The Effect of Straw and Purun Tikus (*Eleocharis dulcis*) Compost to Rice Physiological Traits, Iron Toxicity and Grain Yield on Acid Sulfate Soils

Izhar Khairullah\(^1\)*, Didik Indradewa\(^2\), Azwar Maas\(^2\), and Prapto Yudono\(^2\)

\(^{1}\)Indonesian Swampland Agricultural Research Institute (ISARI), Jl Kebun Karet, Lotabat Utara, Banjarbaru, Kalimantan Selatan, Indonesia. 
\(^{2}\)Plant Physiologist, Soil Science, and Agronomist of Agricultural Faculty, Gadjah Mada University, Yogyakarta Indonesia

*Corresponding author: Izhar.balittra@gmail.com*

Abstract. The experiment was aimed to determine the effect straw and *Eleocharis dulcis* compost on physiological traits and grain yield of rice grown in acid sulfate. The experiment was conducted in 2010 WS in greenhouse of ISARI, Banjarbaru. The soils was sampled from rice fields of acid sulfate soil. The experiment was employed Factorial CRD, in which first factor was three varieties and second factor were six rates straw and *E. dulcis* compost. Variables observed were physiological traits (root length, stomatal density, transpiration rate, total chlorophyll content, polyphenol oxidase and peroxidase activity), Fe toxicity symptoms and grain yield. The result showed that application of 5.0 t ha\(^{-1}\) straw and 5.0 t ha\(^{-1}\) *E. dulcis* compost resulted in the best physiological traits of rice plants, decreased Fe toxicity, but led to increase in grain yield. Inpara 1 was more tolerant to iron toxicity, better physiological traits, lower Fe toxicity symptoms, and higher grain yield compared to Inpara 2. On the other hand, IR64 was susceptible to iron toxicity and the lowest observed. Results of the experiment demonstrate that increasing rate of applied *E. dulcis* compost up to 5 t ha\(^{-1}\) may increase physiological traits and grain yield and decrease Fe toxicity symptoms.

Key words: rice, physiological traits, straw, *Eleocharis dulcis*, compost, acid sulfate soils

1. Introduction
Iron toxicity is a physiological disease of nutrients in paddy field associated with excess dissolved Fe [1] and is one of the main problems in rice production. Iron toxicity could be prevented by using tolerant varieties, crop management, soil and water management, and fertilization and amelioration [2][3]. The simplest control was by using resistant varieties [4] and keeping soil in a flooded condition before planting [5]. The use of compost could maintain soil reduction conditions so as to reduce iron toxicity. Organic acids released by organic matter may chelate dissolved Fe so that availability of excess Fe can be reduced. [6] reported that organic acids play an important role in suppressing solubility of metal ions by forming chelates, while [7] stated that application of rice straw could reduce Fe and sulfate concentrations and increase availability of K and yield of rice in acid sulfate soils.

Rice varieties differ in their tolerance to Fe toxicity [8] due to differences in root structure that were closely related to movement of oxygen from canopy to roots through aerenchyma and differences in excretion of OH ions [9]. Varieties that exclude less OH ions and tend to decrease pH of media were called iron-efficient varieties that were able to absorb more Fe. Conversely, varieties
whose roots excluded a lot of OH ions and increase pH of media were called inefficient varieties of iron which absorb less Fe [10]. Planting tolerant rice varieties to iron toxicity is an effort to reduce iron toxicity while increasing yields [11][2][3].

In addition to varieties that were tolerant to iron toxicity, one way to control iron toxicity and increase rice yield is by using organic matter such as straw and purun tikus (Eleocharis dulcis). Eleocharis dulcis was dominant weed growing in acid sulfate tidal swamplands, especially in South and Central Kalimantan. Eleocharis dulcis can grow naturally on land and grow in the rice fields, especially after harvest. Its potential is around 2.5 - 10 t ha⁻¹, depending on its density and growing old. Organic matter can improve soil structure, added nutrients, improved soil biological properties, and dissolved excess micro nutrients such as Fe which is dominant in acid sulfate soils.

To overcome the problem of anaerobic composting and lime application, it is necessary to innovate by utilizing local organic matter resources (insitu) such as straw and purun tikus (Eleocharis dulcis), however the method of composting organic matter was carried out aerobically which had several advantages, among others time required was relatively quicker to do easily, it's cheaper, and environmentally safely. This method can reduce loss of nutrients during process of decomposition of organic matter and could suppress iron toxicity because of its role in chelating excess Fe dissolved, and in the long time could preserve fertility of the paddy field. The aim of this experiment was to determine the effect of application straw and purun tikus (Eleocharis dulcis) compost on physiological traits, iron toxicity symptoms, and grain yield of three different rice varieties which had tolerance levels of iron toxicity in acid sulfate soils.

