-1}, T3 = 1097 kg kaolin ha^{-1} and T4 = 1465 kg kaolin ha^{-1}) in a complete randomized block design with 5 repetitions. The dose of 366 kg ha^{-1} was sufficient to inhibit the toxic effect of iron on the development of the rice plant. kaolin applying improved the grain yield of rice (0 tha^{-1} to 1.8 tha^{-1}). The dose of 1465 kg kaolin ha^{-1} gave the best grain yield (1.08 t ha^{-1}). The response of rice to kaolin doses was more linear (RDG = 0.98 ×Dose) than quadratic indicating 1391.75 t ha^{-1} of kaolin (1.054 ± 0.07 t ha^{-1}) as the optimal dose in the conditions of 900 ppm Fe^{2+}.

Keyword : *Kaolin, Iron toxicity, Lowland, Rice cultivation, Response curve, Côte d'Ivoire.*

1. INTRODUCTION

Rice (Oryza sativa L.) is the staple food and even the main food for more than half of the world's population [1]. In West and Central Africa, the demand for rice is one of the highest in the world (FAO, 2015). However, its production faces numerous constraints, among which iron toxicity ([Fe2+] soil>300ppm) remains among the most virulent [2]. These effects can cause a yield drop of 10 – 100% depending on the iron concentration in the soil solution and the cultivar used. To combat this constraint, fertilizers and amendments have been recommended. To this end, the potential of silicon (Si) to strengthen the tolerance of plants to biotic and abiotic stresses has been explored [3; 4]. In this recommendation, the effectiveness of silicon (Si) is shown given the oxidizing power of Si in the rhizosphere of rice [5] and its ability to reduce the effect of numerous edaphics toxicities [6;7]). However, access to industrial silicon is difficult for African farmers because of its high cost. Hence the interest in exploring other sources of silicon including kaolin. In fact, kaolin is a clay that contains up to 54.7% SiO_2. It has been mined in an artisanal way since 1960 in the south of Ivory Coast, and is only used for body painting during ceremonies or in traditional medicine, because of its therapeutic virtues. Only a small quantity is used in the paint industry [8].

In Côte d'Ivoire, the rice deficit amounts annually to 750,000 tons of milled rice [9] while good practice in the lowlands could increase yields by 50% (1.5 tha^{-1} – 4 tha^{-1}). This is why we should face the most widespread constraint which is iron toxicity in the lowlands. Audebert and Fofana [10] tested the effect of zinc fertilizers in the Korhogo lowlands as well as that Sanogo [11] in the Gagnoa lowlands. However, these results remain little adopted probably because of the high costs of these inputs. Given the recognized effectiveness of silicon (Si), the use of kaolin would be a good alternative given its rapid dissolution in water [9]. There are kaolin deposits almost everywhere in Côte d'Ivoire, including that of Bingerville in the south of Côte d'Ivoire. Bingerville kaolin (54.7% SiO_2) can serve as a natural source of silicon in rice cultivation. The oxidative power of Si in the rice rhizosphere should lead to the conversion of Fe^{2+} to Fe^{3+}. It is for this purpose this research activity was carried out to analyze the effect of kaolin on rice yield parameters and determine the optimal dose of kaolin for a better response of rice under iron toxicity conditions.

2. MATERIAL AND METHODS

2.1 Experiment site

The study took place at the Scientific Technological Innovation Center of the Félix Houphouët-Boigny University of Cocody located in the town of Bingerville at 05°21'25.6"N 03°54'11.5"W at 2 m of altitude in the south of Côte d'Ivoire during two successive rice cultivation cycles. The temperature of this site varied between 23.9 and 28.2 °C and an annual rainfall average of 2008.8 mm [12].

2.2 Experiment pot and growing substrate

The experiment was carried out in a greenhouse in plastic pots with a surface area of 706.5 cm^2 at the opening, 30 cm in upper diameter, 20 cm in lower diameter and 40 cm in height. Sand (quartz grains) colluvium by runoff was used as culture substrate. This sand was sieved in order to eliminate other elements, in particular 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 20 kg commercial scale with a 100 g graduation to fill the pots.

