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Improvement of Rice Plant Root by Kaolin Application in Iron Toxicity Condition at Zoukougbeu (Central-West of Côte d'Ivoire)

Sehi Zokagon Sylvain[1,2*], Konan Kouassi Urbain[3], Adechina Olayossimi[3], Ouattara Amidou[3], Kouamé Firmin[4], Bongoua Jeanne Devisme[5], Cherif Mamadou[6], Brahima Koné[5]

[1]Département des Sciences et Techniques, Université Alassane Ouattara, Bouaké, Côte d'Ivoire
[2]Centre d'Excellence Africain sur le Changement Climatique, la Bidiversité et l'Agriculture Durable,Université Félix Houphouet Boigny, Abidjan, Côte d'Ivoire
[3]Département Agriculture et Technologie Nouvelle, Université de San-Pedro, San-Pedro, Côte d'Ivoire
[4]Unité de Formation et de Recherche en Agroforesterie, Département des Sciences de la Terre, Université Jean Lorougnon Guédé de Daloa, Daloa, Côte d'Ivoire
[5]Département de Physiologie Végétale, Université Felix Houphouet Boigny, Abidjan, Côte d'Ivoire
[6]Dépatartement des Sciences du sol, Université Felix Houphouet Boigny, Abidjan, Côte d'Ivoire
Email: *sehisylvain_nung@yahoo.fr

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Abstract

In the tropics, lowland rice cultivation is often confronted with the problem of iron toxicity. The solution proposed by research in general is the use of industrial silicon. However, the high cost of industrial silicon limits its adoption by farmers. A study was carried out in Zakogbeu; Center-West of Côte d'Ivoire, to assess the potential of kaolin to mitigate the effect of this soil constraint on the root of the rice plant. Five kaolin-based treatments were analyzed (T_0 = 0 kg kaolin ha^{-1}, T_1 = 366 kg kaolin ha^{-1}, T_2 = 736 kg kaolin ha^{-1}, T_3 = 1097 kg kaolin ha^{-1} and T_4 = 1465 kg kaolin ha^{-1} are 0, 200, 400, 600 and 800 kg SiO_2 ha^{-1}) in a device in complete random blocks, with 5 repetitions. The results obtained show that kaolin supply increases the length of the root tissue as well as the number of branching of the root of the rice plant. Root tissue increased from 10 cm with T_0 treatment to more than 15 cm with treatment T_4. The microscopic observation of the roots shows that in the treatment T_0, the roots present only primary ramifications and the tertiary and quaternary ramifications are observed with the treatments T_3 and T_4. The contribution of kaolin is an alternative to inhibit the effect of iron toxicity on the rice plant root development in iron toxicity condition.

Keywords

Iron Toxicity, Kaolin, Root, Rice, Cote d'Ivoire

1. Introduction

Rice (Oryza sativa L.) is among the oldest plants cultivated in a very large cultivation area, extending between latitudes 45˚ North and South [1]. It constitutes the basic food or even the main food of more than half of the world's population; its culture contributes to sustainable development [2]. In West and Central Africa, demand for rice was 9.9 million tonnes in 2006, well above production. In Ivory Coast, rice has also become the main staple of the population. However, its production struggles to meet this local requirement [3] [4] because of numerous constraints of cropping. Among those constraints diagnosed [5] [6] there is iron toxicity [7] [8] which can reduce yields by 10% - 100% in lowlands [9]. However, it is this agro ecology that offers a great chance of self-sufficiency in rice [10]. This abiotic constraint occurs in more than 60% of the lowlands of West Africa [11] [12]. Variety screening studies in the hot spot Korhogo salient point (savannah) in northern Côte d'Ivoire are taking place as well as testing of agronomic practices that can increase the tolerance of varieties to iron toxicity [13] [14]. But the effectiveness of the recommendations made was unreliable with seasonal variabilities, including those linked to sites [15]. As observed elsewhere [16] [17] [18] with the exception of drainage [19] whose major effect is the reversibility of Fe^{2+} to Fe^{3+}. However, the yield of lowland rice is very dependent on the quantity and duration of water submersion [20]. Hence the need to develop a strategy for the oxidation of ferrous iron in flooded conditions in rice-growing lowlands susceptible to iron toxicity. To this end, the potential of silicon (Si) to reinforce the tolerance of plants to biotic and abiotic stresses [21] [22] [23] is rightly of concern given the oxidizing power of Si in the rice rhizosphere [24]. Silicon is known for its ability to reduce the effect of numerous toxicities of edaphic origin [25] [26]. Faced with such evidence, it is access to commercial silicon that remains an obstacle to the adoption of this technology due to the high cost and availability on the local market. Hence, the need for a less expensive alternative source. This is why the current study aims to explore the potential of kaolin (54.7% SiO_2) as a natural source of silicon in rice cultivation.