2. Materials and Methods

The research was conducted in The Greenhouse of Indonesian Swamplands Agriculture Research Institute (ISARI) in Banjarbaru, South Kalimantan (S -3°26’9”, E 114°48’20”) on May to December 2010. Soils were sampled from paddy field of acid sulfate soils type B of tidal swampland in the Belandean Experimental Station, the Barito Kuala District, South Kalimantan.

The experiment employed was the Randomized Completely Design with two factors. The first factor was three varieties of lowland rice that different level of resistance to iron toxicity, i.e. Inpara 1 (tolerant), Inpara 2 (avoidant), and IR64 (susceptible to Fe toxicity). Factor II were straw and Eleocharis dulcis compost, consisted of six quantities, namely:

\[ B_0 = \text{Control (without straw and Eleocharis dulcis compost) with fixed waterlogged.} \]
\[ B_1 = \text{Control (without straw and Eleocharis dulcis compost) with waterlogged replaced every two weeks}. \]
\[ B_2 = \text{Straw compost 5.0 t ha}^{-1} + \text{Eleocharis dulcis compost 0.0 t ha}^{-1} \]
\[ B_3 = \text{Straw compost 5.0 t ha}^{-1} + \text{Eleocharis dulcis compost 2.5 t ha}^{-1} \]
\[ B_4 = \text{Straw compost 5.0 t ha}^{-1} + \text{Eleocharis dulcis compost 5.0 t ha}^{-1} \]
\[ B_5 = \text{Straw compost 5.0 t ha}^{-1} + \text{Eleocharis dulcis compost 10.0 t ha}^{-1} \]

Soils were taken in a layer of 0-20 cm, mixed then weighed eight kg and put in plastic pot. The soils were analyzed for soil chemical properties. The straw and Eleocharis dulcis compost were added to the experimental plot in accordance with the treatment. The mixtures of soil and compost were evenly homogenized, then flooded to height of five cm for two weeks before planting. Waterlogged of control treatments were replaced every two weeks (B₁) by taking out the remaining water from the experimental plots and then replaced with fresh water collected from tidal swampland in the Belandean Experimental Station.

The 21-days seedlings were transplanted into experiential pots with two seedling per pot. The fertilizers N, P, and K were applied to the pots with the rate of 90 kg N ha⁻¹, 60 kg P₂O₅ ha⁻¹ and 60 kg K₂O ha⁻¹, respectively. The application of N fertilizer was carried out three times: a-third part at 7 days after planting (DAP) together with all P and K fertilizer rate. A second part of N fertilizer was applied at 28 DAP, and a third part was added to the pots at primordial stage. Plant protection management including pest and disease control and pull out weeds were done intensively. Embroidering plants were conducted at seven DAP old. Flooding was done manually to maintain the
water level at around 2-3 cm from soil surface. Water used for flooding was originated from acid sulfate soils of tidal swampland in the Belandean Experimental Station, the Barito Kuala District. The water was taken at high tide, and then collected in a plastic drum.

The physiological traits of rice plants observed were the length and surface area of roots, relative water content (RWC) of plant, density and width of stomata opened, transpiration rate, total chlorophyll content, and activity of polyphenol oxidase (PPO) and peroxidase (POD). Data were analyzed by analysis for variance (ANOVA) and the mean comparison of DMRT 5% using the SAS for Windows Version 9 Software.

3. Results and discussion

3.1. Soil Characteristics

Characteristics of acid sulfate soils of tidal swampland used as planting media is shown in Table 1. The soil pH was low (very acidic), so K and Ca content and base saturation was very low. Preliminary initial Fe content of 596.25 ppm was high in acid sulfate soils. Such soil characteristics could be a limiting factor for rice growth. This was coupled with high soil Fe content which can cause iron toxicity to rice plants. The analysis of rice straw and *Eleocharis dulcis* showed that rice straw had higher levels of N, P, Ca, Mg compared to *E. dulcis*, but lower for K and Fe contents (Table 2).

| Characteristic                      | Value     | Degree       |
|-------------------------------------|-----------|--------------|
| pH (H$_2$O)                         | 4.15      | Very acid    |
| pH (KCl)                            | 3.65      |              |
| EC (mS cm$^{-1}$)                   | 0.068     |              |
| N-total (%)                         | 0.252     | Moderately   |
| P-Bray1 (mg kg$^{-1}$ P$_2$O$_5$)   | 42.39     | High         |
| Al$_{ex}$ (cmol(+)+ kg$^{-1}$)      | 4.20      |              |
| H$_{ex}$ (cmol(+)+ kg$^{-1}$)       | 1.50      |              |
| Ca$_{ex}$ (cmol(+)+ kg$^{-1}$)      | 0.895     | Very low     |
| Mg$_{ex}$ (cmol(+)+ kg$^{-1}$)      | 1.561     | Moderately   |
| K$_{ex}$ (cmol(+)+ kg$^{-1}$)       | 0.095     | Very low     |
| Na$_{ex}$ (cmol(+)+ kg$^{-1}$)      | 0.610     | Moderately   |
| CEC                                 | 72.5      | Very high    |
| Base Saturation (%)                 | 4.36      | Very low     |
| SO$_4$ (mg kg$^{-1}$)               | 40.843    |              |
| Fe (mg kg$^{-1}$)                   | 596.25    | High         |