2.3 Plant Material

WITA 9 (WARA-IITA 9) was used as the rice variety to be tested due to its sensitivity to iron toxicity. It has a cycle of 120 days (four months), an average yield of 6 t ha^{-1} with a potential of 10 t ha^{-1}. The paddy grains of this variety are long and fine. The characteristics are presented in the table below:

Table 1: Characteristics of the WITA 9 variety

Parameters	
Height (cm)	92 cm
Tillers / m^2	205
Flowering 50 % time (day)	80 à 85
Potential yield	10 t ha^{-1}
Grain lenght	3.5 mm
Iron toxicity	sensitive
Genetic Parents	IR 2042-178-1 x CT 19

2.4 Inputs and source of iron

One hundred and thirty grams (130 g) of kaolin from the Bingerville deposit (5°20'47"N 3°52'59"W; 15 m) were dried in an oven at a temperature of 120°C for 24 hours to serve as a source of silicon. Monohydrate iron sulfate (FeSO4 H2O) was used as iron source. One hundred and twelve grams (112 g) of monohydrate iron sulfate (FeSO4 H2O) was used to create the iron toxicity condition (900 ppm/ pot). One hundred and fourteen grams (114 g) of triple super phosphate (Ca(H2PO4), 2H2O), 50g of chloride of potassium (K2OCl) and 61 g of urea ((CO(NH2)2) were used as fertilizer applied at doses of 60 kg P ha-1, 60 kg K ha-1 and 80 kg N ha-1 respectively.

2.5 Kaolin

Kaolin is a clayey, silico-aluminous rock whose characteristic mineral is kaolinite. Other secondary minerals such as quartz, micas, feldspars, titanium oxides, iron and manganese oxides and hydroxides accompany it. It is a pedological formation dominated by kaolinite which belongs to the phyllosilicate family with a 1:1 type structure, an equidistance of approximately 7Å and it is dioctahedral type. The kaolin used in this study was extracted in an artisanal quarry of 10 hectares in area with an exploitable layer of kaolin 40 m thick, located east of the town of Bingerville (5°20'47 "N; 3°52'59"W; It has a light pink color (5YR 7/3) with 61% diameter <2µm. The main oxides that compose it are SiO_2, Al_2O_3, Fe_2O_3, MgO, MnO, K2O, CaO, TiO_2 P_2O_3 and Na_2O.

Table 2: Mass percentages of the main oxides contained in Bingerville kaolin [8].

Oxides	Mass percentages
SiO_2	54.7
Al_2O_3	36.80
Fe_2O_3	5.32
MgO	0.26
MnO	0.03
K_2O	1.26
CaO	0.02
TiO_2	1.18
P_2O_3	0.10

Na_2O	0.29

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

Bingerville kaolin contains 54.7% silicate (SiO_2). However, according to sehi, [9], an average of 200 kg ha^{-1} of SiO_2 is required to treat deficiency and disease problems in rice. Based on this statement, the doses of silicon were adjusted in this study to 0 kg ha^{-1}, 200 kg ha^{-1}, 400 kg ha^{-1}, 600 kg ha^{-1} and 800 kg ha^{-1}. The pots used in our work having a surface area of 1413 cm^2, the corresponding quantities of kaolin and iron sulfate were calculated according to the following formulas:

Q kaolin = (pot surface area × dose) / conversion coefficient, the surface area being expressed in m^2 and the dose in kg ha^{-1}.

Q iron sulfate = (M iron sulfate x total dose per pot) /M iron

The quantity of iron sulfate provided to reach 900 ppm is 13.66 g. This quantity was calculated taking into account that the molar mass of iron sulfate is 170 g mol^{-1} for a molar mass of iron of 56 g mol^{-1}. 1 ppm is equivalent to 1 mg kg^{-1} so for a pot containing 5 kg of sand, you need 4500 mg of Fe for the dose of 9070

Q900ppm= (170×4500.10^{-3}) /56 = 13.66 g.

Table 3: Different doses of SiO_2 and corresponding quantities of kaolin used in the 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

test

2.7 Treatments

The pot test (5 kg of sand) involved five (5) treatments established as follows to counteract the effect of 10.66 g of iron sulfate (900 ppm Fe):

- T0 (control): 0 g of kaolin
- T1: 5.16 g of kaolin
- T2: 10.33 g of kaolin
- T3: 15.49 g of kaolin
- T4: 120.66 g of kaolin

The design used in this experiment is a completely randomized complete block consisting of five treatments with five repetitions.

