Increasing productivity of rice through iron toxicity control in acid sulfate soils of tidal swampland

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Abstract. Increasing rice productivity in acid sulfate soil of tidal swampland face several obstacles, including iron toxicity that can reduce rice growth and yield. This paper describes how to control iron toxicity for increasing rice productivity in acid sulfate soils of tidal swamplands based on the research results. Iron toxicity control could be done through water management, amelioration and fertilizer application and using high yielding varieties (HYV’s) tolerant. Water management intermittently one week combined with delay planting 14 to 21 days increased rice growth and yield higher than that of being flooded continuously and flushing system. Amelioration using 5 t ha\(^{-1}\) of straw and Eleocharis dulcis compost increased rice growth and yield 16.4% compared with dolomite 2 t ha\(^{-1}\). Fertilizer 90 kg ha\(^{-1}\) N, 60 to 90 kg ha\(^{-1}\) P\(_2\)O\(_5\) and 100 to 125 kg ha\(^{-1}\) K\(_2\)O combined with seed treatment using CaO 75% of seed weight increased yield. Using HYV’s such as Margasari, Mendawak, Inpara 1, 2, 3, 6, 7, 8, and 9 also increased rice yield up to 31% compared with Margasari. By combining water management, amelioration and fertilizer application, using tolerant varieties rice could increase so that rice production can be significantly increased at acid sulfate soils of tidal swamplands.

1. Introduction

Acid sulfate soils are one type of tidal swamplands consisting of 4.37 million ha of potential acid sulphate soil and 2.37 million ha of actual acid sulphate soils [1]. Acid sulfate soils have the potential to develop rice, due to the vast availability of land and cultivation technology. Productivity level of tidal swamplands is generally low, due to physico-chemical problems such as a layer of pyrite (FeS\(_2\)). In flooding conditions, the soil pH increases which causes reduction of Fe\(^{3+}\) to Fe\(^{2+}\), so that Fe\(^{2+}\) concentration increases to thousands mg L\(^{-1}\) in soil solution. This phenomenon occurs especially in actual acid sulfate soils which is flooded by rain fall or high tide [2]. Fe\(^{2+}\) concentration of 300 to 400 mg kg\(^{-1}\) can causes iron toxicity in rice plants [3].

Iron toxicity is a physiological disorder of lowland rice plant nutrients associated with excessively dissolved Fe [4], salinity, P deficiency, low bases [3], multiple nutrient stress and low pH [5] and plant physiological conditions [6]. Since it was first reported byPonnampuruma in 1955, iron toxicity was one of main problems in rice production in several countries in Asia, Africa and South America [7, 8, 9]. In Indonesia iron toxicity occurs in rice fields in West Java, Sumatera, Kalimantan and in tidal rice fields in Sumatera, Kalimantan and Papua [10, 11, 12].

The causes of iron toxicity had been reported vary, such as high soil Fe concentration, low soil pH, nutrient deficiency and nutrient imbalance [13], poor drainage, poor root oxidation power, and application of organic matter that is not easily decomposed [14, 15], as well as environmental conditions such as water conditions in rice fields and positioning of location. Excessive iron uptake
increases activity of polyphenol oxidase enzyme so that production of polyphenols is high, resulting in leaf bronzing. Iron toxicity also reduces roots oxidizing power [14, 16].

Rice growth and yields in acid sulfate soils are strongly affected by iron toxicity. The yield reduction due to iron toxicity ranges 30 to 100% depending on tolerance of variety [17], intensity of toxicity [18, 19] and the soil fertility status [20]. Decreasing in rice yields grown on iron-toxic soils in Cilea, West Java was 52% lower than that of healthy plants [21]. In conditions of severe iron toxicity in Belawang District in South Kalimantan, rice plants could only produce 160 kg ha⁻¹ [22]. Research by Koesrini et al. [23] reported that soil acidity was very acidic (pH 3.99) contained high iron (181.89 ppm) in actual acid sulfate soils in Barambai. Average yield of Inpara variety was only 1.99 t ha⁻¹, lower than its potential yield which reaches 5.0 to 7.0 [24].

Iron toxicity can be controlled by water management, amelioration, fertilizing and planting the tolerant rice variety. This paper describes how to control iron toxicity for increasing rice productivity in acid sulfate soils at tidal swamplands based on the research results. By controlling iron toxicity, it is expected to increase rice production and productivity in acid sulfate soils of tidal swamplands.