2. Material and Methods

2.1. Material

2.1.1. Experiment Site

The study takes place in the central west of Côte d'Ivoire, in the village of Zakogbeu located at 06˚46'57.8"N; 06˚48'58.6"W; 227 m. the climate of this zone is transitional equatorial type characterized by an alternation of two (2) rainy seasons with two (2) dry seasons. The first rainy season is from March to mid-July, and the second from August to mid-November. The first dry season, also called the long dry season, is between mid-November and the end of February. The second, shorter dry season is sometimes similar to a simple slowdown in rains between mid-July and mid-August in certain localities [27]. Annual rainfall is generally between 1100 mm and 1400 mm, for an average temperature oscillating between 19˚C and 33˚C. Ferralsols type soils are deep and fertile [28]. The lowland that was the subject of our study is located 200 m east of the village of Zakogbeu [29].

2.1.2. Vegetal Material

WITA 9 (WARA-IITA 9) resulting from the genetic cross between varieties IR2042-178 and CT19 was used as the rice variety to be tested due to its sensitivity to iron toxicity. It has a cycle of 120 days, an average yield of 6 $t \cdot ha^{-1}$ with a potential of 10 $t \cdot ha^{-1}$. The average plant height is 92 cm with an average of 205 tillers per square meter.

2.1.3. Kaolin from Bingerville

Kaolin is a kaolinite-type clay rock, silico-aluminous with secondary minerals such as quartz, micas, feldspars, titanium oxides, iron and manganese oxides and hydroxides (Pouliquen, 2014). It is a pedological formation as a product of clayey alteration belonging to the family of phyllosilicates with a structure of type 1:1, an equidistance of approximately 7Å and it is of dioctahedral type. Bingerville kaolin extracted in an artisanal quarry (5˚20'47"N 3˚52'59"W 15 m), of 10 hectares in area with an exploitable layer of kaolin 40 m thick was used during this study. It has a light pink color (7.5 YR8/7) with 61% fine fraction (diameter < 2 µm). The main oxides that compose it are SiO_2, Al_2O_3, Fe_2O_3, MgO, MnO, K_2O, CaO, TiO_2 P_2O_3 and Na_2O (**Table 1**).

2.2. Method

2.2.1. Root Sampling and Determining of Root Biomass

After harvest, ten roots (10 pockets) were harvested from the center of each unit plot. Then the roots were washed in canal water to remove mud and then dried

Table 1. Mass percentages of the main oxides contained in Bingerville kaolin [29].

Oxides	Mass Pourcentages (%)
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

in the sun for 72 hours. These roots were analyzed in the laboratory to determine their morphology and biomass.

The biomass of each root was weighed (Pt) according to the test treatments. Another weighted weighing (P50) was carried out in the same way, by choosing randomly 50 roots at random, for a second weighing, for each of the treatments.

Then, using a ruler, the average length and width of the ten root per treatment were determined.

In addition, the mass of ten (10) roots long of 10 cm and the root density were determined for each treatment.

2.2.2. Observation of Root Morphology

For the observation of root morphology, ten (10) roots long of 10 cm were taken from the root taken in each treatment. These ten roots were observed under an optical microscope, at a magnification of 1000×, to determine the different types of branching as well as the number of branching for each type per treatment. The observation was made using a LEICA type microscope. A camera incorporated into the microscope allowed images of the elements observed to be taken.

A reliability analysis was carried out to study the occurrence of soil nutrients on the iron toxicity score with the Statistic software.

3. Results and Discussion

3.1. Macroscopic Observations

The observation of the different lengths of the root tissues obtained following the kaolin treatment shows a clear variation in them (**Figure 1**). Indeed, the lengths of the root tissues change with the increase in the doses of kaolin. We see that the length of the root tissue obtained with treatment T_0 is short (8 - 10 cm) while that of treatment T_1 is (10 - 12 cm). The length of the root tissue of treatment T_2 is greater than the previous ones (12 - 14 cm) and treatment T_3 has a length of root tissue greater than those already mentioned (14 - 15 cm). The most pronounced root tissue length is that of treatment T_4, which displays a length greater than 15 cm.

