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# CHARACTERISTICS OF SOILS PRONE TO IRON TOXICITY AND MANAGEMENT - A REVIEW

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## ABSTRACT

**Iron toxicity is a yield decreasing physiological disorder ascribed to the excessive uptake of Fe and sometime together with Mn ascribed to young acid sulphate soils, alluvial or colluvial clayey soils mainly acidic. The symptoms vary with the crop and the intensity is decided by the situation and mainly deficiency of P, K, Ca, Mg and Zn. In rice it is characterized by a reddish brown mottling (bronzing) or in some cultivars, oranging or yellowing spreading downwards from the tips of the older leaves followed by the drying of the leaves. Roots are scanty, coarse and often dark brown due to the coatings of ferric oxide. In case of banana the toxicity of Fe causes marginal blackening followed by necrosis of the leaves. Planting tolerant varieties in Fe toxic soils is a cheap way to overcome the problem. The application of lime and balanced fertilization with the deficient nutrients mitigate iron toxicity.**

The toxicity of Fe occurs mainly in poorly drained inland valleys often with lateral seepage and/or upwelling Fe containing water, coastal saline-acid soils, peat soils, acid sulphate soils and other hydromorphic soils (Ottow *et al.*, 1983). It is a multinutritional disorder syndrome associated with the reduction in the yield of crops. A clear understanding on the probable cause of Fe toxicity is needed for the proper management of these soils. The characteristics, distribution and development of iron toxicity are reviewed in this paper.

### Process causing high iron levels in the soil solution

The anaerobic microorganisms under submergence start the reduction of soil components with a high oxidation state such as $MnO_2^-$ and $NO_3^-$. Once these are depleted the insoluble $Fe^{3+}$ compounds often present in the form of $Fe(OH)_3$ are reduced to soluble $Fe^{2+}$ compounds. In most soils the level of $Fe^{2+}$ increases upon flooding and reaches a peak after 2-5 weeks (Ponnamperuma, 1976). Concentrations above 300-500 mg $lit^{-1}$ occur only in soils with an aerobic pH below 5. In young acid sulphate soils, particularly high levels of $Fe^{2+}$ tend to develop and often persist for several months. Van Breemen and Moormann (1978) attribute this to buffering at a low pH after submergence, which causes the $Fe^{2+}$ to remain in solution, while in normal soils the pH rises high enough to make $Fe^{2+}$ to precipitate.

### Occurrence of iron toxicity

Iron toxicity in lowland rice has been reported in various countries such as Srilanka, India, Indonesia, Malaysia, Philippines, Senegal, Sierra Leone, Liberia, Nigeria and Colombia (Ponnamperuma, 1976). In India, it has been reported from the young acid sulphate soil of Kerala (Elsy *et al.*, 1994), poorly drained alluvial sandy soils of TamilNadu (Ravichandran, 1987), coastal and hilly zones of Karnataka, valley soils receiving interflow water from adjacent higher lands in Orissa (Sahu and Mitra, 1992) and also from the valleys of north East Himalayan region of Meghalaya.

### Characteristics of iron toxic soils

The intensity of iron toxicity varies with pH, organic carbon, water table level and also the nutrient status besides the concentration of iron. The various characteristic features of these soils are reviewed hereunder.

According to Van Breeman and

Moormann (1978) the characteristics of Fe toxic soils are confined to

i. Young acid sulphate soils (Sulphaquepts) in Kalimantan and Sumatra (Indonesia), Vietnam, Western Malaysia, Kerala (India), Sierra Leone;

ii. Poorly drained colluvial and alluvial sandy soils (Hydraquents, Tropaquents) in valleys receiving interflow water from adjacent higher land with plinthite or weathering igneous or sedimentary rocks or with acidic sediments in Srilanka, Kerala and Orissa (India), Sierra leone; and

iii. Alluvial or colluvial clayey soils, mainly acid, Kaolinitic Tropaquepts and Tropaquents, in sediments derived from Ultisols or bunded and levelled fields in Malaysia, Orissa (India), Colombia and Sierra Leone.