2. Level concentration of Fe for iron toxicity

The critical limit for iron toxicity in young rice leaves is >300 to 500 mg kg⁻¹ at tillering phase until panicle initiation, while optimum limit is 100 to 150 mg kg⁻¹ Fe. Iron content in highly toxic plants (300 to 2,000 mg kg⁻¹ Fe), but critical Fe content depends on plant age and plant nutrient status [14, 25]. Critical limits are lower for soils with unbalanced nutrient content [14, 15]. Yoshida et al. [26] and Neue [27] stated that critical limit of toxicity in rice plant tissue is 300 mg kg⁻¹ Fe at maximum tiller phase, but critical Fe content among varieties could differ [28]. The concentration of critical toxicity caused yield loss of about 500 mg Fe kg⁻¹ leaf dry weight [29, 30].

Critical concentrations of Fe in growing media that inhibit rice growth were reported to be varied. Concentrations of 50 mg kg⁻¹ Fe could toxic rice [31], but at 500 mg kg⁻¹ or 1,000 mg kg⁻¹ Fe [32] did not affect plants. Research results of [8] reported that concentration of Fe in soil of 300 to 1,500 mg kg⁻¹ was a growing medium that caused iron toxicity.

The criteria used to determine toxic levels were plant growth, bronzing rate, and plant Fe content. Bronzing symptoms appear at concentrations of 100 to 500 mg kg⁻¹ in culture solution [32] and 300 to 400 mg kg⁻¹ in sufficiently nutrient soil [33]. The concentration of Fe differs from pH of soil solution, i.e. 100 mg kg⁻¹ Fe at pH 3.7 [32] and 100 mg kg⁻¹ Fe or more at pH 5.0 [34] and containing small amounts of K, P, Ca and Mg. Toxic plants with Fe had low leaf K levels (<1%), and a K: Fe ratio <17 to 18:1 for straw and <1.5:1 for roots [14].

This wide range is due to different criteria used, varieties, forms of Fe given, concentrations of other solutes, plant nutrient status, susceptibility of plants to different growth phases, and environmental factors such as temperature and solar radiation [7], as well as differences in root oxidation power and physiological status [3, 14].

Fe levels in plants of a variety correlate with degree of bronzing, but levels of Fe from different varieties could vary from 110 to 1,100 mg kg⁻¹ [35, 36]. Fe content in bronzing leaves was three to six times that of healthy leaves. Fe content in healthy leaves was about 0.05%, while in bronzing leaves 0.1 to 0.15% or more. Healthy plants could contain >0.1 to 0.15% Fe [4], so it was difficult to determine levels of critical Fe that could be generally applied in plant tissue. It was possible to use a comparison of Fe content of toxic leaves and healthy leaves on the same cropping area [7].

3. Iron toxicity control

Based on some research results, iron toxicity in acid sulfate tidal swamplands can be controlled in several ways, i.e. water management, amelioration, fertilization, and using tolerant varieties of iron toxicity. According to Doberman and Fairhurst [14] and Fairhurst and Dobermann [15], efforts to control iron toxicity in rice can be carried out through soil and water management, amelioration, fertilization, and using tolerant varieties.
3.1. Water management

Water management is one of the keys to success in increasing rice production in acid sulfate soils of tidal swamplands. The existence of tidal and natural dynamics caused soil to be in reductive and oxidative conditions. This is important in controlling iron toxicity, especially for suppressing ferro ion in reductive conditions. However, regulation of reductive and oxidative conditions can ensure sufficient water for rice growth especially during dry season. The results of water management research (continuous, intermittent, flushing) combined with planting time (0, 7, 14, 21 days) in acid sulfate soils in Belandean Research Station during dry season with very high Fe content in soil and acid soil with pH 4.36 had great potential to cause iron toxicity in rice plants being planted.

The intermittent water system showed dominance in increasing soil pH at planting 0, 7, and 14 days after application of water system. Planting time of 14 days showed the lowest soil pH. The intermittent water system and planting time of 14 days and 21 days after application of water system showed the lowest soil Fe content. A delay of planting 14 days to 21 days after initial flooding of tidal swamps was a safe time to plant HYV’s rice. Likewise, water system used i.e. intermittently (flooding and drying) one week apart, will be able to suppress soil Fe solubility so that it was safe for growth of HYV’s especially those sensitive to iron toxicity.

The highest number of tillers was obtained from intermittent water treatment and delayed planting time 14 and 21 days. The number of tillers was a variable that was directly related to results. Intermittent water treatment combined with planting delay 14 to 21 days was an effective treatment in increasing number of tillers. Intermittent water treatment and delayed planting time 14 and 21 days showed a low iron toxicity score, thus the treatment was able to control iron toxicity. The highest number of grains (168.7 grains) and fertile grains (140.2 grains) showed low iron toxicity, thus the treatment was able to control iron toxicity. The highest number of grains (168.7 grains) and fertile grains (140.2 grains) (table 1).

