Excessive iron uptake (iron toxicity) by wetland rice (Oryza Sativa L.) on an acid sulphate soil in the Casamance/Senegal

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L'effet de la fertilisation (N, N+P, N+K, N+P+K, N+Ca) sur l'absorption d'éléments nutritifs (analyse des feuilles) ainsi que l'effet de la toxicité ferreuse sur le développement du pH, du Eh et du Fe(II) dans la rhizosphère, ont été évalués pendant toute la durée du cycle végétatif.

Le site expérimental, de même que d'autres rizières où l'on avait relevé des graves symptômes de toxicité ferreuse, ont été caractérisés du point de vue physico-chimique.

Dans le cas du témoin non traité, deux périodes de pointe ont été observées dans

lem. Based on physico-chemical analyses of various iron-toxic soils (Ottow et al. 1982; Ottow et al. 1983) and pot experiments (Benckiser et al. 1984) iron toxicity was explained by a multiple nutrient stress in which deficiencies of P, K and other elements (Ca, Zn?) were considered to trigger the breakdown of the root oxidizing capacity by an increased exudation resulting in high iron influx. This hypothesis was tested in a field experiment on a typical acid sulphate soil in the Casamance.

3 Material and methods

3.1 Characterization of soils

Amongst the sites under rice cultivation in the Basse Casamance various soils were sampled and characterized physico-chemically (Schlichting und Blume 1966). Profiles which showed net jarosite mottling at less than 50 cm depth or residual sulfidic material at less than 100 cm depth were considered to be acid sulphate soils. Their properties (0-20 cm layer) are listed in Table 1.

Table 1. Analytical parameters (0-20) of rice soils derived from acid sulfate soils

Soil	pH H_2O/KCl	mS/cm 1/2,5	$P_{av.}$ ppm	CEC*	K	Na	Ca	Mg	Fe	Al	Fe-toxicity**
				meq/100g at pH pH 8,1							
L.O	3,8/3,6	3,2***	3,7	11,6	0,13	0,76	1,16	0,99	0,80	0,45	+++
E 6	4,2/3,7	0,29	9,9	11,5	0,05	0,11	2,35	0,19	0,93	0,73	++
1	3,4/3,3	1,9	83,6	8,1	0,03	0,08	0,35	0,13	0,70	0,59	+++
3	3,4/3,3	0,75	52,0	7,4	0,03	0,40	0,31	0,25	0,92	1,14	+++
4	3,7/3,6	0,5	6,2	10,1	0,01	0,05	0,20	0,31	0,50	2,13	+++
6	3,2/3,2	3,6***	n.d.	10,0	0,03	0,49	0,26	0,17	1,38	1,07	+++
7	4,1/3,8	1,9***	1,5	19,0	0,16	1,57	2,52	2,27	1,75	1,09	+
9	5,0/4,8	0,77	n.d.	28,0	0,06	0,41	16,25	2,33	1,54	0,51	++
15	3,7/3,5	0,55	2,5	9,1	0,03	0,19	0,68	0,30	1,12	1,37	++
KA 2	3,7/3,6	0,63	n.d.	9,2	0,03	0,27	0,42	0,20	0,39	1,85	+++
KA 5	4,3/3,9	1,65***	2,1	11,2	0,39	2,36	1,23	0,90	0,25	n.d.	+
DD 3	3,4/3,3	0,89	6,5	9,8	0,03	0,09	0,83	0,18	1,24	1.68	++
DD 4	3,3/3,3	0,66	n.d.	7,9	n.d.	0,46	0,68	0,08	1,34	2,32	+

* CEC in saline soils after desalination
** Iron-toxicity symptoms: + leaf symptoms, ++ beginning mortality, +++ severe mortality
*** Dry season values,
$P_{av.}$: available P extracted with 0.5m $NaHCO_3$ (Olsen)

– +N+P, – +N+K, – +N+P+K, – +N+Ca and – +N with P+K application only in the nursery) in 5 replications were randomized and arranged in blocs. Plot size was 5 × 4 m with 27 seedlings/m² planted on small levees according to the system of the local Diola farmers.

All plots received N (11.25 g N/m² as urea) and Zn (0.23 g/m² as $ZnSO^4$) while P (6.75 g P/m² as ammonium phosphate), K (15 g/m² as KCl) and Ca (7 g/m₂ as $CaCl_2$) were only given in the corresponding plots. Fertilization was splitted: 2/3 were applied before transplanting and 1/3 at maximum tillering. The seedling nurseries received 8 g N/m² or 8g N + 8g P + 22g K/m², respectively.