2.8 Experimental device

Two pot tests were carried out consecutively using the same practices. WITA 9 rice variety which sensitive to iron toxicity was used as plant material. After drying, the sand was mixed with iron sulfate at a dose of 900 ppm, or 13.66 g of iron sulfate per 5 kg of substrate. The twenty-one (21) day old plants were transplanted into pots at the rate of one plant per pot placed in a hole dug in the center of each pot. Five kaolin treatments were carried out, namely a kaolin intake in doses of 0 g, 5.16 g, 10.33 g, 15.49 g and 20.6 6g, i.e. 0, 366, 736, 1097 and 1465 kg. kaolin ha^{-1}. Fertilizer was added as a base fertilizer per pot 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 divided into two urea contributions, i.e. 0.5 g at tillering and 0.5 g at the panicle heading stage. The fertilizer, iron sulfate and kaolin combination was carefully mixed with the sand before planting the plants. Then, all the pots were kept flooded with a water height of approximately 3 cm above the surface of the substrate until the end of the test to create an anoxic environment favorable for maintaining the iron in the form Fe^{2+}.

2.9 Data collection

At 30 days after transplanting, an iron toxicity rating was carried out. This consisted of determining the number of yellowed or browned plants, determining the average height of the plants, the number of tillers/pots, the mortality rate per treatment, the severity score of iron toxicity on the plant and the score of foliar severity according to the standard method for evaluating rice systems of the International Rice Research Institute (IRRI). Likewise, these parameters cited above were determined at heading at 75 days, at flowering at 90 days after transplanting and at maturity at 120 days. Finally, at maturity, the number of panicles, the average panicle length, the average number of full and empty grains per panicle were determined per pot. After harvest, grain yield and straw yield were determined per pot and for each treatment.

To determine the effect of kaolin on the soil and rice roots, a test set up according to the same protocol was prepared for this purpose. At 30 and 60 days after sowing, a rice plant was dug up from each pot for notations of hue (Hue), purity of hue (Chroma) and luminance of hue (Value) using of a Munsell code.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Effect of kaolin on iron toxicity parameters

Table 4 presents the average values of the iron toxicity score on the rice plant. We see that the highest iron toxicity score (9) on plants and leaves was obtained with treatments T0, while T3 and T4 have the lowest score (1). Additionally, there is a significant difference between the four treatments. Kaolin applying had a very significant effect on the iron toxicity score, both on the leaves and on the plant. There is a very significant difference between the number of browned plants and T4 has the lowest number of browned plants as well as that of empty grains per panicle. Treatments T3 and T4 had practically the same effect on the parameters considered. Kaolin applying had a very significant effect on the number of browned plants and the number of empty grains per panicle.

Table 4: Average values of iron toxicity parameters measured

	Plant score	Score sheet	Browned	Yellow	Nber of Gr.V/pani
T_0	9a	9a	-	-	-
T_1	5b	5b	11a	1a	13a
T_2	3c	3c	9a	0,9a	15a
T_3	1d	1d	3b	0,1a	13a
T_4	1d	1d	1b	0a	11a
ppds.05	0	0	-	-	3,02
MG	3.60	3.60	6.07	0,48	16.79
CV (%)	0	0	44.46	198.63	13
P>F	<0.0001	<0.0001	<0.0001	0.08	0.16

Browned. = Browning, Juni.: Yellowing Nber: Number, Gr. V: Empty grain, Pani: Panicle MG: general average, CV: coefficient of variation, P: probability NB: The averages of a column followed by the same letter are not statistically different by the Newmann-Keuls test at the 5% threshold

3.1.2 Effect of treatments on agronomic parameters

Table 5: Average values of yield parameters by treatment in trials 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 grains per panicle	-	152±9.1	197±9.1	210±9.1	193±9.1
	Number of empty grains / panicles	-	18±0.6	15±0.6	9±0.6	11±0.6
	Number of panicles/pots	-	17±0.3	13±0.3	15±0.3	21±0.3
	Straw/pot yield (t ha-1)	-	1.40±0.02	1.37±0.02	3.31±0.02	3.45±0.02
	Grain/pot yield (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 grains per panicle	-	148±9.2	162±9.2	198±9.2	187±9.2
	Number of empty grains / panicles	-	20±0.6	14±0.6	11±0.6	10±0.6
	Number of panicles/pots	-	19±0.3	14±0.3	16±0.3	17±0.3
	Straw/pot yield (t ha-1)	-	1.20±0,02	1.44±0.02	3.60±0.02	3.42±0.02
	Grain/pot yield (t ha-1)	-	0.18±0.01	0.53±0.01	0.63±0.01	1.08±0.01

-: *undetermined; ±: standard deviation*

The results recorded in Table 5 present the average values of the yield parameters by treatment. Analysis of the results shows that panicle length remains practically identical for all treatments. However, the number of grains per panicle varies. The highest number of grains (210 grains) was obtained in the T3 treatment compared to a higher number of empty grains (18 - 20 grains) in the T1 treatment. The grain yield of 1.08 t ha^{-1} was obtained with treatment T4 in tests 1 and 2.