Ca$_{ex}$, Mg$_{ex}$, K$_{ex}$, Na$_{ex}$, and CEC extracted with NH$_4$Cl

Table 1: Soils properties of acid sulfate soils type B at the Belandean Experiment Station, Barito Kuala District, South Kalimantan, 2010 WS
Table 2: Chemical analysis of composted straw and purun tikus (*E. dulcis*), the Greenhouse ISARI Banjarbaru, 2010 WS

| Characteristic     | Straw   | *Eleocharis dulcis* |
|--------------------|---------|---------------------|
| C-organik (%)      | 31.283  | 37.834              |
| N-total (%)        | 1.76    | 1.95                |
| C/N                | 17.77   | 19.40               |
| K₂O (%)            | 0.940   | 1.595               |
| P (%)              | 0.295   | 0.056               |
| Ca (%)             | 1.014   | 0.907               |
| Mg (%)             | 0.089   | 0.079               |
| Fe (ppm)           | 0.182   | 0.278               |

3.2. Physiological Traits
The physiological traits of rice plant observed or measured were root length and surface areas, the relative water content of rice plant, the density and width of stomata opening, transpiration rate, total chlorophyll content, and enzymes activity of polyphenol oxidase (PPO) and peroxidase (POD). There were interaction between compost and varieties on stomatal opened width and POD, while other variables were only significantly affected by compost or variety.

Length and surface area of rice root and plant relative water content (RWC). Length and surface area of rice root and plant water content significantly affected by treatments of organic matter and rice varieties. Control with water replaced and application of straw compost 5 t ha⁻¹ only increased roots length. The increase in root length was due to control with water replaced and application 5 t ha⁻¹ straw compost was not significantly different. Root length increased if the application of 5 t ha⁻¹ straw compost coupled with *E. dulcis* compost to 5 t ha⁻¹, but replaced *E. dulcis* compost to 10 t ha⁻¹ resulted in reduction in root length. The Inpara 1 and the Impara 2 varieties had the longest root, while the IR64 has the shortest root (Table 3).

Table 3: Root length, surface area, and relative water content (RWC) of three rice varieties applied with organic matter straw and *E. dulcis* composts at Greenhouse ISARI Banjarbaru, 2010 WS

| Treatment                          | Root length (m) | Root surface area (cm²) | RWC (%) |
|------------------------------------|-----------------|-------------------------|---------|
|                                    |                 |                         |         |
| **Organic matter**                 |                 |                         |         |
| Control                            | 19.13           | d                       | 60.14   |
| Control with water replaced        | 23.23           | c                       | 65.38   |
| 5.0 t ha⁻¹ S + 0.0 t ha⁻¹ *Ed*     | 25.83           | c                       | 70.78   |
| 5.0 t ha⁻¹ S + 2.5 t ha⁻¹ *Ed*     | 33.89           | b                       | 75.47   |
| 5.0 t ha⁻¹ S + 5.0 t ha⁻¹ *Ed*     | 40.89           | a                       | 81.30   |
| 5.0 t ha⁻¹ S + 10.0 t ha⁻¹ *Ed*    | 30.81           | b                       | 73.21   |
| **Varieties**                      |                 |                         |         |
| Inpara 1                           | 32.89           | x                       | 75.80   |
| Inpara 2                           | 30.92           | x                       | 71.11   |
| IR64                               | 23.08           | y                       | 66.23   |

*Number a column followed by the same letter are not significantly different based on the DMRT 0.05.  S = straw compost; *Ed* = *Eleocharis dulcis* compost
Water replaced did not increase root surface area, while application straw compost 5 t ha\(^{-1}\) increased it. Increasing in root surface area was observed with application 5 t ha\(^{-1}\) straw and \(E.\) \textit{dulcis} compost to 5 t ha\(^{-1}\), but increasing \(E.\) \textit{dulcis} compost to 10 t ha\(^{-1}\) led to decreasion in root surface area. Inpara 1 and Inpara 2 had the widest root surface, while IR64 has the narrowest it (Table 3). Increasing in root length due to application of \(E.\) \textit{dulcis} compost to straw compost followed pattern of quadratic regression equations. The optimum levels of \(E.\) \textit{dulcis} compost added to straw compost 5 t ha\(^{-1}\) for Inpara 1, Inpara 2, and IR64 were 5.31, 5.35, and 5.37 t ha\(^{-1}\), respectively. Inpara 1 had a maximum root length relatively longer than Inpara 2, while IR64 had a relatively shorter maximum root length (Table 4).