Treatment of intermittent water system showed the highest grain yield, i.e. 3.51 t ha$^{-1}$. The treatments flooding and flushing water system did not show any difference in results, i.e. 3.09 t ha$^{-1}$ and 3.10 t ha$^{-1}$, respectively. Treatment of delayed planting time 14 days and 21 days showed higher yields, while initial planting time (0 days) and delayed 7 days after the application showed not significantly differences. The highest yield was at 14 days of planting, followed by delayed 21 days, i.e. 3.37 t ha$^{-1}$ and 3.28 t ha$^{-1}$, respectively. Meanwhile, planting time for 0 and 7 days after water management application only showed grain yield about 3.15 t ha$^{-1}$ and 3.14 t ha$^{-1}$, respectively. Thus, to obtain high grain yield in acid sulfate soils, it is necessary to apply intermittent system accompanied by a delayed planting time 14 to 21 days after flooding (table 1).

Planting time is one strategy to reduce risk of iron toxicity in rice plants. At the beginning of irrigation, there is a relatively intensive washing, so the risk of iron toxicity was higher. Young plants or young seedlings were susceptible to iron toxicity; therefore, it was necessary to adjust planting time so that rice plants did not experience iron toxicity. Fe content in soil during rainy season was lower than dry season (table 2) [37]. This means that the risk of iron toxicity in rice plants in rainy season is higher. Even though Fe in soil is lower in rainy season, the solubility of ferro was higher which caused risk of iron toxicity. This is because during rainy season there was a more intensive dilution due to rain or water from upstream, and tidal movements of water in rivers. Changes in Fe levels in soil was determined by length of flooding. Based on the data collected, it was advisable to plant rice 2 to 3 weeks after flooding so that rice seedlings were not stressed by the change and increase of Fe levels in the soil.

Other research conducted in greenhouse and in field rice on acid mineral soils of new opened lands in Bandar Buat and Sitiung-I Research Station in rainy season 1985/1986 showed that intermittent drainage (drain 1 week and flooding 1-2 weeks) from planting to 30 days before harvesting could increase grain yield about 37% and 51% compared with flooding continuously (table 3). Increasing in yield with intermittent drainage was a positive effect of drying which reduced Fe$^{2+}$ solubility in soil, so that Fe uptake was reduced, while uptake of P, K, Ca and Mg plants increased (table 4).
Table 1. Scoring, growth, grain yield of Batanghari rice variety in potential acid sulfate soils, Belandean Research Station, dry season 2007.

| Treatment          | Fe tox. (score) | Tiller number | Grain number | Fertile grain number | Grain yield (t ha⁻¹) |
|--------------------|-----------------|---------------|--------------|----------------------|----------------------|
| Water system:      |                 |               |              |                      |                      |
| Flooding           | 3-5             | 11.4 a        | 131.2 a      | 106.2 a              | 3.09 a               |
| Intermittent       | 3               | 15.4 b        | 168.7 b      | 140.2 b              | 3.51 b               |
| Flushing           | 3-6             | 12.3 ab       | 128.8 a      | 105.9 a              | 3.10 a               |

| Planting time (after application of water system): | Treatment | Tiller number | Grain number | Fertile grain number | Grain yield (t ha⁻¹) |
|--------------------------------------------------|-----------|---------------|--------------|----------------------|----------------------|
| 0 day                                            | 3-4       | 11.7 a        | 134.3 a      | 111.8 a              | 3.15 a               |
| 7 days                                           | 4-6       | 12.2 a        | 136.3 a      | 117.8 a              | 3.14 a               |
| 14 days                                          | 3         | 13.9 b        | 146.5 a      | 121.3 a              | 3.37 b               |
| 21 days                                          | 3         | 14.2 b        | 154.5 a      | 118.9 a              | 3.28 ab              |

Numbers followed by the same letter are not significantly different (DMRT 5%)
Fe toxicity score: 1-2 very tolerant, 3 tolerant, 5 moderate, 7 susceptible, 9 very susceptible
Source: Khairullah et al. [38]; Khairullah and Sarwani [39].

Table 2. Dynamics of available-Fe in the soil during the dry and rainy seasons.

| Flooding time (weeks) | Dry season | Rainy season |
|-----------------------|------------|--------------|
| 2                     | 5.19       | 1.40         |
| 4                     | 9.84       | 1.53         |
| 6                     | 10.44      | 1.60         |
| 8                     | 8.12       | 1.67         |
| 10                    | 5.46       | 1.97         |
| 12                    | 3.06       | 2.15         |

Source: Masganti et al. [37].