Iron toxicity at low Fe concentrations seems to be typical for zones with upwelling ground water (in inland valleys) and in areas with strongly weathered soils very poor in bases (Van Breeman and Moormann, 1978). The Fe toxic soils of Asia were alluvial, inland or coastal plains and also recognizable by a red brown oily scum on the surface of stagnant water which are more pronounced at the lowest elevations (Benckiser *et al.*, 1982). The disorder is primarily confined to highly leached areas, nutritionally poor peat soils, poorly drained and permanently saturated valley soils (Ottow *et al.*, 1983).

pH: The reduction of Fe has important chemical consequences. As the concentration of water soluble Fe increases, pH was also found to increase and the cations are displaced from exchange sites (Patra and Mohanty, 1994). Five to fifty per cent of the free Fe oxides present in the soil was found to be reduced within few weeks of submergence depending on the temperature, organic matter and the crystallinity of the oxides. Ottow *et al.* (1983) found that the pH of slightly acidic soils on submergence increased and approached the neutrality after three weeks of submergence. According to Makerim *et al.* (1991) the Fe toxic soils grouped under Ultisols, Oxisols or Inceptisols had pH values < 5.5. The study conducted in acid sulphate soils of Thailand revealed that the hydrogen and aluminum were the main cause for soil acidity.

**Electrical conductivity:** The EC of the soil was also found to increase to the tune of 5-10 fold after three weeks of submergence. Ottow *et al.* (1983) stated that the EC of Fe toxic soils varied between 0.02 and 0.07 dS $m^{-1}$ in Srilanka, 0.1-0.2 dS $m^{-1}$ in Lapulapu, Cheria, Africa and reached a maximum of 0.57 dS $m^{-1}$ in the soils of Brunei.

**Organic carbon:** Several workers pointed out that the organic matter content of the soil markedly increased the availability of iron (Patil and Patil, 1981; Swarup, 1982). The organic complex formed with Fe gets easily released. The higher the organic matter of the soils, the more amorphous and crystalline $Fe^{3+}$ compounds are used as electron acceptors and the more intensive is the accumulation of $Fe^{2+}$ compounds upon flooding (Ottow, 1981).

**Redox potential:** The important electrochemical change in the submerged soil is the decrease of redox potential which gives an index of soil reduction. The rate of fall of redox potential in submerged soil depends on the amount of decomposable organic matter and the amount of reducible Fe and Mn. In the lower redox potential range of +180 to +150 millivolts, $Fe^{3+}$ is converted to $Fe^{2+}$ in the soil (Ponnamperuma, 1976).

The Eh value of the soil was found to decrease gradually after submergence and it was also lower with the increasing soil depth (Mukherjee and Basu, 1971). There was a sharp fall in Eh from +555 mv to +210 mv within 4 days of submergence. The increase of soluble and exchangeable forms of Fe and Mn occurred initially followed by the reversal of these processes after about 20 days (Moore and Patrick, 1989).

Patrick and Jugsujinda (1992) stated that the ferrous iron first appeared in the soil solution when the redox potential was decreased below 100 mv and increased in concentration with further decrease in redox potential.

**Soil texture:** The textural characteristics of the soil decides the oxidation reduction systems in the soil. These inturn was found to influence the iron availability. Patra and Mohanty (1994) reported that the high content of reducible Fe in most of the well aerated soil with light texture was due to the oxidation of ferrous iron to ferric iron. The exchangeable Fe content was also the lowest in the light textured soil due to hydrolysis of Fe and $Fe(OH)_3^-$. According to Makerim *et al.* (1991) the clay content of Fe toxic soils grouped under Ultisols and Oxisols was normally high, while the Fe toxic Inceptisols had low clay content.