| Variable             | Reg. equation | X optimum | Y maximum |
|----------------------|---------------|-----------|-----------|
| Root length (m)      |               |           |           |
| Inpara 1             | \(y = -0.512x^2 + 5.801x + 29.29\) | 5.67      | 78.58     |
|                      | \(R^2 = 0.729\)                           |           |           |
| Inpara 2             | \(y = -0.414x^2 + 4.648x + 28.42\)       | 5.61      | 67.56     |
|                      | \(R^2 = 0.812\)                           |           |           |
| IR64                 | \(y = -0.467x^2 + 5.220x + 18.05\)       | 5.59      | 61.81     |
|                      | \(R^2 = 0.861\)                           |           |           |
| Surface area (cm\(^2\)) |               |           |           |
| Inpara 1             | \(y = -3.708x^2 + 39.24x + 302.9\)       | 5.29      | 614.34    |
|                      | \(R^2 = 0.731\)                           |           |           |
| Inpara 2             | \(y = -3.399x^2 + 37.64x + 284.5\)       | 5.54      | 597.12    |
|                      | \(R^2 = 0.702\)                           |           |           |
| IR64                 | \(y = -3.508x^2 + 39.63x + 177.2\)       | 5.65      | 513.00    |
|                      | \(R^2 = 0.728\)                           |           |           |
| Relative water content (%) |           |           |           |
| Inpara 1             | \(y = -0.281x^2 + 3.069x + 75.86\)       | 5.46      | 99.38     |
|                      | \(R^2 = 0.717\)                           |           |           |
| Inpara 2             | \(y = -0.330x^2 + 3.593x + 70.29\)       | 5.44      | 99.63     |
|                      | \(R^2 = 0.715\)                           |           |           |
| IR64                 | \(y = -0.377x^2 + 4.213x + 64.30\)       | 5.59      | 98.61     |
|                      | \(R^2 = 0.762\)                           |           |           |

Table 4: Quadratic regression equations of root length and surface area, and plant relative water content (RWC) of three rice varieties applied with organic matter straw and \(E.\) \textit{dulcis} compost at Greenhouse ISARI Banjarbaru, 2010 WS

The relative water content (RWC) of plant increased with water replaced. Straw compost 5 t ha\(^{-1}\) increased RWC greater than water replaced. Increasing in RWC will be higher if the application of 5 t ha\(^{-1}\) straw and \(E.\) \textit{dulcis} compost to 5 t ha\(^{-1}\), but application \(E.\) \textit{dulcis} compost up to 10 t ha\(^{-1}\) will reduce plant RWC. Inpara 1 had a greater RWC than Inpara 2, while IR64 had the smallest RWC (Table 3). The increased in RWC due to application \(E.\) \textit{dulcis} compost to straw compost followed pattern of quadratic regression equations. The optimum level of \(E.\) \textit{dulcis} compost was added to straw compost 5 t ha\(^{-1}\) for Inpara 1, Inpara 2, and IR64 as many as 5.46; 5.44; and 5.59 t ha\(^{-1}\). Inpara 2 had a maximum RWC relatively greater than Inpara 1, while IR64 had a relatively shorter maximum RWC (Table 4 and Fig. 1).

The application of organic matter increased RWC followed pattern of quadratic equations. The result of this experiment was in line with research by [12] which showed that the increase concentration of Fe in soil decreased RWC. In this research, iron toxicity could be controlled by
application straw and *E. dulcis* compost, so that RWC increased.

Figure 1: Relationship between *E. dulcis* compost level and relative water content (RWC) in three rice varieties, greenhouse ISARI, Banjarbaru, 2010 WS

*Width and density of stomata and transpiration rate.* Water replaced did not increase width of stomata opening in three varieties, while application straw compost 5 t ha\(^{-1}\) was able to increase the width of stomata. Increasing *E. dulcis* compost to 5 t ha\(^{-1}\) in soil that was given 5 t ha\(^{-1}\) straw compost increased width of stomata, although increasing was not significant compared to 5 t ha\(^{-1}\) straw compost. Application *E. dulcis* compost to 10 t ha\(^{-1}\) actually tends to narrow stomata opening. The increase in width of stomata openings in three varieties was not significantly different in conditions given organic matter. The width of stomata opening is narrower in soils planted by IR64 under natural conditions or water replaced than Inpara 1 and Inpara 2, but no different if soil is given straw and *E. dulcis* compost (Table 5).