Table 3. Effect of intermittent drainage on rice yield in pots and field, Bandar Buat and Sitiung I Research Station in wet season 1985/86.

| Treatment                                           | Grain yield |
|-----------------------------------------------------|-------------|
|                                                     | Pot (g pot⁻¹) | Field (t ha⁻¹) |
| Flooding continuously                               | 33.41       | 2.32           |
| Drain 1 week, interval 1 week                        | 25.63       | 3.40           |
| Drain 1 week, interval 2 weeks                       | 45.35       | 3.28           |
| Drain 1 week, interval 1 week²                       | 34.00       | 3.50           |
| Drain 1 week, interval 1 week¹                       | 45.86       | 3.28           |
| Drain 1 week, interval 2 weeks¹                      | 42.21       | 3.33           |
| Drain 1 week, interval 2 weeks²                       | 45.83       | 3.37           |

¹vegetative phase; ²generative phase
Source: Zaini et al.[40]; Burbey et al.[41].
The application of ameliorant to acid sulfate soils in tidal swamplands can control iron toxicity, increase rice growth and yield. Ameliorant in form of straw and purun tikus grass (*Eleocharis dulcis*) can be used to control iron toxicity. Purun tikus is dominant insitu weed that grows in acid sulfate soils. Aerobic composting of 5 t ha\(^{-1}\) straw and 5 t ha\(^{-1}\) *E. dulcis* could control iron toxicity and increase rice growth and yield. Application of *E. dulcis* compost up to 10 t ha\(^{-1}\) on 5 t ha\(^{-1}\) straw compost would reduce growth and grain yield of rice (table 6 and figure 1).

The reduction in iron toxicity symptoms and increased growth and yield of rice due to the application of purun tikus compost to the straw compost followed the quadratic regression equation pattern. The optimum level of purun tikus compost added to 5 t ha\(^{-1}\) straw compost for Inpara 1, Inpara 2, and IR64 were 5.14, 5.29, and 5.31 t ha\(^{-1}\), respectively. Although average grain yield per hill of

### Table 4. Effect of intermittent drainage on nutrient status of freshly opened lowland rice in pots, Bandar Buat Research Station in dry season 1986.

| Treatment                        | P (%) | K (%) | Ca (%) | Mg (%) | Fe (ppm) |
|----------------------------------|-------|-------|--------|--------|----------|
| Flooding continuously           | 0.08  | 0.78  | 0.24   | 0.20   | 387      |
| Drain 1 week, interval 1 week   | 0.10  | 0.80  | 0.33   | 0.23   | 229      |
| Drain 1 week, interval 2 week   | 0.09  | 0.86  | 0.34   | 0.23   | 265      |
| Drain 1 week, interval 1 week\(^1\) | 0.09 | 0.80  | 0.29   | 0.22   | 288      |
| Drain 1 week, interval 1 week\(^2\) | 0.10 | 0.98  | 0.37   | 0.26   | 140      |
| Drain 1 week, interval 2 week\(^1\) | 0.09 | 0.78  | 0.25   | 0.22   | 293      |
| Drain 1 week, interval 2 week\(^2\) | 0.12 | 0.93  | 0.40   | 0.24   | 167      |

\(^1\)vegetative phase, \(^2\)generative phase

Source: Zaini et al. [40].

The effect of drain time and duration for 6 and 9 days within 30 days after transplanting could increase grain yield by 2 and 3 times compared with that without drying. Drain time 6 and 9 day after transplanting yielded 25.6 g pot\(^{-1}\) and 23.5 g pot\(^{-1}\), meanwhile control treatment oly yielded 8.3 g pot\(^{-1}\). The same results were obtained by the drain of 3.6 and 9 days from 0 until 30 days after planting [41].

Drained land could also reduce the effect of iron toxicity but increase grain yields by 4.8, 8.5, and 1.7 times compared with that without leaching. With fertilizer application, the difference between with and without drainage was not significantly different. Based on the average results of several treatments it showed that drainage could increase yield by 50% in Banjit location. The effect of the leaching could reduce solubility of Fe\(^{2+}\) and improve soil aeration so that some nutrients were more available and gave better root development. In Setianegara location, the difference between with and without drainage was not significantly different (table 5). It was because in Banjit location, K content was classified as very high and the highest soluble Fe\(^{2+}\) level was 23.9 ppm after 6 weeks of flooding, so the effect of drainage was not visible. According to Tanaka A and Yoshida [42] and Ismunadji et al. [21], iron toxicity in lowland rice was related to the role of potassium. The higher K content of plant resulted in better rice growth.

### Table 5. Effect of land drained in Podzolik soils in Setianegara and Banjit in Central Lampung District and Sitiung I in West Sumatera.

| Treatment | Grain yield (g pot\(^{-1}\)) |
|-----------|-----------------------------|
|           | Setianegara | Banjit | Sitiung |
|           | WF | F | Average | WF | F | Average | WF | F |
| No leaching | 0.6 | 24.5 | 13.5 | 0.4 | 21.9 | 10.3 | 1.3 | - |
| Leaching   | 2.9 | 20.1 | 13.6 | 3.4 | 23.0 | 15.7 | 2.2 | 68.2 |

WF = without fertilizer, F = fertilizer NPK

Source: Adiningsih and Sudjadi [43]; Taher and Misran [44].