**Cation exchange capacity:** According to Ottow *et al.* (1983) majority of the Fe toxic soils possessed a relatively low cation exchange capacity of about 10-15 cmol ($p^+$) $kg^{-1}$ and are characterized by relatively weak saturation with bases. The low CEC of these soils revealed both restricted buffering capacity as well as a limited supply of easily available nutrients of the soils (Ottow *et al.*, 1991).

**Iron fractions:** Ferrous iron may be distinguished as water soluble, exchangeable, complexed and precipitated forms. The soil reaction and redox potential was found to play an important role in determining relative proportions among the various forms. The percentage of water soluble Fe was found to increase steadily with the decrease of pH at the expense of precipitated iron which constitutes the greater part (64 to 83 per cent). According to Yu (1976) water soluble Fe varied from 2 to 25 per cent of the total Fe. For reduced paddy soil, complexed Fe fraction was found to constitute 15 to 40 per cent of the total Fe (Yu, 1976). Shukla and Singh (1973) found that the Sierozem soils of Haryana had the total Fe content ranged from 2.05 to 6.87 per cent, the available Fe from 2.2 to 107.2 mg $kg^{-1}$ . More and Patrick (1989) found that the content of water soluble and exchangeable Fe was nil under the air dried condition. Aime Lala (1990) stated that the surface water flow did not decrease the active Fe content of the soil. The content of Fe in the soil follow the order of Fe as crystalline oxides > Fe as amorphous form > Fe associated with organic matter > Fe in exchangeable form.

Van Breeman and Moormann (1978) stated that the Fe toxic soils of Srilanka had active $Fe_2O_3$ content upto 0.5 per cent. The soils were classified mainly as Tropaquents, Hydraquents and Fluvaquents and were found in wet valleys. According to Gunawardena *et al.* (1981) a concentration of 300-500 mg $kg^{-1}$ of water soluble Fe in the root zone generally caused bronzing. However with low nutrient levels, especially potassium and phosphorus or with respiratory inhibitors such as hydrogen sulphide, the water soluble Fe concentration as low as 30 mg $kg^{-1}$ was toxic to rice.

**Nutrient availability:** The Fe toxic soils are characterized by a general low fertility status and the crops grown on these soil suffered from a multiple nutritional stress (Ottow *et al.*, 1991).

A strong reductive condition depressed the availability of various nutrients. The Fe toxicity is aggravated by the low levels of P and K (Ponnamperuma, 1958; Ismunadji and Ardjasa, 1989). A deficiency of Ca in these soils was reported by Viswanath Setty *et al.* (1995).

In the Fe toxic acid soils of Java and Sumatra the deficiencies of P, exchangeable

Ca and K was a common feature (Ismunadji *et al.*, 1989). Ponnamperuma and Lantin (1985) opined that the presence of excess Fe in these soils induced the deficiencies of available P, K, S and DTPA-Zn. In the Fe toxic valley soils of Meghalaya, Singh *et al.* (1992a) observed as a major obstacle followed by K, Zn and Cu for optimum productivity.

## Symptoms of iron toxicity in crops and yield under lowland situation

Iron toxicity is a yield decreasing physiological disorder ascribed to the excessive uptake of Fe and sometime together with Mn (Ottow *et al.*, 1983). The symptoms varies with the crop and the intensity is decided by the situation and mainly deficiencies of P, K, Ca, Mg and Zn. The symptoms of Fe toxicity in rice and banana are reviewed below.

**Rice:** In rice the symptoms of Fe toxicity will occur in about 50-55 days after transplanting (Singh and Singh, 1988). It is characterized by a reddish brown mottling (bronzing) or in some cultivars, oranging or yellowing spreading downwards from the tips of the older leaves followed by the drying of the leaves. Roots are scanty, coarse and often dark brown due to the coatings of ferric oxide (Ponnamperuma *et al.*, 1981; Lantin and Neue, 1988 and Jugsujinda and Patrick, 1993).