| Organic matter                  | Inpara 1 | Inpara 2 | IR64   | Average |
|---------------------------------|----------|----------|--------|---------|
| Control                         | 9.17     | 8.49     | 5.92   | 7.86    |
| Control with water replaced     | 9.83     | 9.14     | 7.19   | 8.72    |
| 5 t ha\(^{-1}\) S + 0.0 t ha\(^{-1}\) Ed | 10.72    | 10.53    | 10.10  | 10.45   |
| 5 t ha\(^{-1}\) S + 2.5 t ha\(^{-1}\) Ed | 11.32    | 11.06    | 11.06  | 11.15   |
| 5 t ha\(^{-1}\) S + 5.0 t ha\(^{-1}\) Ed | 11.88    | 11.65    | 11.16  | 11.56   |
| 5 t ha\(^{-1}\) S + 10.0 t ha\(^{-1}\) Ed | 10.96    | 10.69    | 10.49  | 10.71   |
| Average                         | 10.65    | 10.26    | 9.32   | (+)     |

\(^{a}\)Number a column followed by the same letter are not significantly different based on DMRT 0.05.  
S = straw compost ; Ed = *Eleocharis dulcis* compost

Table 5: Width of stomata opening (µm) of three rice varieties that were given straw and *E. dulcis* compost, greenhouse ISARI Banjarbaru, 2010 WS

Increasing in stomata opening width due to *E. dulcis* compost in straw compost followed pattern of quadratic regression equation. The optimum level of *E. dulcis* compost added for Inpara 1, Inpara 2, and IR64 were 5.41; 5.41; and 5.51 t ha\(^{-1}\), respectively. Inpara 1 showed stomata opening width relatively wider than Inpara 2, while IR64 had the narrowest maximum stomata opening width (Table 6). Water replaced did not increase stomatal density, but replaced of 5 t ha\(^{-1}\) straw compost could increase stomatal density. Increased stomatal density due to 5 ha\(^{-1}\) straw compost was not different
from water replaced. The density of stomata increased again if application of 5 t ha\(^{-1}\) straw compost coupled with \textit{E. dulcis} compost to 5 t ha\(^{-1}\), but on the replaced of \textit{E. dulcis} compost to 10 t ha\(^{-1}\), the density of stomata will decrease. Inpara 1 had the highest stomatal density which was denser than Inpara 2, while the stomatal density of Inpara 2 was not different from IR64 which had the lowest stomatal density (Table 7).

Increasing in stomatal density due to replaced of \textit{E. dulcis} compost to straw compost followed the pattern quadratic regression equation. The optimum level of \textit{E. dulcis} compost added with 5 t ha\(^{-1}\) straw compost for Inpara 1, Inpara 2, and IR64 as many as 5.31; 5.35; and 5.37 t ha\(^{-1}\). Inpara 1 had a maximum stomatal density was relatively higher than Inpara 2, whereas IR64 with a maximum stomatal density was relatively lower (Table 6).

| Variable                          | Regression equation         | X optimum | Y maximum   |
|-----------------------------------|-----------------------------|-----------|-------------|
| Stomatal density                  |                             |           |             |
| Inpara 1                          | \(y = -8.121x^2 + 89.37x + 723.8\) | 5.50      | 1461.42     |
|                                  | \(R^2 = 0.754\)             |           |             |
| Inpara 2                          | \(y = -8.193x^2 + 93.28x + 661.5\) | 5.69      | 1458.02     |
|                                  | \(R^2 = 0.724\)             |           |             |
| IR64                             | \(y = -8.218x^2 + 96.27x + 612.6\) | 5.86      | 1458.42     |
|                                  | \(R^2 = 0.704\)             |           |             |
| Width of stomata opening (µm)     |                             |           |             |
| Inpara 1                          | \(y = -0.038x^2 + 0.411x + 10.67\) | 5.41      | 14.00       |
|                                  | \(R^2 = 0.729\)             |           |             |
| Inpara 2                          | \(y = -0.037x^2 + 0.400x + 10.46\) | 5.41      | 13.70       |
|                                  | \(R^2 = 0.744\)             |           |             |
| IR64                             | \(y = -0.037x^2 + 0.408x + 10.14\) | 5.51      | 13.51       |
|                                  | \(R^2 = 0.708\)             |           |             |
| Transpiration rate (minute)       |                             |           |             |
| Inpara 1                          | \(y = 0.072x^2 - 0.685x + 6.713\) | 4.76      | 5.08        |
|                                  | \(R^2 = 0.701\)             |           |             |
| Inpara 2                          | \(y = 0.119x^2 - 1.284x + 9.268\) | 5.39      | 5.80        |
|                                  | \(R^2 = 0.726\)             |           |             |
| IR64                             | \(y = 0.072x^2 - 0.685x + 6.713\) | 5.32      | 12.41       |
|                                  | \(R^2 = 0.701\)             |           |             |