### 4. Amelioration

The application of ameliorant to acid sulfate soils in tidal swamplands can control iron toxicity, increase rice growth and yield. Ameliorant in form of straw and purun tikus grass (*Eleocharis dulcis*) can be used to control iron toxicity. Purun tikus is dominant insitu weed that grows in acid sulfate soils. Aerobic composting of 5 t ha\(^{-1}\) straw and 5 t ha\(^{-1}\) *E. dulcis* could control iron toxicity and increase rice growth and yield. Application of *E. dulcis* compost up to 10 t ha\(^{-1}\) on 5 t ha\(^{-1}\) straw compost would reduce growth and grain yield of rice (table 6 and figure 1).
Inpara 1 was the highest, but IR64 had the largest percentage increase in grain yield. This means that IR64 was more responsive to application of straw and *E. dulcis* compost in acid sulfate soils of tidal swamplands. This was understandable because IR64 was a HYV that was also responsive to fertilizer. Thus, application of straw and *E. dulcis* compost could increase higher grain yield of IR64, although grain yield was still lower than that of tolerant variety of Inpara 1 and Inpara 2 which prevented iron toxicity.

**Table 6.** Growth and yields of three rice varieties treated with straw and *E. dulcis* compost, greenhouse ISARI.

| Organic matter | Tiller number | Dry root weight (g) | Index of root resistant | Fe tox. symptom* | Grain yield (g/hill) |
|----------------|---------------|---------------------|-------------------------|-----------------|---------------------|
| Control        | 13.4 e        | 2.22 e              | 0.18 e                  | 6.11 a          | 8.25 e              |
| Control fresh water | 14.8 d        | 3.11 d              | 0.23 d                  | 5.55 ab         | 13.25 d             |
| 5 t ha\(^{-1}\)S + 0 t ha\(^{-1}\) Ed | 17.0 c        | 3.82 c              | 0.30 c                  | 5.00 bc         | 18.50 c             |
| 5 t ha\(^{-1}\)S + 2.5 t ha\(^{-1}\) Ed | 19.0 b        | 4.61 b              | 0.40 b                  | 3.56 d          | 22.94 b             |
| 5 t ha\(^{-1}\)S + 5.0 t ha\(^{-1}\) Ed | 20.4 a        | 5.22 a              | 0.46 a                  | 2.33 e          | 27.17 a             |
| 5 t ha\(^{-1}\)S + 10.0 t ha\(^{-1}\) Ed | 17.4 c        | 3.99 c              | 0.33 c                  | 4.33 c          | 19.35 c             |
| Inpara 1       | 18.1 x        | 4.33 x              | 0.35 x                  | 4.11 y          | 21.59 x             |
| Inpara 2       | 17.4 x        | 4.07 x              | 0.33 x                  | 4.50 xy         | 19.56 y             |
| IR64           | 15.6 y        | 3.08 y              | 0.27 y                  | 4.83 x          | 13.57 z             |
| CV             | 8.16          | 7.41                | 6.51                    | 12.96           | 6.88                |

Numbers in a column followed by the same letter were not significantly different based on DMRT5%

\^Fe tox. symptom score: 1-2 very tolerant, 3 tolerant, 5 moderate, 7 susceptible, 9 very susceptible

Source: Khairullah and Sarwani [39].

Improved cultivation methods using ameliorant could increase grain yield. The farmers method with anaerobic organic matter management could increase grain yields, although it was not as good as giving dolomite 2 t ha\(^{-1}\). Application of 5 t ha\(^{-1}\) straw compost and 2.5 t ha\(^{-1}\) *E. dulcis* compost could increase grain yield which was not different from dolomite application of 2 t ha\(^{-1}\). Application of *E. dulcis* compost to 5 t ha\(^{-1}\) increased grain yields more than that by the application of 2.5 t ha\(^{-1}\) *E. dulcis* compost and 2 t ha\(^{-1}\) dolomite (table 7).

![Figure 1. Relationship between purun tikus compost level and grain yield on three rice varieties, greenhouse ISARI, rainy season 2010. Source: Khairullah and Sarwani [39].](image-url)
Table 7. Amelioration treatment on three rice varieties in acid sulfate soil in Belandean.

| Ameliorant                        | Grain yield (t ha\(^{-1}\)) | Average Varieties | Average |
|-----------------------------------|-------------------------------|-------------------|---------|
|                                    | Inpara 1 | Inpara 2 | IR64 |           |
| Control                           |          |          |      | 2.78 d    |
| Farmer’s method                   |          |          |      | 3.59 c    |
| Dolomite 2 t ha\(^{-1}\)          |          |          |      | 4.15 b    |
| Straw 5 t ha\(^{-1}\) + E. dulcis 2.5 t ha\(^{-1}\) |          |          |      | 4.20 b    |
| Straw 5 t ha\(^{-1}\) + E. dulcis 5.0 t ha\(^{-1}\) |          |          |      | 4.83 a    |
| Average                           |          |          |      | 4.45 x    |

Numbers followed by the same letter are not significantly different (DMRT 5%).