**Banana:** In case of banana since trenches were dug in wetlands for its cultivation to improve drainage, Fe toxicity was reduced to a greater extent. The toxicity of Fe in banana causes marginal blackening followed by necrosis of the leaves and can be visualized during 6-7 months after planting (active vegetative stage). This was reported by Lahav and Turner (1988).

## Critical nutrient level for Fe toxicity

The critical nutrient level is the limit above or below which causes toxicities or deficiencies. In some cases the crop will not exhibit any symptom even if the content in both soils and plants did not satisfy the critical limit. The critical limit varies with the crop, age, plant part and the situation with which it is grown. It also varies with the type of soil.

**Rice:** The critical concentration of different nutrients in the soil and rice reported by various authors at different situations are furnished in the table below.

**Critical limit (deficiency) in soils prone to Fe toxicity**

| Total-N(%) | Av. P. | Av. K. | Ex. Ca | Ex. Mg | DTPA-Zn | DTPA-Cu | Authors |
|---|---|---|---|---|---|---|---|
| | (mg $kg^{-1}$) | | (c mol $kg^{-1}$) | | (mg $kg^{-1}$) | | |
| 0.2 | 10 | 70 | 10 | 2-5 | 2 | - | Benckiser *et al.* (1982) |
| - | 10 | 70 | - | - | 2.15 | 0.71 | Singh *et al.* (1992a) |

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| Critical limit | | |
|---|---|---|
| Water soluble Fe(mg $kg^{-1}$) | Active $Fe_2O_3$ (%) | Authors |
| 300 | - | Tanaka and Yoshida (1970)<br>Benckiser *et al.* (1982)<br>Ottow *et al.* (1983) |
| 125 | - | Lantin and Neue (1988)<br>Moore and Patrick (1989)<br>Singh *et al.* (1992b) |

**Critical limit of nutrients in rice shoots of Fe toxic soil**

| Critical limit | | | | | | | | | | Authors |
|---|---|---|---|---|---|---|---|---|---|---|
| Particulars | N | P | K | Ca | Mg | Zn | Cu | Fe | Mn | |
| | % | | | | | (mg kg$^{-1}$) | | | | |
| Deficiency | - | 1.0 | 1.0 | 1.5 | 1.0 | 1.0 | 6 | 70 | 20 | Tanaka and Yoshida (1970) |
| | 2.5 | 0.1 | 1-2 | 0.1 | 20 | 20 | - | 70 | 20 | Benckiser *et al.* (1982) |
| Toxicity | - | - | - | - | - | 1500 | 30 | 300 | 2500 | Ottow *et al.* (1983) |

**Critical limit for nutrients in the third leaf of banana**

| Nutrients | Critical limit | | |
|---|---|---|---|
| | Deficient | Sufficient | Toxicity |
| N (%) | 2.0-2.49 | 2.5-3.0 | >3.0 |
| P (%) | 0.14-0.17 | 0.18-0.5 | >0.5 |
| K (%) | 2.0-2.29 | 2.30-4.00 | >4.00 |
| Ca (%) | 0.40-0.69 | 0.70-1.40 | >1.40 |
| Mg (%) | 0.20-0.24 | 0.25-0.40 | >0.40 |
| Zn (mg kg$^{-1}$) | 10-12 | 13-50 | >50 |
| Cu (mg kg$^{-1}$) | 4-5 | 6-30 | >30 |
| Fe (mg kg$^{-1}$) | 80-99 | 100-300 | >300 |
| Mn (mg kg$^{-1}$) | 150-199 | 200-2000 | >2000 |

## Management of soils prone to iron toxicity

Iron toxicity can be alleviated by liming the soil, delayed planting, late flooding to avoid excess Fe in the early stages and providing sufficient Fe in the reproductive phase of the plant development (Van Breemen and Moormann, 1978; Ponnamperuma and Solivas, 1982). Since neither of these operations are always possible for economic or other reasons, varietal resistance to Fe toxicity should be exploited.

