Nutrient application reduces iron toxicity in lowland rice in West Africa

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Iron toxicity is a widespread nutrient disorder that affects rice growing in inland swamps and on irrigated lowland soils throughout the humid forest and savanna zones of West Africa. It has been reported to reduce lowland rice yields in West Africa by 12–100%, depending on the intensity of the toxicity and the tolerance of the rice cultivar (Sahrawat et al 1996).

The disorder occurs when large amounts of iron are mobilized *in situ* or when an inflow of iron occurs from adjacent upper slopes, especially in the inland valley systems of West and Central Africa. In mineral soils, the occurrence of iron toxicity is associated with a range of concentration of ferrous ions in the soil solution. Light-textured soils high in extractable acidity are especially prone to iron toxicity (Moormann and van Breemen 1978). It is also known that a high concentration of iron in solution decreases the absorption of other nutrients, especially phosphorus (P), potassium (K), and zinc (Zn) (Yoshida 1981).

To test the role of other nutrients in reducing iron toxicity, field experiments were conducted during the 1995-98 wet seasons (July to November) under irrigated conditions at an iron-toxic site at Korhogo, Côte d'Ivoire. The site is in the savanna zone and is at the bottom of a gently sloping toposequence. The soil is an Ultisol with pH in water, 5.7; pH in KCl, 4.0; organic C, 10.2 g kg^{-1}; Bray 1 extractable P, 7 mg kg^{-1}; exchangeable K, 65 mg kg^{-1}; exchangeable Ca, 320 mg kg^{-1}; exchangeable Mg, 75 mg kg^{-1}; DTPA-extractable Fe, 170 mg kg^{-1}; and DTPA-extractable Zn, 5 mg kg^{-1}. From 3 to 10 wk after flooding, the concentration of Fe^2 in the soil solution is 50–150 mg L^{-1} (Narteh and Sahrawat 1999). This is much greater than in the groundwater along the toposequence, indicating that the Fe^2 is formed *in situ* rather than brought in by interflow.

The effects of nine nutrient treatments (no fertilizer, N, N + P, N + K, N + Zn, N + P + Zn, N + K + Zn, N + P + K, and N + P + K +Zn) were tested in a randomized complete block design with four replications. The plot size was 24 m^2. Nitrogen was applied at 100 kg ha^{-1} as urea in three splits, P was applied at 50 kg ha^{-1} as triple superphosphate, K at 80 kg ha^{-1} as KCl, and Zn at 10 kg ha^{-1} as ZnO. All nutrients except N were applied basally. Rice seedlings (3–4 wk old) were transplanted using a spacing of 0.25 m × 0.25 m. Three lowland rice cultivars were tested: CK4, an iron-tolerant cultivar, and Bouake 189 and TOX3069-66-2-1-6, both iron-susceptible cultivars. Plants were visually scored for iron toxicity symptoms using a scale of 1–9 based on the IRRI *Standard evaluation system for rice*. A score of 1 indicates normal growth and 9 indicates that almost all plants are dead or dying. All data underwent analysis of variance and results presented are means of 4 years (1995-98).

Results showed that, without the application of nutrients, iron-tolerant CK4 outyielded susceptible cultivars Bouake 189 and TOX3069-66-2-1-6. With the application of N + P + K + Zn, yields of all three cultivars increased significantly, ranging from 4.7 to 5.7 t ha^{-1} (see table). The increase in yield of iron-susceptible Bouake 189 and TOX3069-66-2-1-6 was more than that of iron-tolerant CK4.

Iron toxicity scores based on normal symptoms were generally lower in treatments where plant nutrients were added than in treatments without fertilizer. Applying a combination of N + P + K + Zn resulted in the lowest iron toxicity score in all three cultivars, indicating that the application of other plant nutrients reduced iron toxicity and increased grain yields (see table). Results showed that grain yield on iron-toxic soils can be improved by applying nutrients.