The addition of kaolin improves the development of the rice rhizosphere. The

Figure 1. Length of root tissues of the rice plant according to different doses of kaolin.

doses 1097 kg kaolin ha^{-1} (T_3) and 1465 kg kaolin ha^{-1} (T_4) of kaolin allowed the development of the length of the root tissue of the rice plant under iron toxicity conditions.

3.2. Microscopic Observations

The results of microscopic observation of the roots (**Figure 2**) show that the addition of kaolin increases the number of root branches of the rice plant. A single branching is observed with the control treatment T_0 (0 kg kaolin ha^{-1}), and up to five branches with the treatments T_3 (1097 kg kaolin ha^{-1}) and T_4 (1465 kg kaolin ha^{-1}). We see at the level of treatment T_0, in addition to the main root, we only have secondary roots. The roots resulting from the T_1 treatment present tertiary branching in addition to primary and secondary roots. Likewise, at the level of treatment T_2 we also observe the tertiary roots, but, at this level, we have a high number of tertiary roots unlike the treatment T_1. For treatment T_3, there is an appearance of quaternary roots, as in treatment T_4, but with a greater number of quaternary roots.

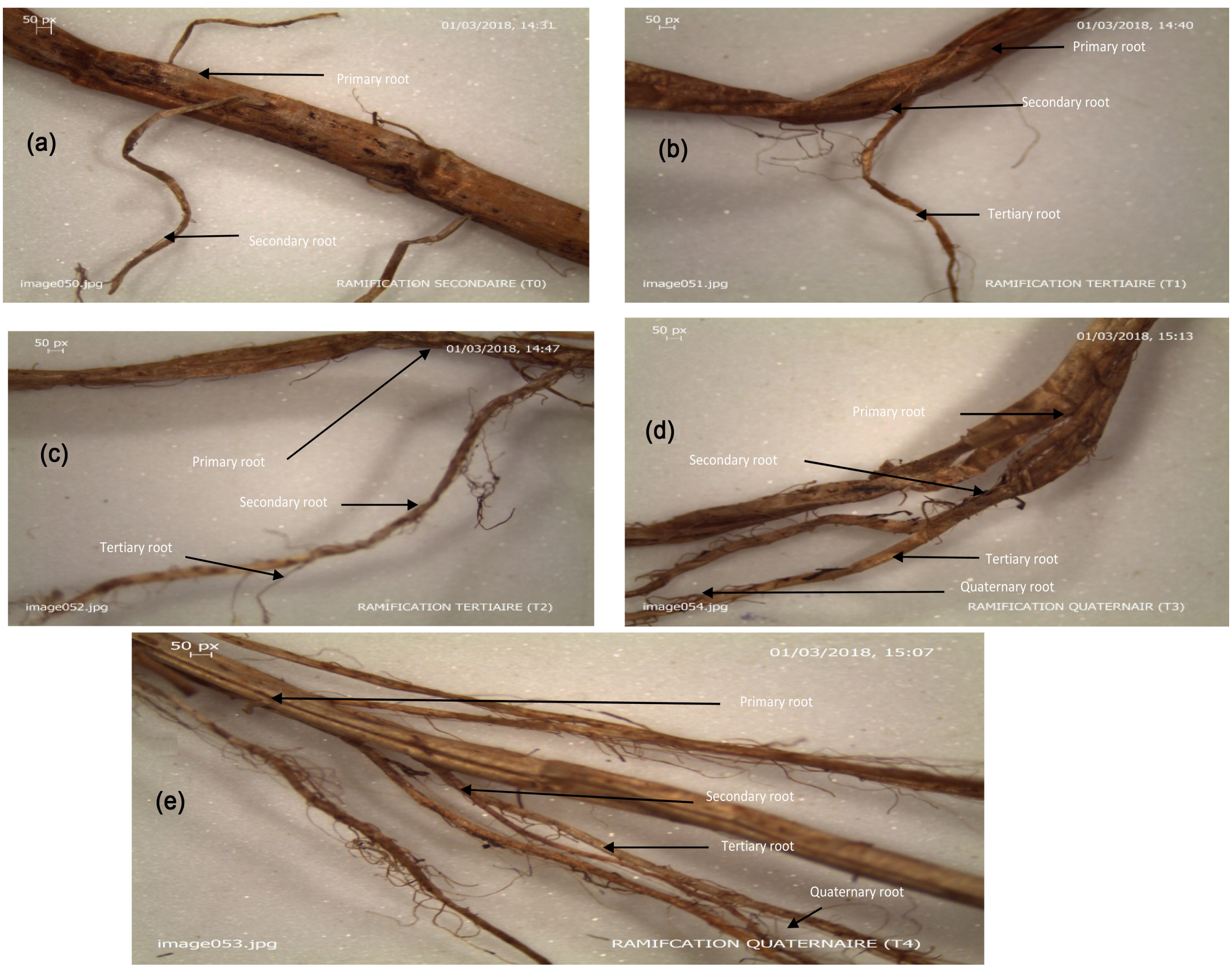

Figure 2. Effect of different treatments T_0 (a), T_1 (b), T_2 (c), T_3 (d) T_4 (e) on the root system of the rice plant.