### Agronomic management

Iron toxicity could also be alleviated by drainage. Under oxidized condition ferrous iron ($Fe^{2+}$) would be converted to ferric iron ($Fe^{3+}$) which is not available to the rice plant. Burbley and Zaini (1990) reported that intermittent drainage could lessen the severity of Fe toxicity. For experiment using Fe toxic soils conducted by Tahir and Misra (1984) indicated that the application of N, P, K, Mg, Cu and Zn along with draining twice during the crop growth increased plant height, tiller number and yield of rice. Burbley and Zaini (1990) also indicated that the yield of rice could be increased by draining the soils for nine days after one month of planting compared to continuous flooding. The decrease in the water soluble Fe from 468 to 228 mg kg$^{-1}$ due to draining was reported by Singh *et al.* (1993) which had led to 5-10 per cent increase in rice yield.

### Varietal tolerance

There are varietal differences in the sensitivity of rice to Fe toxicity. Planting tolerant varieties in Fe toxic soils is a cheap way to overcome the problem. However for moderate to severe Fe toxicity a combination of amendments and varietal tolerance is necessary for increasing the yield of rice (Anonymous, 1987 and Sahrawat *et al.*, 2000).

The varietal performance trial with 40 genotypes in lateritic rice soil of Kerala revealed that the high yielding genotypes exhibited characteristics visual symptoms of Fe toxicity (Elsy *et al.*, 1994) wherein the average yield recorded by the high yielding genotypes in the Fe toxic fields was 2.6 t ha$^{-1}$ as against their average performance of 4-4.5 t ha$^{-1}$ under normal soil conditions. At IRRI, rice varieties were screened in the greenhouse using a strongly acid clay soil which maintained higher concentration of Fe (400 mg $kg^{-1}$) during most of the growing season. In the study , IR36, IR42, IR46 and Suakoko were noted for their tolerance (Anonymous, 1977). Ponnamperuma *et al.* (1981) identified Dewaredden, IR36, IR42, IR52 and Gudungogung as tolerant with respect to Kelera and Semera rice varieties for Fe toxicity was reported by Ismunadji *et al.* (1989).

The experiment conducted by Ismunadji *et al.* (1989) in Tamanbogo indicated that the application of major nutrient fertilizers appreciably increased the yield of different rice varieties in Fe toxic soil. The substantial increase in the yield from 170 to 2539 kg $ha^{-1}$ of the most Fe toxicity susceptible variety *viz.*, IR 64 by fertilization was reported by Antyyantaro and Slamet (1991).

## Chemical amendments

The application of lime not only increase the pH of the soil but also enhances the nutrient availability by nullifying the Fe toxicity. The effect of chemical amendments on mitigating Fe toxicity in rice and banana are furnished below.

**Rice:** The beneficial effect of lime was shown in a green house study on the amelioration of an acid sulphate soil in Vietnam. Application of $CaCO_3$ at 0.4 per cent enabled the plants to produce moderate amounts of straw and grain, while at 0.8 per cent the yield was doubled by causing an appreciable decrease in the concentration of $Fe^{2+}$ in the soil solution (Ponnamperuma and Lantin, 1985). In an Fe toxic Sulfaquept soil the application 50 kg $ha^{-1}$ of manganese dioxide produced a highly significant response in grain yield (Lantin and Neue, 1988). The effects of manganese dioxide (9100 kg $ha^{-1}$) and lime (5 t $ha^{-1}$) on Fe toxicity symptoms and yield of a moderately susceptible variety (IR 26) and a moderately tolerant variety (IR 43) was studied on a Sulfaquept. On the basics of grain yield the best treatment was IR 43 with $MnO_2$ and lime since it exhibited 30 per cent increase over the control (Anonymous, 1977).