Table 6: Average values of agronomic parameters

	Nber. Grain /pan.	Nber. Empty grain /Pan.	Grain yield (tha^{-1})	Straw yield (tha^{-1})
T0	138a	14b	1.26a	4.62a
T1	144a	13b	1.26a	4.61a

T2	153ab	13b	2.44ab	5.33a
T3	179b	11b	4.67b	8.28b
T4	176b	9a	4.70b	8.43b
CV (%)	11.08	20.18	24.68	12.65
MG	89.02	12	3.58	6.25
ppds.05	**0.005**	**0.0004**	**0.001**	**<0.0001**

Nber: Number; Pan.: panicle, MG: General average

3.1.3 Determination of the optimal dose of kaolin

3.1.3.1 Kaolin dose response curve

Table 7: Characteristic of the linear regression of grain yields following the doses of kaolin

	Regression	**DDL**	**Sum of squares**	**R^2**	**P>|r|**
TEST 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
TEST 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

DOF: degree of freedom; R2: coefficient of determination; P: probability

Table 8: Quadratic regression of yield in trial 1

	Parameters	**DOF**	**Coefficient**	**P>|r|**
Test1	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 (unit)		1456,47	
Test 2	Constant	1	0,05	0,47
	Dose	1	0,001	0,0001
	$Dose^2$	1	$-4,80.10^{-7}$	0,004
	Critical value		1,04	
	Optimal dose (unit)		1496,99	

The characteristics of the response of rice to doses of kaolin are represented in Tables 7 and 8 and in Figure 1. We note that the response of rice has a highly significant linear appearance ($p < 0.0001$) with R^2 = 0, 68, while its quadratic appearance is only significant at 0.03, for a lower value of R^2 = 0.06. Figure 2 illustrates this linear trend in the response of rice to kaolin doses. However, the analysis of the surface of the response curve reveals the absence of significant difference between the yields of 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 VI.

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

Y = 0.98×X.

The equation obtained for the response of rice to doses of kaolin in trial 2 is Y = 1.4×X.

As in the first test, we note a linear pattern in the response of rice to doses of kaolin (Figure 1).

Tables 7 and 8 reveal that the linear pattern of the rice response is highly significant (p = 0.005 and R2=0.79) as is the quadratic pattern (p=0.004) but with a low value of R2= 0.06 (Table 7). The response curve shows the absence of significant difference between the yields of doses 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 optimal dose to 1496.99 kg ha-1 of kaolin as noted in Table 8.

3.1.3.2 Effect of kaolin on the roots of the rice plant

Table 9 shows the root color of the rice plant at 30 and 60 days after germination. In detail, we note a stability of the color (5YR) in the treatments in absence or with kaolin. However, there is a variation in the purity (Chroma) and clarity (Value) of the shades. The purities observed range from 1 to 8 passing through 3 and 6. The clarity or luminances range from 5 to 8 passing through 6 and 7. On the other hand, the pendant did not affect the components (C, V) of the color of the roots. Additionally, there is a reduction in purity with increasing doses of kaolin resulting in darker colors in gray and brown. We notice the yellowish red color (5YR5/6) in T4 while it evolves into light in T0. We see that the color of the root of the rice plant varies with the addition of kaolin. From 5YR1/8 and 5YR8/6 increased to 5YR8/7, 5YR6/7, 5YR3/8 5YR6/8 after 30 and 60 days of sowing respectively with T1, T2, T3 and T4

Table 9: Effect of kaolin on the 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

T0 =0 kg kaolin.ha^{-1}, T1= 366 kg kaolin.ha^{-1}, T2= 735 kg kaolin.ha^{-1}, T3= 1097 kg kaolin.ha^{-1}, T4= 1465 kg kaolin.ha^{-1}

3.2 DISCUSSION

3.2.1 Potential for Toxicity Management

The results of the experiment showed that none of the plants in the pots that had not received the kaolin survived. While these pots received, in the same way as all the other pots in the test, nitrogen, phosphorus and potassium at respective doses of 80, 60 and 60 kg ha^{-1} (Table 4). This observation attests to the severity of iron toxicity for rice at a dose of 900 ppm of Fe^{2+}, in particular, it underlines the sensitivity of WITA 9. Indeed, certain varieties of the TOX lineage can tolerate this constraint at 900 ppm of Fe^{2+} knowing that the critical threshold is 300 ppm [13]. This toxicity manifested despite the presence of nutrients (NPK) in the culture medium would explain that the action of iron would be to make the nutrients essential for its development unavailable to the rice plant. Indeed, the symptoms of iron toxicity in rice are the result of a deficiency of P and K [14]. Zadi [15] argued that Fe^{2+} substitutes for K+ at soil cation exchange sites. Also, reduced soil conditions that cause ferrous iron accumulation result in increased requirements for nutrients such as P and K needed to overcome stress [16, 17]. This deficiency led to the wilting of plants in the T0 treatment pots, in agreement with the observations made by Bode [18].