3.3. Relationship between Treatments and Root Parameters

Table 2 presents the average values of the root parameters measured on ten roots. These are the mass of 10 roots of 10 cm, the root density, the mass of 10 roots fabrics and the number of root branches. The effects of the treatments are very highly significant ($p < 0.0001$) on the root parameters considered. Indeed, the smallest average values are obtained with the T_0 treatment, and these values increase following increasing doses of kaolin. We note an average root length of 16.18 cm under treatment T_0, this value evolves increasingly to reach the value of 20.58 cm with treatment T_4, an increase of 4.4 cm compared to T_0. Likewise, root density increased from 0.04 g/cm^3 with treatment T_0 to 0.08 g/cm^3 with treatment T_4 with a probability $p < 0.0001$. The trends remained identical at the level of the other parameters measured. It emerges from this analysis that respectively 1097 and 1465 kg kaolin ha^{-1} T_3 and T_4 stand out from the other treatments by the high average values of the root parameters.

3.4. Relationship between Iron Toxicity Score and Root Parameters

Table 3 presents the correlation between the root parameters and the iron toxicity score on the leaves of the plant in each treatment. Analysis of the table shows that the length and width of the root tissues are perfectly correlated ($R = -0.86$ and $R = -0.68$) with the iron toxicity score in T_3 and T_4, with a respective probability, $p = 0.02$ and $p = 0.02$. The treatments had a significant effect on the root length and width of rice plants. Root density is strongly correlated with the iron toxicity score on the leaf $R = -0.95$ and $p < 0.0001$. The addition of kaolin had a very significant positive effect on root density.

Table 4 presents the reliable soil parameters for the description of the root length of the rice plant under iron toxicity condition. We note that the reliable soil parameters for the description of root length are Ca, Mg, Fe, Zn, Si, pHeau

Table 2. Average values of root parameters following treatments.

	Roots parameters					
	Width (cm)	Length (cm)	Number of ramifications	Mass (g)		Root density (g/cm^3)
				Root	10 roots of 10 cm	
T_0	3.64a	16.18a	2a	101.74a	0.057a	0.04a
T_1	3.72a	16.68b	2a	112.51a	0.064a	0.05ab
T_2	4.20a	17.47c	2a	126.02a	0.072ab	0.06b
T_3	4.24a	19.57d	3b	192.25b	0.088b	0.07c
T_4	4.29a	20.58e	4c	198.51b	0.109c	0.08d
CV (%)	15.57	9.53	40.61	34.92	30.16	21.29
MG	4.02	18.10	2.50	146.20	0.078	0.06
P > F	0.03	<0.0001	<0.0001	<0.0001	0.5849	<0.0001

Table 3. Relationships between root parameters and leaf symptom score, iron toxicity of rice in treatments, T_2, T_3 and T_4 at maturity.

	Iron toxicity score					
	T_2		T_3		T_4	
	R	P > |r|	R	P > |r|	R	P > |r|
Average width of 10 roots	-	-	**−0.86**	**0.02**	**−0.68**	**0.02**
Average length of 10 roots	-	-	**−0.78**	**0.01**	0.30	0.38
Mass of 10 roots	-	-	0.28	0.46	**−0.95**	**<0.0001**
Root density	-	-	−0.29	0.44	−0.55	0.09
Mass of 10 roots	-	-	−0.32	0.38	−0.27	0.43
Number of root ramification	-	-	-	-	-	-
Iron toxicity score on the plante	-	-	**0.91**	**<0.0001**	**0.91**	**<0.0001**

- : Note determinated.

Table 4. Determination of reliable soil parameters for description of rice plant root length.