Source: Khairullah [45].

Application 5 t ha\(^{-1}\) straw and 5 t ha\(^{-1}\) E. dulcis compost showed the highest grain yield. The treatment increased grain yield by 73.4%, 34.5% and 16.4%, respectively compared with without ameliorant, farmer's method, and dolomite 2 t ha\(^{-1}\). Inpara 1 had the highest yield which was not different from Inpara 2, while IR64 had the lowest grain yield. Although grain yield of Inpara 1 was the highest, but IR64 had the largest percentage increase in yield (table 8). Application 5 t ha\(^{-1}\) straw and 5.0 t ha\(^{-1}\) E. dulcis compost increased grain yield of IR64 almost two times compared with that without ameliorant [45].

This increase was much greater than that of Inpara 1 and Inpara 2, which only ranged from 65-67.8% compared to those without ameliorant. This means that IR64 was more responsive to application of ameliorant, in this case the organic matter of straw compost and purun tikus compost and dolomite in acid sulphate tidal swamplands. Thus, application ameliorant could increase higher yield of IR64 grain, although grain yield was still lower than Inpara 1 which was resistant and Inpara 2 which prevents iron toxicity.

Table 8. Percentage of Inpara 1, Inpara 2 and IR64 due to ameliorant treatment in acid sulfate soil of Belandean.

| Ameliorant                        | Increasing grain yield (%) | Inpara 1 | Inpara 2 | IR64 |
|-----------------------------------|---------------------------|---------|---------|------|
| Control                           | -                         | -       | -       | -    |
| Farmer’s method                   | 25.9                      | 27.8    | 36.1    |
| Dolomite 2 t ha\(^{-1}\)          | 43.5                      | 43.9    | 67.7    |
| Straw 5 t ha\(^{-1}\) + E. dulcis 2.5 t ha\(^{-1}\) | 46.5                    | 44.5    | 69.4    |
| Straw 5 t ha\(^{-1}\) + E. dulcis 5.0 t ha\(^{-1}\) | 67.8                    | 65.0    | 96.9    |

Source: Khairullah [45].

5. Fertilizer

Iron toxicity in paddy fields is not only caused by low pH and high Fe, but also caused by deficiencies of K, P, Ca, Mg, Mn and soil organic matter content [46, 47]. Fertilizer P and K combined with seed treatment using lime could control iron toxicity and increase rice growth and yield. Combination CaO 75% of seed weight + 90 kg ha\(^{-1}\) P\(_2\)O\(_5\) + 100-125 kg ha\(^{-1}\) K\(_2\)O was a better combination than other treatments. Soil pH increased especially at age 9 WAT, and P rate 60 kg ha\(^{-1}\) P\(_2\)O\(_5\) and K rate 100 kg ha\(^{-1}\) K\(_2\)O showed the lowest dissolved soil Fe content [48].

At age of 3 WAT, increasing K to 75 kg ha\(^{-1}\) K\(_2\)O will reduce plant Fe. P fertilizer was more effective in reducing plant F, where rate of 120 kg ha\(^{-1}\) P\(_2\)O\(_5\) showed the lowest plant Fe (0.257% Fe). The highest grain yield was shown by treatment of 75-90-125 (3.65 t ha\(^{-1}\) which was not different from all rates of K fertilizer ranging from 25-100 kg ha\(^{-1}\) at treatment of 75% seed and P rate of 90 kg ha\(^{-1}\). Increasing rate of P fertilizer to 150 kg ha\(^{-1}\) was not different from K fertilizer in grain yields. The
combination of 75% seed treatment and 90 kg ha\(^{-1}\) P\(_2\)O\(_5\) and 100 kg ha\(^{-1}\) K\(_2\)O was an efficient for grain yield [48].

Research by [21] on Cihea soil resulted in potassium deficiency that could cause iron toxicity. But it could be corrected by K fertilizer. Application of 60 kg/ha K\(_2\)O with both KCl and K\(_2\)SO\(_4\) fertilizers could increase yields two times compared with that only N and P (table 9). Plant K levels increased from 0.35 to 1% and Fe levels decreased from 214 ppm to 167 and 139 ppm. Other studies gave information that application of 1 t ha\(^{-1}\) of lime or 5 t ha\(^{-1}\) of manure in addition to NPK can increase yields by one to two times higher than that of NPK (table 10).