References

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Effects of field application of nutrients on grain yield of iron-tolerant CK4 and susceptible Bouake 189 and TOX3069-66-2-1-6 lowland rice cultivars grown in an iron-toxic soil, Korhogo, Côte d'Ivoire.

Treatment	Grain yield (t ha^{-1})		
	CK4	Bouake 189	TOX3069-66-2-1-6
No fertilizer	4.3 (3)	3.4 (5)	2.9 (7)
N	4.4 (3)	4.1 (5)	3.3 (7)
N + P	5.3 (2)	4.3 (4)	4.2 (5)
N + K	4.8 (2)	4.4 (4)	3.8 (5)
N + Zn	4.8 (2)	4.6 (4)	4.6 (5)
N + P + Zn	5.0 (2)	4.4 (4)	4.2 (4)
N + K + Zn	5.2 (2)	4.6 (3)	4.6 (4)
N + P + K	5.4 (2)	4.5 (3)	4.5 (3)
N + P + K + ZN	5.7 (2)	4.7 (3)	4.7 (3)
LSD (0.05)	1.01	1.02	1.15

[a]Iron toxicity scores are given in parentheses. Results are av of 4 years (1995-98).

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Relationship between applied potassium and iron toxicity in rice

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Highly weathered soils that are acidic, low in bases, deficient in P and K, and rich in sesquioxides occur on 11.7 million ha in India (Prasad and Biswas 2000) and 0.75 million ha in Orissa (Sahu 1993). Rice grown in low- to medium-elevation lands with this type of soil and adjacent to leached uplands often suffers from Fe toxicity associated with interflow of water from the uplands. The mechanism by which interflow exacerbates the toxicity is uncertain, but it appears to involve dilution of plant nutrients and upsetting of the plant's ability to exclude toxic Fe, rather than the inflow of large amounts of dissolved Fe (van Breemen and Moormann 1978). Related to this, the application of liberal doses of K has been found to reduce Fe toxicity in rice and increase yields.

To investigate the relationship between K application and Fe toxicity under these conditions and interactions with climate and genotypes, field experiments were conducted for three wet seasons (WS, 1991-93) and two dry seasons (DS, 1993-94) on an iron-toxic soil at the Central Research Station of OUAT in Bhubaneswar. The soil is an Aeric Haplaquept derived from highly weathered material, with pH 4.9, CEC 4.4 $cmol_c$ kg^{-1}, 0.36% organic C, 10 ppm Olsen's P, 51 ppm NH_4OAc K, and 398 ppm DTPA-extractable Fe. Treatments included five K levels (0, 33, 66, 99, and 132 kg K ha^{-1}) and four rice varieties—Mahsuri in the WS and Parijat in the DS (tolerant of Fe toxicity) and Jaya in the WS and Pathara in the DS (susceptible to Fe toxicity).

The experimental design was a split plot with rice varieties in the main plot and K levels in the subplots, replicated three times. All treatments received 80 kg N and 18 kg P ha^{-1} as urea and single superphosphate, respectively. Nitrogen was applied in three splits (25% at transplanting, 50% at mid-tillering, and 25% at panicle initiation). All the P and 50% of the K were applied at transplanting with the rest of the K at 25 d after transplanting (DAT). The K used was muriate of potash.

Symptoms of Fe toxicity appeared in the control and lowest K plots at 25 and 30 DAT in susceptible varieties in the WS and DS, respectively. Symptoms were reddish brown spots on the tips of lower leaves with bronzing, later spreading over the entire leaf. The intensity of bronzing decreased with K application. Bronzing symptoms were scored at 40 DAT according to the IRRI *Standard evaluation system for rice* (IRRI 1980). Data (Table 1) showed that, among the four rice varieties tested, Jaya and Pathara were more susceptible to Fe toxicity than Mahsuri and Parijat. Toxicity scores were higher during the WS than during the DS and in the year with higher rain-