Table 6: Quadratic regression equation of density and width of stomata and transpiration rate of three rice varieties that were given straw and \textit{E. dulcis} compost, greenhouse ISARI Banjarbaru, 2010 WS

Water replaced did not increase transpiration rate, but added of 5 t ha\(^{-1}\) straw compost could increase plant transpiration rate. Increasing in transpiration rate due to added of 5 t ha\(^{-1}\) straw compost was not different from water replaced. The transpiration rate would increase again if added of 5 t ha\(^{-1}\) straw compost and \textit{E. dulcis} compost to 5 t ha\(^{-1}\), but added \textit{E. dulcis} to 10 t ha\(^{-1}\) would actually reduce transpiration rate. Inpara 1 had the fastest transpiration rate which was faster than Inpara 2, while IR64 had the slowest transpiration rate (Table 7).

Increasing transpiration rate due to application \textit{E. dulcis} compost in straw compost followed quadratic regression equation. The optimum level of \textit{E. dulcis} compost added to straw 5 t ha\(^{-1}\) for Inpara 1, Inpara 2, and IR64 were 4.76; 5.39; and 5.32 t ha\(^{-1}\) respectively. Inpara 1 had a maximum transpiration rate faster than Inpara 2, while IR64 with a maximum transpiration rate was slow (Table 7 and Fig. 2).
| Treatment                        | Stomatal density (stomata mm$^{-2}$) | Transpiration rate (minute) |
|---------------------------------|--------------------------------------|----------------------------|
| Organic matter                  |                                      |                            |
| Control                         | 551.11 $^d$                          | 13.33 $^a$                 |
| Control with water replaced     | 611.11 $^{cd}$                       | 11.78 $^{ab}$              |
| 5 t ha$^{-1}$ S + 0.0 t ha$^{-1}$ Ed | 673.33 $^c$                          | 10.36 $^{bc}$              |
| 5 t ha$^{-1}$ S + 2.5 t ha$^{-1}$ Ed | 827.78 $^b$                          | 8.87 $^{cd}$               |
| 5 t ha$^{-1}$ S + 5.0 t ha$^{-1}$ Ed | 941.11 $^a$                          | 7.49 $^d$                  |
| 5 t ha$^{-1}$ S + 10.0 t ha$^{-1}$ Ed | 775.56 $^b$                          | 10.18 $^{bc}$              |
| Varieties                       |                                      |                            |
| Inpara 1                        | 784.44 $^x$                          | 6.23 $^{z}$                |
| Inpara 2                        | 723.89 $^y$                          | 8.62 $^y$                  |
| IR64                            | 681.67 $^y$                          | 15.32 $^x$                 |

*Number a column followed by the same letter are not significantly different based on DMRT 0.05.
S = straw compost; Ed = Eleocharis dulcis compost

Table 7: Stomatal density (stomata mm$^{-2}$) and transpiration rate (minutes) of three rice varieties that were given straw and E. dulcis compost, greenhouse ISARI Banjarbaru, 2010 WS

Increased width of stomata opening was thought to had something to did with leaf K levels. Inpara 1 had higher leaf K content than Inpara 2. One of functions of K element was to play a role in regulating opening and closing of leaf stomata for photosynthesis and respiration [13]. A smoother process of opening and closing of stomata allowed CO$_2$ inflows into leaves for photosynthesis and O$_2$ outflows in respiration to flow more smoothly, so that metabolic processes and catabolism of plants took place well.

Inpara 1 had a faster transpiration rate than Inpara 2, which was 6.23 minutes compared to Inpara 2 (8.62 minutes). Application organic matter decreased transpiration time or increased rate of transpiration following a quadratic equation pattern. The optimum level of purun tikus compost from Inpara 1 and Inpara 2 were 4.76 and 5.39 t.ha$^{-1}$ to reach the fastest transpiration time. Faster respiration could reduce symptoms of iron toxicity, because temperature regulation of leaves becomes more stable due to continued availability of water that enters the plant tissue. The same thing was stated by [14] who suggested that in severe iron toxicity, symptoms of iron toxicity develop more in older leaves with slower transpiration rates.