	Analysis 1		Analysis 2		Analysis 3		Analysis 4		Analysis 5	
	Root length									
	Cor with total	Alpha	Cor with total	Alpha	Cor with total	Alpha	Cor with total	Alpha	Cor with total	Alpha
N	−0.19	0.15								
C	−0.37	0.23								
MO	−0.12	0.11	−0.43	0.55	−0.60	0.79				
P	0.12	−0.02	−0.004	0.42						
K	−0.52	0.30	−0.48	0.56	−0.32	0.74	−0.10	0.90	−0.10	0.87
Na	0.33	−0.15	0.31	0.31	0.09	0.65				
Ca	0.76	−0.46	0.84	0.09	0.74	0.49	0.58	0.80	0.56	0.71
Mg	−0.12	0.11	0.34	0.30	0.58	0.54	0.70	0.78	0.67	0.68
Fe	0.20	−0.06	0.60	0.20	0.87	0.45	0.89	0.75	0.82	0.64
Al	0.07	0.009	−0.12	0.45						
Zn	0.04	0.02	0.45	0.26	0.75	0.49	0.80	0.76		
Si	0.58	−0.32	0.75	0.13	0.81	0.47	0.76	0.77	0.77	0.66
pH_{eau}	0.05	0.08	0.31	0.31			0.52	0.81	0.48	0.73
Ev (mV)	−0.15	0.13	−0.35	0.52	0.76	0.23	0.87	0.50	0.80	0.47
Alpha	**0.04**		**0.40**		**0.63**		**0.82**		**0.76**	

and Ev with a value of apha = 0.82 at the level of analysis 4. This is justified by the fact that the deletion of one of these parameters leads to the reduction of the value of apha to 0.76. There is a stronger contribution from K (α = 0.90) with, however, a weak correlation (−0.10) with the other parameters, although weak.

With the exception of pH (0.53; 0.81), the other reliability parameters have the same orders of magnitude.

4. Discussion

In the absence of kaolin, the rice root development was limited to the primary ramification and increased to the quaternary branches, in parallel with the increasing doses of kaolin, and this, in accordance with the assertions of [29]. Given the activating role of P in root growth [30], the addition of kaolin would not only have stimulated the appearance of new roots, but also the absorption of phosphorus, despite the oxidation of iron in deposit on the oldest roots.

The analysis of variance of the weight of the root tissues, of 10 roots of 10 cm, and of the root density shows that there is a significant difference between the treatments. Treatments T_3 and T_4 gave weights higher than the general average obtained at the level of each parameter. This increase in the weight of the different parts of the roots could be explained by the rust deposit observed on the roots, which would be due to the oxidation of iron on the roots. Indeed, the work of Sehi and collaborators and Sehi showed that the rice plant naturally develops mechanisms to cope with excessive iron concentration [10] [29]. According to Sehi, the rice plant inhibits the absorption of iron through the oxidation of the rhizosphere, which promotes the passage from Fe^{2+} to Fe^{3+} in the rhizospheric zone, hence the rust deposition on the roots under conditions of iron toxicity [29]. Bongoua, maintains that the plant develops an iron exclusion system on the root surface [31]. When these root barriers are crossed, the plant resorts to mechanisms of adaptation or enzymatic inactivation of iron in plant tissues [32]. The resistance of these different barriers depends on several factors, in particular, the duration of the stress. Indeed, longer the duration of stress is, less the resistant these barriers will be [33]. The observation of the symptoms of iron toxicity in the T_0 treatment during this work confirms such an assertion. The addition of kaolin inhibited the absorption of Fe^{2+} by strengthening the oxidative barrier of the rhizosphere of the rice plant. Kaolin enhances the rice plant's tolerance to iron toxicity.

Chemical silicon, hitherto indicated as a way of resolving stress and toxicity problems in plants, particularly in rice plants [21] [22] [25] [34], through this result, we are able to affirm that kaolin is now proving to be a way of sustainable and low-cost resolution of iron toxicity, which slows down rice cultivation in the lowlands in several regions of Africa, and which, consequently, 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 larger volume of soil, which improves 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. Despite all the possible criticisms, we will inevitably remember that the root parameters displayed a greater reliability (α = 0.82) of the expression of iron toxicity than the visual symptoms of scoring (α = 0.76). The silicon (Si) provided by Kaolin has one of the highest alpha values (α = 0.77) after those of Ev, pH and Mg.

5. Conclusion

Iron toxicity is an abiotic constraint that affects the rice plant agronomic parameters such as roots. This study focused on reducing the effect of iron toxicity on the development of the roots of the rice plant by adding successive doses of kaolin. The results show that the addition of kaolin promotes the development of the roots of the rice plant by increasing the number of root ramification and the length of the roots.

Conflicts of Interest

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

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