### Table 9. Effect of potassium on grain yield and nutrient content of IR5 in Cihea West Java.

| Fertilizer (kg/ha) | Nutrient status | Yield | N | P | K | Ca | Mg | Fe | Mn |
|-------------------|-----------------|-------|---|---|---|----|----|----|----|
|                   | N               | P     | K | Ca | Mg | Fe | Mn |
| N                 | P\(_2\)O\(_5\)  | K\(_2\)O | t ha\(^{-1}\) | 2.96 | 0.76 | 0.39 | 0.35 | 0.33 | 0.14 | 214 | 48 |
| 90                | 60              | 0     | 5.59 | 0.61 | 0.44 | 1.00 | 0.34 | 0.12 | 167 | 45 |
| 90                | 60              | 60\(^1\) | 5.93 | 0.62 | 0.46 | 1.00 | 0.35 | 0.12 | 139 | 53 |
| 90                | 60              | 60\(^2\) |  |   |   |   | | | | |

K source of K\(_2\)O: \(^{1}\)KCl and \(^{2}\)K\(_2\)SO\(_4\)
Source: Burbey [41].

### Table 10. Effect of NPK fertilizer, lime, and manure in lowland in new opened lowland, Riau.

| Treatment | Uwai\(^1\) | Air Tiris\(^2\) | Air Tiris\(^3\) | Air Tiris\(^4\) |
|-----------|------------|----------------|----------------|----------------|
| Control   | 1.68       | 3.03           | 3.03           | 3.03           |
| NPK       | 3.23       | 3.95           | 4.90           | 4.79           |
| NPK + 1 t ha\(^{-1}\) CaCO\(_3\) | 4.10 | 4.91 | 5.80 | 5.84 |
| NPK + 5 t ha\(^{-1}\) manure | 3.93 | 4.92 | 5.40 | 5.54 |

\(^{1}\)45 kg ha\(^{-1}\) N + 45 P\(_2\)O\(_5\) + 60 K\(_2\)O; \(^{2}\)\(\frac{1}{2}\) of 90 kg ha\(^{-1}\) N + 90 P\(_2\)O\(_5\) + 60 K\(_2\)O; \(^{3,4}\) 90 kg ha\(^{-1}\) N + 90 P\(_2\)O\(_5\) + 60 K\(_2\)O ha.
Source: Jalid and Hirwan [49]; Burbey and Yusril [50].

### 6. Tolerant varieties

Tolerant rice varieties of iron toxicity can come from specific HYV’s and local varieties of tidal swampland. The research resulted in acid sulfate tidal swampland in Belandean Res. Sta. South Kalimantan and Palingkau village Central Kalimantan in dry season 2004 showed that HYV’s Margasari and Mendawak were able to grow and give yields of 3.06 t ha\(^{-1}\) and 2.89 t ha\(^{-1}\) (Belandean) and 3.00 t ha\(^{-1}\) and 2.87 t ha\(^{-1}\) (Palingkau). Soil pH and soil Fe in Belandean were 4.36 and 569.4 ppm, while in Palingkau were 3.80 and 869.8 ppm respectively. Soil pH and soil Fe concentration could be toxic to rice plants. Fe\(^{2+}\) concentrations of 300 to 400 ppm were highly toxic to rice and resulted in low plant nutrient availability [3].

Some HYV’s were tested for their adaptability in tidal swamplands by Noor et al. [51] during the 2006 dry season. The results showed that Indragiri variety was the most tolerant of iron toxicity, and it had the lowest score of toxicity and highest productivity (table 11). Other results also reported by Mildaeirizanti [52], yield components and grain yield of two HYV’s cultivated in new opened rice field. Performance and productivity of Inpara 3 variety was higher than Inpari 30 variety. Productivity of Inpara 3 variety reached 6.3 t ha\(^{-1}\), while Inpari 30 variety was only 5.7 t ha\(^{-1}\), but higher than Ciherang variety 3 t ha\(^{-1}\).
Table 1. Scores of iron toxicity and grain yield of several varieties.

| Varieties   | Fe toxicity score⁵ | Grain yield (t ha⁻¹) |
|-------------|--------------------|----------------------|
| Indragiri   | 2                  | 4.56                 |
| Air Tenggulang | 2.3             | 4.11                 |
| Ciharang    | 3                  | 3.75                 |
| Lambur      | 2.3                | 3.65                 |
| Bondoyudo   | 4                  | 3.23                 |
| IR64        | 1.3                | 3.34                 |
| Margasari   | 2-3                | 3.24                 |

Fe tox. score: 1-2 very tolerant, 3 tolerant, 5 moderate, 7 susceptible, 9 very susceptible.

⁵Standard Evaluation System for Rice, IRRI (1996).

Source: Noor et al 2007 [51].