![Figure 2: Relationship between E. dulcis compost level and transpiration rate in three rice varieties, greenhouse ISARI Banjarbaru (wet season 2010).](image-url)
Enzymatic activities and total chlorophyll content. The enzyme peroxidase (POD) and polyphenol oxidase (PPO) activities were shown in Table 8 and Table 9. Water replaced did not significantly increase activity for POD of three tested varieties. The addition of 5 t ha\(^{-1}\) straw compost was able to increase POD activity in Inpara 1 and Inpara 2, whereas in IR64 the increasing was not significant. Increasing in *Eleocharis dulcis* compost to 5 t ha\(^{-1}\) in soil that was given 5 t ha\(^{-1}\) straw compost increased POD activity, whereas the addition of higher *E. dulcis* compost more than 10 t ha\(^{-1}\), which actually decreased POD activity (Table 8).

| Organic matter | Varieties | PPO Activities (unit) | Total Chlorophyll Content (mg g\(^{-1}\)) |
|----------------|-----------|-----------------------|------------------------------------------|
|                | Inpara 1  | Inpara 2  | IR64 |                  |
| Control        | 0.126 \(^{ij}\) | 0.137 \(^{hij}\) | 0.117 \(^{j}\) | 0.126 |
| Control with water replaced | 0.159 \(^{bij}\) | 0.190 \(^{ghi}\) | 0.135 \(^{hij}\) | 0.161 |
| 5 t ha\(^{-1}\) S + 0.0 t ha\(^{-1}\) *Ed* | 0.263 \(^{def}\) | 0.225 \(^{f}\) | 0.158 \(^{hij}\) | 0.215 |
| 5 t ha\(^{-1}\) S + 2.5 t ha\(^{-1}\) *Ed* | 0.364 \(^{b}\) | 0.350 \(^{bc}\) | 0.242 \(^{efg}\) | 0.319 |
| 5 t ha\(^{-1}\) S + 5.0 t ha\(^{-1}\) *Ed* | 0.496 \(^{a}\) | 0.377 \(^{b}\) | 0.326 \(^{cde}\) | 0.400 |
| 5 t ha\(^{-1}\) S + 10.0 t ha\(^{-1}\) *Ed* | 0.322 \(^{bcd}\) | 0.289 \(^{cde}\) | 0.196 \(^{gh}\) | 0.269 |
| **Average**   | 0.288     | 0.261     | 0.196 \((+)^{e}\) |                  |

\(^{a}\)Number a column followed by the same letter are not significantly different based on DMRT 0.05. 
S = straw compost; *Ed* = *Eleocharis dulcis* compost

Table 8: POD (unit) peroxidase enzyme activity in three rice were given straw and *E. dulcis* compost, greenhouse ISARI Banjarbaru, 2010 WS.

The enzyme peroxidase (POD) activity on soils planted with IR64 under natural conditions or water replaced was not different from soils planted with Inpara 1 and Inpara 2. Differences will arise if the soil is given straw and *E. dulcis* compost. The POD activity in soils that were given low-level organic matter from IR64 was lower than Inpara 1 and Inpara 2. The difference would be more striking if soil was given *E. dulcis* compost in high-level. The POD activity of Inpara 1 was higher than Inpara 2, while POD activity of IR64 was the lowest. If *E. dulcis* compost is added, the POD...
activity of Inpara 1 and Inpara 2 is not significantly different, but its was higher than the POD activity of IR64. The POD activity of soils planted with IR64 under conditions of straw and *E. dulcis* compost was higher than of land planted with Inpara 1 and Inpara 2, but did not differ if the soil was in natural conditions or water replaced (Table 8). The increase in POD activity due to the addition *E. dulcis* compost to straw compost followed pattern of the quadratic regression equation. The optimum level of *E. dulcis* compost added to straw compost 5 t.ha\(^{-1}\) for Inpara 1, Inpara 2, and IR64 as many as 5.64; 5.60; and 5.90 t ha\(^{-1}\). Inpara 1 had a relatively high maximum POD activity compared to Inpara 2, while IR64 had the lowest maximum POD activity (Table 10).

**Table 10:** Quadratic regression equation of POD and PPO enzymes activities and total chlorophyll levels of three rice varieties added with *E. dulcis* compost, greenhouse ISARI, Banjarbaru,  2010 WS

| Variabel                  | Persamaan                                                                 | X optimum | Y maksimum |
|---------------------------|---------------------------------------------------------------------------|-----------|------------|
| POD activity (unit)       |                                                                           |           |            |
| Inpara 1                  | \(y = -0.0072x^2 + 0.0796x + 0.2486\) \(R^2 = 0.712\)                       | 5.64      | 0.917      |
| Inpara 2                  | \(y = -0.0051x^2 + 0.0568x + 0.2288\) \(R^2 = 0.883\)                       | 5.60      | 0.698      |
| IR64                      | \(y = -0.0054x^2 + 0.0593x + 0.1494\) \(R^2 = 0.842\)                       | 5.90      | 0.671      |
| PPO activity (unit)       |                                                                           |           |            |
| Inpara 1                  | \(y = 20.005x^2 - 185.9x + 1080.8\) \(R^2 = 0.852\)                        | 4.65      | 648.01     |
| Inpara 2                  | \(y = 14.639x^2 - 148.44x + 1332.4\) \(R^2 = 0.756\)                       | 5.07      | 955.67     |
| IR64                      | \(y = 11.729x^2 - 125.93x + 1530.6\) \(R^2 = 0.722\)                      | 5.37      | 1191.89    |
| Chlorophyll content (mg g\(^{-1}\)) |                                                                         |           |            |
| Inpara 1                  | \(y = -0.0141x^2 + 0.1568x + 0.5083\) \(R^2 = 0.865\)                      | 5.57      | 1.812      |
| Inpara 2                  | \(y = -0.0136x^2 + 0.1442x + 0.4131\) \(R^2 = 0.716\)                     | 5.54      | 1.609      |
| IR64                      | \(y = -0.0139x^2 + 0.1493x + 0.2088\) \(R^2 = 0.757\)                     | 5.73      | 1.489      |