Three or five weeks old seedlings (R8) were transplanted 1 or 21 days after flooding. The experimental site was guarded by the farmer's wife to chase away the birds.

3.3 Measurements

From transplanting to harvesting pH and Eh in situ as well as the concentration of Fe(II) in the soil solution (= Fe(II)-sol) were measured periodically in each plot. At the same time samples of leaves (2nd and 3rd leaf from top) were taken and analyzed afterwards.

For electrochemical measurements (WTW pH meter 191, with Ingold combined pH-Eh-electrode Pt 405-85) undisturbed soil columns (0-50 cm) were sampled with handaugers (Eijkelkamp, ∅ 7 cm) and pH- and redox values recorded in the 0-10 cm, 10-20 cm and 40-50 cm layers of each plot. The results obtained are averages of three to four measurements per layer and were related to the standard hydrogen electrode by addition of 208 mV (30 °C).

For measurement of F(II)-sol a soil/soil-solution mixture was aspired by means of a plexiglass tube (50 cm long, ∅ 1 cm, inserted in 15 cm depth at proximity of the rice root systems) and a hand vacuum pump (Soil moisture Cat. Nr. 2005G1). Care was taken to prevent surface water from entering into the tube, especially during the insertion and extraction of the tube. As soon as the aspired soil/soil-solution mixture appeared in the upper part of the tube, the system was withdrawn from the soil and its content passed immediately through a paper filter (S+S Nr. 311609) into a 10 ml volumetric flask containing 7 ml of specific reagent solution. This solution contained 5 ml orthophenanthroline solution (in concentrations depending on the Fe(II) content) and 2 ml mono-sodium citrate buffer (0.5 m) of pH 3.3. The contents of the flasks were homogenized and the extinctions measured at 508 nm (Perkin and Elmer spectral photometer 550 s) after appropriate dilution. Blanks without ortho-

4 Results and discussion

4.1 IR8 performance in the field

The first IR8 seedlings were transplanted immediately after field inundation and a nearly total loss of plants occurred within a few days due to heavy iron toxicity. This damage was recorded irrespectively of fertilization. The iron contents of the leaves increased in one week from 156 to 3780 ppm. This period of iron intoxication (= primary iron toxicity) coincided with a very high Fe(II)-sol.

Transplantation was repeated 3 weeks later when Fe(II)-sol had decreased. These plants again suffered heavily from 'bronzing' as revealed by symptoms and increased Fe content of the leaves. However, losses were limited and dead plants were replaced 10 days later.

Only fertilization with P (*in the treatments N+P and N+P+K*) visually improved rice growth, diminished 'bronzing' and reduced Fe uptake. This effect was maintained throughout the whole vegetation period and resulted in significant (at 5% level) yield differences between P-fertilized and non-P-fertilized treatments. However, factors other than iron toxicity (rice borer attack, consumption of paddy by weaver birds and asynchronous ripening) affected grain yields considerably.

Highest mean paddy yield was obtained with N+P+K application (1100 kg/ha)

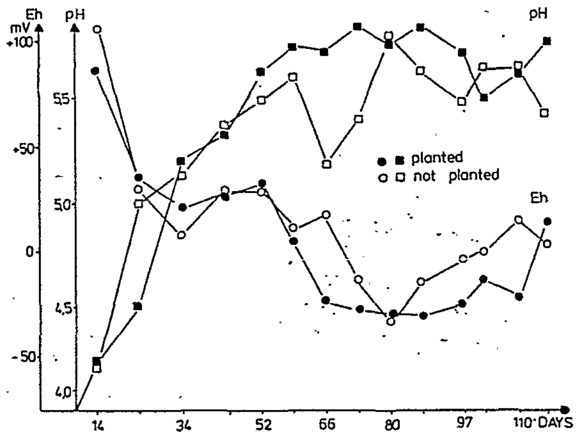
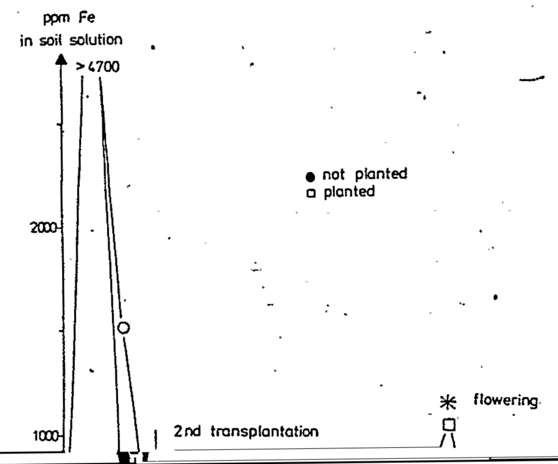