The HYV’s of Lambur on acid sulfate land with soil Fe concentration of 866.5 ppm and soil pH of 3.63 was able to give a yield of 3.17 t ha⁻¹ and was higher than susceptible variety for iron toxicity IR64 which yielded 1.94 t ha⁻¹ [53]. Martapura variety at soil pH conditions of 4.66 and soil Fe concentration 1064.9 ppm in Belandean were able to produce 3.45 t ha⁻¹ [54]. Likewise, Inpara 1 and Inpara 2 were able to adapt well to acid sulfate tidal swamplands [44].

On acid sulfate soils that have just been cleared or have undergone oxidation, local varieties can be planted. The local varieties characterized in field did not show any visual symptoms of iron toxicity. This might be due to seedlings age (about 4 months) that were already strong and big when they were planted. In addition, it was also possible on the condition of rice fields has begun to decrease in dissolved iron levels in the soil so that the seedling was protected from iron toxicity. Based on the results of research by Khairullah et al. [55], there was a mechanism for iron toxicity tolerance in local rice varieties, i.e. prevention mechanism.

Inpara 1, 2, 3, 6, 7, 8, 9 and 10 were improved from crossing lines or varieties that had superior traits, while Inpara 4 and 5 varieties were introduced by IRRI which had good adaptability in swamps (table 12). Inpara 4 variety comes from Swarna-Sub1 line (IR05F101). This variety was developed from a variety that was widely developed in India and Bangladesh, i.e. Swarna which was improved by introducing sub1 gene that was submergence tolerant. The gene comes from local variety FR13A. Meanwhile, Inpara 5 variety comes from IR 64 sub1 line (IR07F102) which had potential to be developed in flood-prone areas in shallow lowland swamps and coastal rice fields [56].

Table 12. Yield potential and Fe toxicity of Inbrid rice varieties (Inpara).

| Varieties      | Grain yield (t ha⁻¹) | Tolerance to |
|----------------|----------------------|--------------|
| Inpara 1       | 6.5                  | Fe, Al tox   |
| Inpara 2       | 6.1                  | Fe, Al tox   |
| Inpara 3       | 5.6                  | Fe, Al tox and submergence |
| Inpara 4       | 7.6                  | submergence  |
| Inpara 5       | 7.2                  | submergence  |
| Inpara 6       | 6.0                  | Fe           |
| Inpara 7       | 5.1                  | Fe, Al       |
| Inpara 8 Agritan | 6.0              | Fe           |
| Inpara 9 Agritan | 5.6                | Fe           |
| Inpara 10 BLB  | 6.8                  | Fe           |

⁶Balai Besar Penelitian Tanaman Padi [24].

The yield potential of Inpara was above 5 t ha⁻¹, so it was quite prospective to be developed in its adapted area. Inpara varieties has a shorter age than local varieties which was 6-9 months old (>165 days). Inpara 5, Inpara 6 and Inpara 7 are classified as early age (105-124 days), while Inpara 1, Inpara
2. Inpara 3 and Inpara 4 were classified as medium age (125-164 days). All Inpara varieties have an upright plant shape like other high yielding varieties, so they were effective in receiving light for photosynthesis. Semi tolerance dwarf swamp rice plant height (<110 cm) were Inpara 2, 3, 4, 5, 6 and 7 varieties, while medium plant height (110-130 cm) was Inpara 1.

7. Conclusions
Control of iron toxicity in acid tidal swamplands can be done through water management, amelioration, application of fertilization, and use of high yielding varieties of iron toxicity tolerant. Intermittent water management increased rice growth and yield higher than that of being flooded continuously by 13.6% and/or flushing system by 13.2%. Intermittent system after one week was accompanied by a delay in planting time of 14 days to 21 days after being flooded. Application of 5 t ha\(^{-1}\) straw compost and 5 t ha\(^{-1}\) purun tikus (E. dulcis) compost also increased rice growth and yield by 16.4% compared with that of dolomite rate 2 t ha\(^{-1}\). Fertilization of P 90 kg ha\(^{-1}\) P\(_2\)O\(_5\) and K 100 to 125 kg ha\(^{-1}\) K\(_2\)O combined with seed treatment using CaO 75% of seed weight increased rice growth and grain yield. Likewise, fertilizer application of 90 kg ha\(^{-1}\) N, 60 kg ha\(^{-1}\) P\(_2\)O\(_5\) and 60 kg ha\(^{-1}\) K\(_2\)O could also increase rice yield. Using adaptive and high yielding varieties (HYV’s) such as Margasari, Lambur, Indragiri, Air Tenggulang, Mendawak, Inpara 1, 2, 3, 6, 7, 8, and 9 also increased rice yield up to 31% compared with Margasari. By combining water management, ameliorant and fertilizer application, and use tolerant varieties rice in acid sulfate soil of tidal swamplands could increase grain yield so that rice production can be significantly increased.

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