kaolin applying therefore allowed the survival of rice plants in conditions of 100% loss. Normal development of the plant, however with the symptoms of iron toxicity which are: reduction in the number of grains per panicle and grain yield. Panicle sterility was observed at 366 kg ha^{-1} of kaolin, contrasting with the plants from pots having received doses of 736, 1097 and 1465 kg ha^{-1} of kaolin. This result is confirmed by the analysis of the response of rice to increasing doses of kaolin from 366 kg ha^{-1} of kaolin with a linear increase in rice grain yield. However, there is no significant difference between the yields from doses of 1097 and 1465 kg ha^{-1} of kaolin, hence the recommendation of the optimal dose of 1456.47 kg ha^{-1} of kaolin in a controlled environment with an iron content of 900 ppm for a grain yield of 1.05 t ha^{-1}. The application of the optimal dose of 1456.47 kg ha^{-1} of kaolin on rice under iron toxicity conditions (900 ppm) made it possible to obtain a grain yield of 0.98 t ha^{-1}. These results are similar to those obtained by Aboa and Dogbé [19] in their work on the effect of iron toxicity on rice yield in Togo. According to Mamadou applying a dose of 240 g of silica to rice under iron toxicity conditions makes it possible to increase production [20].

3.2.2 Kaolin action mechanism

The color of the root of the rice plant varies with the addition of kaolin. Indeed, from 5YR1/8 and 5YR8/6, it went to 5YR8/7, 5YR6/7, 5YR3/8 5YR6/8 after 30 days and this trend was preserved up to 60 days after germination respectively in the treatments T1, T2, T3 and T4. The dark color (gray) observed for the roots of the control treatment indicates necrosis of the root cells following the wilting that occurred to the plants in this treatment. Consequently, the bright colors (yellow and red) observed on the roots from pots with added kaolin testify to their vitality. Indeed, the rice plant can naturally develop mechanisms to cope with excessive iron concentration [9]. It inhibits the absorption of iron through its oxidation in the rhizospheric zone, which promotes the transition from Fe^{2+} to $Fe3^{+}$ in this zone, causing rust deposition on the roots in conditions of iron toxicity [21, 15]. This is what Sehi [9] described as exclusion of iron from the root surface. The change from light gray to reddish yellow in parallel with increasing doses of kaolin augurs an intensification of this mechanism during the current study. There would be an ability of Si to oxidize the root surface so as to cause the reversibility of the iron. When these root barriers are overcome, the plant resorts to mechanisms of adaptation or enzymatic inactivation of iron in plant tissues [22].

The resistance of these different barriers depends on several factors, notably the duration of the stress. Indeed, the longer the duration of stress, the less these barriers will resist [23]. The observation of the symptoms of iron toxicity in the T0 treatment during this work confirms this assertion. The addition of kaolin inhibited the absorption of Fe^{2+} by strengthening the oxidative barrier of the rhizosphere of the rice plant, which could explain the variation in the color of the roots observed. Kaolin strengthens the rice plant's tolerance to iron toxicity. Chemical silicon, previously indicated as a method to control stress and toxicity problems in plants, particularly in rice plants [24, 9]), through this result, we are able to affirm that kaolin is now revealed as a control method of lasting and low-cost resolution of toxicity. iron which slows down lowland rice cultivation in several regions of Africa and which therefore accentuates deforestation.

In addition to solving the problem of toxicity in rice, kaolin promotes the root development of the rice plant which is manifested by the increase in 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. The adoption of kaolin to resolve the problem of iron toxicity in the lowlands would contribute to the fight against climate change because rice growing in the lowlands allows the preservation of the forest.

4.CONCLUSION

This study revealed the ability of kaolin to inhibit the effect of iron toxicity under conditions of 900 ppm in a controlled environment. Analysis of the surface of the response curve makes it possible to adjust the optimal dose to 1456.47 kg of kaolin ha^{-1} to obtain a grain yield of 0.98 t ha^{-1}.

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