**Banana:** The Fe toxicity was drastically reduced as trenches were dug for improving drainage in the management of the cultivations of banana. The reports on the management of these soils specially with reference to banana are almost nil. However a few reports are available with regard to the effect of lime on banana in acid soils. Reynolds and Langenegger (1985) stated that the use of 200 g $plant^{-1}$ $year^{-1}$ of limestone and ammonium nitrate increased bunch weight, number of hands per bunch and the yield of banana Cv.Dwarf Cavendish. The application of 400 kg of dolomitic limestone with 900 kg N, 40 kg K per hectare in a red yellow Podzolic soil of pH 5.1 for Pome bananas recorded 25 percent increase in yield over the NPK control (Anonymous, 1988).

## Balanced fertilization

The toxicity of Fe is caused due to presence of excess water soluble or active Fe. The toxic effect of Fe could be mitigated by supplying enough quantity of the deficient nutrient elements. The effect of balanced fertilization on the yield of rice and banana in excess Fe soils are reviewed here.

## Balanced fertilization for rice

Ismunadji *et al.* (1989) stated that the Fe toxic soils could be made productive with proper fertilization. An increase in the yield of rice from 2958 to 5594 kg $ha^{-1}$ and a low percentage of empty grains (<30%) was reported by them for the application of potash in these soils. Similar report was also made by Yoshida (1981). Application of 90 kg $P_2O_5$ $ha^{-1}$ to Fe toxic soils resulted in a drastic reduction in $Fe^{2+}$ from 3.60 to 1.63 mg $kg^{-1}$ at Barapani farm of Meghalaya in India (Singh *et al.*, 1992b).

The field experiment conducted in Meghalaya revealed that the application of 26 kg P ha$^{-1}$ produced rice plants free from disorders with healthy vegetative growth in Fe toxic soil. The highest grain yield response was observed in the treatment where rice seedling roots were dipped in single super phosphate and farm yard manure shiny before transplanting (Singh *et al.*, 1994).

Benckiser *et al.* (1984) claimed that Ca and Mg played an important role in alleviating Fe toxicity of rice. They indicate that a multiple nutritional stress was the main cause of Fe toxicity in rice and suggested that fertilization with N, P, K, Ca, Mg and Zn improved the Fe excluding mechanism of the plant, since root tissues had lower Fe and higher K, Ca and Mg than in fertilized plants. Singh *et al.* (1992a) recorded the greatest yield response (1.2 t ha$^{-1}$) with 4 kg Cu ha$^{-1}$ and almost equaled with the treatment receiving 12 kg Zn ha$^{-1}$ in Fe toxic soils of Meghalaya. According to him the significant increase in the uptake of Zn, Cu, Mn, P and K over the control and the simultaneous reduction in Fe might have led to proper nutrient balance and higher efficiency. According to Aime Lala (1990), the application of Mn and Cu alleviated Fe toxicity by counter balancing higher Fe concentration and reducing sterility. Patra and Mohanty (1994) observed that liming without NPK produced lesser grain yield than the application of lime with K. The application of K alone increased the grain yield by 27 per cent over the control compared to 2.6 per cent increase observed with the application of Mn alone in a lateritic rice soil (Typic Hapludalf) in Orissa. The experiment conducted by Yesril (1989) indicated that, besides the application of major nutrient, lime and stable manure were also effective in increasing the rice yields grown on Fe toxic soil. The check yield was 2.7 t ha$^{-1}$, while NPK, NPK + 5 t ha$^{-1}$ of stable manure and NPK + 11 lime ha$^{-1}$ yielded 4.2 , 5.0 and 5.21 ha$^{-1}$, respectively.

## Balanced fertilization for banana

According to Dumas and Martin Prevel (1885) the yield of banana was dependent largely on the N, K, Ca and Mg balance. The increase in the yield by 15.3 per cent over the control in case of Robusta banana for the application of N, P, K, Ca and Mg was reported by Beragohasi and Shanmugavelu (1986). Shanmugavelu *et al.* (1992) reported that the application of $ZnSO_4$ 5 g plant/ha along with recommended fertilizers resulted in an increase of over 500 kg of banana fruit per acre over the unfertilized control. They also opined that the soil application of NPK with B reduced the leaf abnormalities while foliar spray with B increased the number of green leaves and yield.