Figure 1 Development of pH and redoxpotential on an acid sulfate soil during the growth period. Experiment 'Loudia Ouolof'



dissolution of P-rich Fe oxides. But at present the involvement of potassium in the iron intoxication process seems to be more evident.

The chemical analysis of some other acid sulphate rice soils in Basse Casamance (Table 1) revealed to a large extent low nutrient availability, especially for P and K. In the same area we frequently witnessed well developed rice populations suffering heavily from iron toxicity at the heading stage, finally resulting in very low grain yields. These findings are in agreement with those of Ottow et al. (1982) who noticed the congruency of low nutrient availability and iron toxicity on various soils.

4.4 Management and alleviation

The excessive uptake of Fe(II) by wetland rice seems to be most pronounced shortly after the beginning of submergence (primary iron toxicity) as well as during growth phases of high physiological activity between maximum tillering and flowering (secondary iron toxicity). In terms of management, primary iron toxicity should be easily excluded by transplanting the seedlings not until 5-20 days after the onset of flooding. This delay in planting may vary from soil to soil and depends largely on the rate of

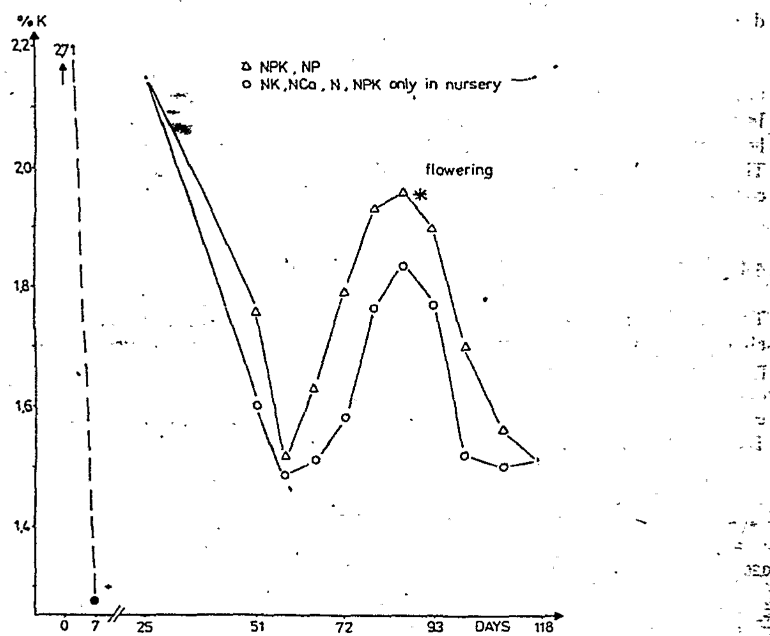


Figure 4 Development of K-contents in the leaf dry matter throughout the growth period (% total potassium in the second and third leaf from top). Compared are treatments with or without P-application

microbial iron reduction under the soil conditions given. Generally speaking, the higher the amount of easily decomposable organic matter, the more intensive and rapid are the bacterial reduction processes (Ottow and Glathe 1973; Munch and Ottow 1983).

Under field conditions, re-precipitation of dissolved ferrous iron as ferrous sulphide usually indicates the end of mineralization with Fe(II) oxides as an electron acceptor. This situation may also be indicated by the formation of a red scum on the flood water and/or on the soil surface. In southern Senegal, we ascribe a major part of rice crop losses to primary iron toxicity because presently most farmers tend to transplant their seedlings immediately after flooding and salt removal. This is a change of customs caused by a significant shortening of the rainy season during the last 15 years.

