AMELIORATING EFFECTS OF POTASSIUM ON IRON TOXICITY IN SOILS OF ORISSA

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Iron toxic soils

- Iron toxicity is a problem associated primarily with rice crop grown on iron rich low land red and laterite soils.
- Under these conditions Fe$^{+++}$ is reduced to Fe$^{++}$, which is absorbed by rice plant in larger quantities and causes Fe-toxicity.
- Other crops grown on such soils also suffer from iron toxicity and consequent yield loss.
Predisposing factors for iron toxicity

- Low lands adjacent to uplands. There is lateral flow of soluble iron from uplands to low lands, which enriches its iron content to toxic levels.
- Lower temperature and high rainfall
- Coarse texture and high water table
- Acidic pH
- Poor nutrient status (K, P, Ca, Mg, Zn, Si)
- High salt content

Land situations for manifestation of acute iron toxicity
Symptoms of iron toxicity

- Floating brickish red scums on surface
- Tiny brown spots on lower leaves
- Bushy brown roots, absence of white roots
- Shy tillering, reduced growth, short panicle, yield reduction 10-100%

Why were we interested in problem of iron toxicity?

- The Research Farm, where we conduct field trials at Bhubaneswar is located on laterite soils.
- Late Dr. B. N. Sahu, a senior Agronomist reported (1968) bronzing of rice leaves caused probably by iron toxicity.
- The Plots of LTF Experiment (rice-rice cropping system), started in 1972 adjacent to an upland showed symptoms of iron toxicity, confirmed by soil and plant analysis.
- A detailed study on iron toxicity was initiated.
Iron content of soils of Orissa

- Soils of Orissa are in general rich in iron (DTPA-Fe: 8.2-356.0ppm.)
- Red and laterite soils, which constitute 70% of the soils of Orissa contain 17.8-356ppm of DTPA-Fe
- Iron toxic soils, which show visual symptoms of toxicity contain 105.1-569.5ppm DTPA-Fe

Occurrence of Red and laterite soils in Orissa
Characterization of iron toxic soils of Orissa (Av.of 88 samples collected from 12 districts of the State)

**Chemical composition**

<table>
<thead>
<tr>
<th>Texture</th>
<th>pH (1;2)</th>
<th>Org. C (g kg⁻¹)</th>
<th>N (mg kg⁻¹)</th>
<th>P (mg kg⁻¹)</th>
<th>K (mg kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL-C</td>
<td>4.6-5.8</td>
<td>2.6-6.5</td>
<td>42.0-145.0</td>
<td>3.0-12.0</td>
<td>21.5-80.5</td>
</tr>
</tbody>
</table>

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

DTPA Fe < 4.5 mg kg⁻¹ is rated as low, 4.5-9 medium and > 9 high
Profile distribution of different forms of iron

A total of four pedons were exposed. The following Table gives results of one of the test pedons:

<table>
<thead>
<tr>
<th>No. &amp; Name of Pedon</th>
<th>Depth (cm)</th>
<th>Total Fe (%)</th>
<th>Fe-O (%)</th>
<th>DTPA-Fe (mg kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bhubaneswar</td>
<td>0-17</td>
<td>3.8</td>
<td>0.52</td>
<td>428</td>
</tr>
<tr>
<td></td>
<td>17-33</td>
<td>4.8</td>
<td>0.98</td>
<td>398</td>
</tr>
<tr>
<td></td>
<td>35-53</td>
<td>6.3</td>
<td>1.23</td>
<td>384</td>
</tr>
<tr>
<td></td>
<td>53-120</td>
<td>5.8</td>
<td>1.78</td>
<td>372</td>
</tr>
</tbody>
</table>

Classification of iron toxic soils of Orissa

<table>
<thead>
<tr>
<th>Ped-on No.</th>
<th>Order</th>
<th>Sub-Order</th>
<th>Great Group</th>
<th>Sub-Group</th>
<th>Family</th>
<th>Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Inceptisol</td>
<td>Ustips</td>
<td>Haplu-stepts</td>
<td>Aquic Haplu-stepts</td>
<td>Coarse, loamy, mixed, perthermic</td>
<td>Bhubaneswar</td>
</tr>
<tr>
<td>2.</td>
<td>Inceptisol</td>
<td>Ustips</td>
<td>Haplu-stepts</td>
<td>Fluven-tic Haplu-stepts</td>
<td>-do-</td>
<td>Chiplima</td>
</tr>
<tr>
<td>3.</td>
<td>Alfisol</td>
<td>Ustals</td>
<td>Rhodustals</td>
<td>Kanh-aplic Rhodustals</td>
<td>-do-</td>
<td>Gajamara</td>
</tr>
<tr>
<td>4.</td>
<td>Alfisol</td>
<td>Ustals</td>
<td>Paleustals</td>
<td>Kandic Paleustals</td>
<td>-do-</td>
<td>Duburi</td>
</tr>
</tbody>
</table>
Estimated area under Iron Toxic Soils