From the review of the works on Fe toxicity it has been inferred that proper knowledge on the nature and cause of toxicity is needed for ameliorating these soils. Since Fe toxicity is a multinutrient disorder syndrome caused due to the excess Fe, the screening of varieties for tolerating such stresses along with proper nutrient management are considered a prerequisite for increasing the productivity of these soils.

## REFERENCES

Aime Lala, R. (1990). *Ph.D* Thesis, University of Philippines at Los Banos.
Antyyantaro, S. and Slamet D.M. (1991). *Agrikam.*, 6: 85-88.
Anonymous (1977). *Annual Report*, International Rice Research Institute, Los Banos, Laguna.
Anonymous (1987). *Annual report*, International Rice Research Institute, Los Banos, Languna.
Anonymous (1988), *Banana News.*, **11**: 19-21.
Benckiser *et al.* (1982). *Int. Rice Res. Paper Series No. 85.* Int. Rice Res. Institute, Los Banos, Philippines.
Benckiser, G. *et al.* (1984). *Pl. Soil*, **79**: 305-316.
Beragohasi, R. and Shanmugavelu K.G. (1986). *Banana Newsl.*, **9**: 19-23.

Burlbey, Z. *et al.* (1990). Presiding Pengelolaan Sawah Bukaan Baru menujang Swasembada Pangan dan Program Transmigrasi, Padang, 17-18. Sep., 1990.

Dumas, J. and Martin Prevel, P. (1985). *Preliminary results d'outre mer.*, **13**:376-386. *Hort. Abstr.*, **29**: 1980.

Elsy, C.R. *et al.* (1994). *Oryza.*, **31**: 67-68.

Gunawardena, S. (1981). In: Int. Rice Research Conference, IRRI, Los Banos, Laguna. April 27 to May 1, Philippines.

Ismunadji, M. and Ardjasa, W.S. (1989). In: Seminar Bogor Research Institute for food crops, Bogor, Indonesia. Feb. 13-14.

Ismunadji, M. *et al.* (1989). In: Int. Symp. on rice production on acid soils of the tropic, Kandy, Sri Lanka , 26-30, June.

Jugsujinda, A. and Patrick, W.H. Jr. (1993). *Pl. Soil,* **152**: 237-243.

Lahav, E. and Turner, D.W. (1988). Banana Nutrition. Plant Bulletin No.7. Int. Potash. Institute, Berne, Switzerland, pp 127.

Lantin, R.S. and Neue, H.U. (1988). In: 17th Irrigated Rice Meetings, Brazil, 26-30 Sep.

Makerim, A.K. *et al.* (1991). In: Rice Production of Acid Soils of the Tropics. (Detrurck, P. and Ponnamperuma, F.N. eds.), Institute of Fundamental Studies, Kandy, Srilanka.

Moore, P.A. Jr. and Patrick, W.H. Jr. (1989). *Soil Sci. Soc. Am. J.*, **53**: 471-476.

Mukherjee, S.K. and Basu, S.N. (1971). *J. Indian Soc. Soil Sci.*, **19**: 197-202.

Ottow, J.C.G. (1981). In: Proc. Symp. Paddy soil. Inst. of Soil Sci., (Academia Sinia ed.), Science Press, Beijing & Spring & Springer Verlag, Berlin-Heidelberg, New York, pp 330-343.

Ottow, J.C.G. *et al.* (1983). *Trop. Agric.*, **60**: 101-106.

Ottow, J.C.G. *et al.* (1991). Strategies to alleviate iron toxicity of wet land rice on acid sulphate soils. In:Rice production on acid soils of the tropics. (Deturk, P. and Ponnamperuma, P.N. eds). Institute of Fundamental Studies, Kandy, Sri Lanka, pp. 186.

Patil, J.D. and Patil, N.D. (1981). *J. Maharashtra. Agric. Univ.*, **6**: 185-188.