While primary iron toxicity may be explained by a high sensitivity of the rice plant to Fe(II) stress immediately after transplanting (caused by death and replacement of the primary root system) secondary IT should be considered as a physiological disorder induced by an insufficient supply of essential nutrients involved directly (K, possibly also Ca and Zn) or indirectly (P) (see also Benckiser et al. 1984a, b). An insufficient supply of K, Ca and Zn (in relation to the uptake of N) probably increases root permeability, carbohydrate exudation and iron reduction, which are a pre-

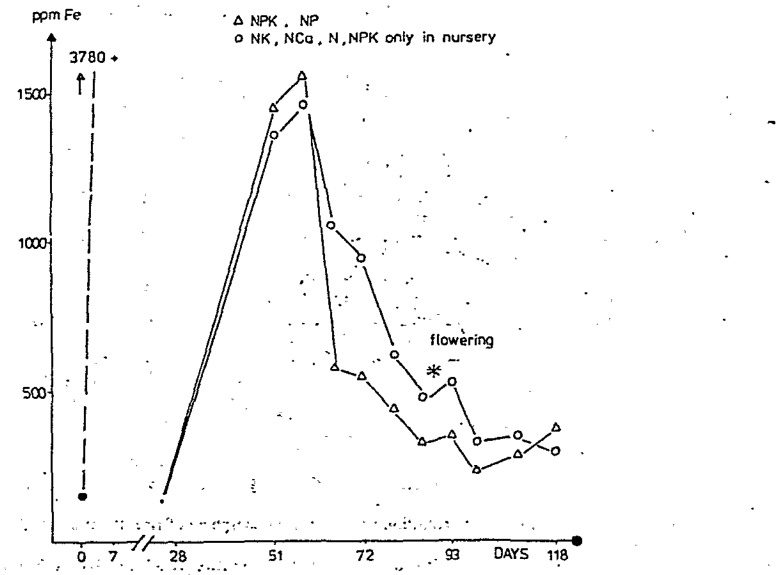


Figure 5 Development of Fe-contents in the leaf dry matter throughout the growth period (ppm total iron in the second and third leaf from top). Compared are treatments with or without P-application

requisite for the breakdown of the effective iron-oxidizing and excluding mechanism, particularly during the most active phase of plant metabolism. This secondary iron toxicity may be alleviated only by fertilization, either in mineral form or by the incorporation of organic remains that are rich in at least P, K, Ca and Zn such as manure and/or ashes. To be effective, intensive, repeated nutrient supply is necessary, particularly on leached acid sulphate soils (which become oxidized upon drying and desalinized by intensive leaching) or on highly weathered Ulti-, Oxi- or oligotrophic Histosols. In fact, secondary iron toxicity can be considered as a 'reclamation disease', which disappears as soon as the soils are regularly fertilized (Japan).

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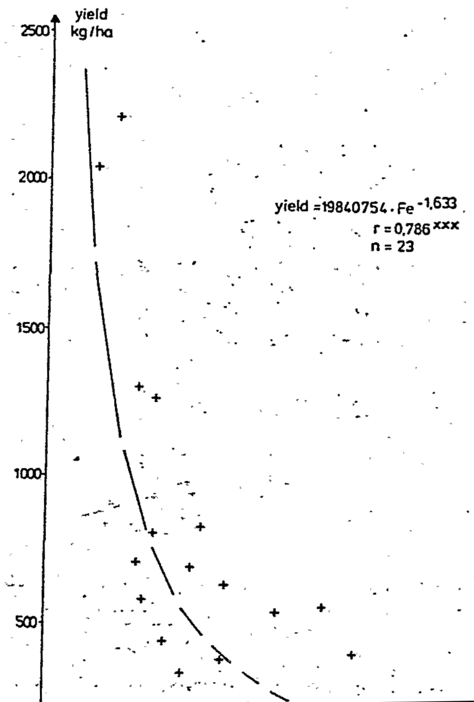

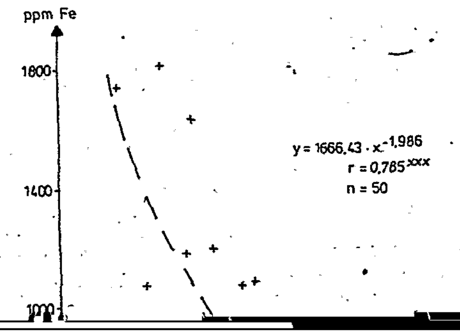

Rice improvement in the mangrove swamps of West Africa

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1 Summary

In West Africa more than 200,000 ha of mangrove swamp, with predominantly acid sulphate soils are being cropped for rice. Rainfall regimes, tidal movement, fresh water supply from river and rainfall, and environmental stress of the mangrove swamp differ from area to area and the need for varieties and farming practices differ accordingly.

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