- Soils with DTPA-Fe > 100mg kg\(^{-1}\) and showing visual symptoms: 52000 ha
- Nutrient index (NI) for Fe (NI < 2.0 def., 2.01-2.33 adequate, 2.33-2.66 moderately high, > 2.67 high)
- 29 out of 30 districts of the state have NI > 2.67.
- State average of NI is 2.66. (Jena et al. 2008)
- 22 districts out of 30 have mean DTPA-Fe, 50-100mg kg\(^{-1}\).
- Soils with latent iron toxicity (50-100 mg kg\(^{-1}\)) without showing visual symptoms but causing yield loss probably covers a very large area (~1.5-2.0 million ha), especially in a scenario, where fertiliser consumption is 53.2 kg ha\(^{-1}\). (N:P:K = 34:12:7)

Studies on Fe-K interaction

- Some of the treatments of LTF-Experiment showed that Fe-toxicity symptoms could be alleviated by application of higher doses of K.
- A systematic study was initiated through
- Solution culture studies
- Pot culture Experiments
- Field Trials
Effect of Fe conc. on N, P, K uptake by rice
(Solution culture studies)
Plants harvested after exposing 21 days old seedlings for 40 days in graded doses of Fe.

Effect of Fe conc. on N, P, K uptake by rice

Fe Conc. (mg kg⁻¹) vs N, P, K uptake (mg pot⁻¹)

- K-uptake
- N-uptake
- P-uptake

Effect of Fe conc. on uptake of Fe and Zn
(Solution culture studies)

Effect of Fe concn. uptake of Fe, Zn by rice

Fe Conc. (mg kg⁻¹) vs Uptake of Fe, Zn (mg pot⁻¹)

- Fe-uptake
- Zn-uptake

Fe and Zn uptake also tended to decrease beyond 10 mg kg⁻¹.
Iron-potassium interaction
(Pot culture studies)

Effects of Fe-K interaction on dry matter yield of 40 days old rice plants (g pot⁻¹) (pH of soil used=5.4, DTPA-Fe=79 mg kg⁻¹)

<table>
<thead>
<tr>
<th>Levels (mg kg⁻¹)</th>
<th>Fe-0</th>
<th>Fe-50</th>
<th>Fe-100</th>
<th>Fe-200</th>
<th>Fe-300</th>
<th>Fe-400</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-0</td>
<td>7.86</td>
<td>7.95</td>
<td>5.75</td>
<td>1.05</td>
<td>0.99</td>
<td>0.56</td>
<td>4.06</td>
</tr>
<tr>
<td>K-30</td>
<td>7.05</td>
<td>8.00</td>
<td>6.27</td>
<td>1.54</td>
<td>1.05</td>
<td>0.60</td>
<td>4.23</td>
</tr>
<tr>
<td>K-60</td>
<td>7.89</td>
<td>8.16</td>
<td>6.75</td>
<td>2.00</td>
<td>1.07</td>
<td>0.61</td>
<td>4.41</td>
</tr>
<tr>
<td>K-90</td>
<td>7.88</td>
<td>8.20</td>
<td>6.79</td>
<td>2.10</td>
<td>1.21</td>
<td>0.80</td>
<td>4.46</td>
</tr>
<tr>
<td>mean</td>
<td>7.67</td>
<td>8.08</td>
<td>6.39</td>
<td>1.67</td>
<td>1.07</td>
<td>0.64</td>
<td></td>
</tr>
</tbody>
</table>

C(0.05) K= 0.15  Fe = 0.18  K X Fe = 0.36

Effects of Fe-K interaction on K-uptake
(Pot Culture Studies)

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Effects of Fe-K interaction on Fe-uptake (Pot culture studies)

Effects of K application on leaf bronzing and yield of rice grown on iron toxic soil
Field Trials, Av. of 3 years, pH 4.9, DTPA-Fe 396 mg kg⁻¹