Patrick, W.H. Jr. and Jugsujinda, A. (1992). *Soil Sci. Soc. Am. J.*, **56**: 1071-1073.

Patra, B.N. and Mohanty, S.K. (1994). *Biol Fertile. Soils.*, **17**: 285-288.

Ponnamperuma, F.N. (1958). *IRC Newsl.*, **1**: 10-13.

Ponnamperuma, F.N. (1976). In: Proc. of Workshop on Plant Adaptation to Mineral Stress in Problem Soils, Beltsville, Maryland, 22-23, Nov., p.341-353.

Ponnamperuma, F.N. (1981). In: Int. Programme Review. IRRI, Los Banos, Philippines.

Ponnamperuma, F.N. and Solivas, J.L. (1982). In : Proc. of Bangkok Symp. on Acid Sulphate Soils. (Dost, H. and Van Breemen, N. eds). Int. Inst. for Land Reclamation and Improvement, Wageningen.

Ponnamperuma, F.N. and Lantin, R.S. (1985). In : Proc. Int. Rice Res. Conference, IRRI, Los Banos, Philippines.

Ravichandran, R. (1987). *M.Sc. (Ag.) Thesis.* Tamil Nadu Agric. Univ., Coimbatore.

Reynolds, R. and Langenegger, W. (1985). Nitrogen requirements of bananas. Information Bulletin, Citrus and Subtropical Fruits Research Institute, No. **151**: 9-11.

Sahrawat *et al.* (2000). *Oryza.*, **37**: 44-47.

Sahu, S.K. and Mitra, G.N. (1992). *J. Pot. Res.*, **8**: 311-319.

Shanmugavelu, K.G. *et al.* (1992). Banana : Taxonomy, Breeding and Production Technology. Metropolination Book Co. Pvt. Ltd. New Delhi- 110002, India, pp.330.

Shukla, U.C and Singh, R. (1973). *J. Indian Soc. Soil Sci.*, **21**: 35-40.

Singh, B.P. *et al.* (1992a). *J. Indian Soc. Soil Sci.*, **40**: 326-328.

Singh, B.P. *et al.* (1992b). *Int .Rice Res. Newsl.*, **17**: 18.

Singh, B.P. *et al.* (1993). *Ann. Agric. Res.*, **14**: 100-102.

Singh, B.P. *et al.* (1994). *Ann. Agric. Res.*, **15**: 81-84.

Singh, B.P and Singh. B.N. (1988). *Indian J. Agric. Sci.*, **58**: 851.

Singh, B.P *et al.* (1992a). *J Indian Soc.Soil Sci.*, **40**: 326-328.

Swarup, A. (1982). *Pl. Soil.*, **66**: 37-43.

Tahir, A. and Misra, M. (1984). Control of iron toxicity on newly opened paddy fields . Contribution. Sukarami Res. Inst. for food crops, m 4: 3-6 (In Indonesia).

Tanaka, A. and Yoshida, S. (1970). Nutritional Disorders of the Rice Plant in Asia. *IRRI Technical Bulletin.*, **10**: 51.

Van Breeman, N. and Moormann, F.R. (1978). Iron Toxic Soils. In: Soils and Rice. International Rice Research Institute, Los Banos, Laguna, Philippines. pp781-800.

Viswanath Setty, Y. *et al.* (1995). *Mysore J. Agric. Sci.*, **29**: 22-26.

Yesril, B.D. (1989). Pemupukan NPK, kapur dan hara mikro sawah kerakunan besi. Laperum Hasil Penelitian balittan Sukkrami, M.J. 1988-1989, 97p.

Yoshida, S. (1981). Fundamentals of Rice Crop Science. Intl. Rice. Res. Inst., Los Banos, Philippines, 269p.

Yu, T. (1976). Oxidation - reduction processes in soils (in Chinese). In: Soils of China, Science Press, Beijing, pp. 345-359.