<table>
<thead>
<tr>
<th>Levels of K₂O (kg ha⁻¹)</th>
<th>Leaf bronzing (1-9 scale)</th>
<th>Grain yield (q ha⁻¹)</th>
<th>Straw yield (q ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jayas Superior</td>
<td>Mahsuri Tolerant</td>
<td>Jayas Superior</td>
</tr>
<tr>
<td>0</td>
<td>8</td>
<td>3</td>
<td>10.3</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td>18.2</td>
</tr>
<tr>
<td>40</td>
<td>7</td>
<td>2</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>22.1</td>
</tr>
<tr>
<td>80</td>
<td>5</td>
<td>2</td>
<td>19.4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>22.7</td>
</tr>
<tr>
<td>120</td>
<td>5</td>
<td>1</td>
<td>22.1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>26.8</td>
</tr>
<tr>
<td>160</td>
<td>3</td>
<td>1</td>
<td>24.4</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td>28.8</td>
</tr>
<tr>
<td>Mean</td>
<td>18.0</td>
<td>23.7</td>
<td>22.6</td>
</tr>
<tr>
<td></td>
<td>31.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
K-content (%) of plants at MT stage for different levels of K

(Field Trial, pH 4.9, DTPA Fe 396 mg kg⁻¹)

Fe content of plants at MT stage for different levels of potash

(Field Trial, pH 4.9, DTPA Fe 396 mg kg⁻¹)
Zn content of plants at MT stage for different levels of potash

*(Field Trial, pH 4.9, DTPA Fe 396 mg kg⁻¹)*

**Need for application of higher doses of K to soils of Orissa**

- Soils of Orissa have a huge negative K-balance of –242.87 thousand tonnes (-30 kg ha⁻¹).
- The deficit is currently met from K-bearing minerals (Mica, orthoclase, microcline etc.) present in the soil. (Pl. see the article of Dr. Jena in the Souvenir)
- In LTF-Experiments laid out in 1972-73, responded to K-application in 1982-83.
- Application of K at a higher dose (60-80kg ha⁻¹) to the main crop rice is essential not only to prevent K-mining, but to alleviate latent iron toxicity of soils. (Rice crop removes 62% of K from the soil.)
Mechanism of ameliorating effects of K on Fe-toxicity

- Waterlogged rice roots excrete O₂ to the rhizosphere from aerenchyma tissues, which constitute 40-50% of their cross sectional area (Evans, 2003).
- Application of K in higher doses increases root oxidising power of rice, which results in oxidation of Fe²⁺ to Fe³⁺ and exclusion of this ion from uptake.
- This is evident from increase in intensity of iron oxide coating on rice roots at higher levels of K application.
- Results of pot culture and field experiments showed that an increase in K application increased K and Zn content of plants and reduced Fe content.

Mechanism of ameliorating effects of K on Fe-toxicity

- Lowering of Fe content by K reduces oxidative injury, which is caused by oxidation of Fe²⁺ to Fe³⁺ in the apoplast leading to auto-oxidation, Fenton reaction and formation of free radicals such as O₂⁻ and HO⁻ resulting in oxidative loss of defense enzymes, catalase, superoxide dismutase etc.
- Potassium increases proline content of leaves and suppresses malondialdehyde (MDA) content formed by lipid peroxidation.
Mechanism of ameliorating effects of K on Fe-toxicity

- Potassium maintains the balance of internal hormone level of CTK, ABA and ethylene.
- It maintains integrity of plasma membrane and thus protects the symplast from possible injury from Fe accumulation in the apoplast.
- Leaf bronzing is caused by precipitation and deposition of ferric compounds in the apoplast.

The role of genes of Fe and K transporters in alleviating iron toxicity by K is not known.

Under Fe toxic conditions root border cells tend to protect the root tip after sloughing off from it and forming a mucilage, which binds Fe and prevents it from reaching the root tip. (Xing et al. 2008)

TRH1 a member of KT/KUP/HAK family of K-transporter genes encodes a K transporter protein essential for root tip growth. (Rigas et al. 2001)

(Please read the article on K-transporters in the Souvenir)
Contrary views

Mehraban et al. (2008)

• Potassium nutrition could not alleviate effects of iron stress on plant growth.
• Iron toxicity induced greater oxidative stress in rice plants and supplemental potassium was ineffective in preventing iron accumulation in shoots and consequently did not ameliorate plant growth under iron toxic levels.

Thank you