Replaced of water could reduce PPO activity, but the decrease was not different from the application of organic matter 5 ha\(^{-1}\) straw compost. The PPO activity would increase again if the addition of straw compost 5 t ha\(^{-1}\) plus *E. dulcis* compost up to 5 t ha\(^{-1}\). If the addition of *E. dulcis* compost to 10 t ha\(^{-1}\), the PPO activity would decrease. Inpara 1 variety had the lowest PPO activity which was lower than Inpara 2, while IR64 had the highest PPO activity (Table 9). Decreasing in PPO activity due to addition of *E. dulcis* compost to straw compost followed pattern of quadratic regression equation. The optimum level of *E. dulcis* compost added to straw compost 5 t ha\(^{-1}\) of Inpara 1, Inpara 2, and IR64 were 4.65; 5.07; and 5.37 t ha\(^{-1}\) respectively. Maximum PPO activity of Inpara 1 was relatively lower than Inpara 2, while maximum PPO activity of IR64 was relatively the highest (Table 10 and Figure 3).

Chlorophyll content of leaves did not increase with water replaced, but application straw and *E. dulcis* compost could increase leaf chlorophyll content. Chlorophyll level would increase again if addition 5 t ha\(^{-1}\) straw plus *E. dulcis* compost to 5 t ha\(^{-1}\). If addition *E. dulcis* compost to 10 t ha\(^{-1}\).
leaf chlorophyll content would decrease. Inpara 1 had the highest chlorophyll content which was not different from Inpara 2, while IR64 had the lowest leaf chlorophyll content (Table 9). Increasing leaf chlorophyll content due to application of *E. dulcis* compost to straw compost followed pattern of quadratic regression equation. The optimum level of *E. dulcis* compost added with 5 t ha\(^{-1}\) straw compost of Inpara 1, Inpara 2, and IR64 were 5.57; 5.54; and 5.73 t ha\(^{-1}\) respectively. Maximum chlorophyll content of Inpara 1 was relatively higher than Inpara 2, while IR64 with the lowest chlorophyll content (Table 10).

![Graph showing the relationship between Eleocharis dulcis compost level and polyphenol oxidase (PPO) activity in three rice varieties, greenhouse of ISARI, Banjarbaru, 2010 WS.](image)

Figure 3. Relationship between *Eleocharis dulcis* compost level and polyphenol oxidase (PPO) activity in three rice varieties, greenhouse of ISARI, Banjarbaru, 2010 WS

High activity of POD could be linked to production of free radicals, especially hydrogen superoxide (H\(_2\)O\(_2\)) which could damage plant tissue. Hydrogen superoxide or peroxide is a less active oxidizing agent than free radicals. The POD enzyme plays a role in detoxifying hydrogen superoxide (peroxide) so that it did not damage tissue [15], [16] in [17] stated that tolerant varieties to iron toxicity with higher POD activity when stressed with Fe. In this case Inpara 1 and Inpara 2 were tolerant varieties, while IR64 was sensitive sensitive varieties to iron toxicity.

Increased PPO activity due to high Fe absorption will increase production of oxidized polyphenols so that leaves appear bronzing or brown spots [2] and [3]. This means that Inpara 1 with lower PPO activity will produce less oxidized polyphenols so that symptoms of bronzing leaves were relatively smaller than Inpara 2, and significantly smaller than IR64. Inpara 1 with low PPO activity and high POD activity indicates the work of enzymes in controlling high Fe in leaf tissue. This leads to inclusion / tolerance where plants tolerated high Fe\(^{2+}\) in leaf cells through enzymatic detoxification [14], especially POD. This strategy was mentioned by [19] as same "excluder" or tolerant mechanism.

**Iron Toxicity Symptom and Grain Yield.** Water replacement was not able to reduce symptoms of iron toxicity, while addition of organic matter straw compost and *E. dulcis* compost could reduce these symptoms. Reduction in symptoms of iron toxicity in addition of 5 t ha\(^{-1}\) straw compost was not different from replaced water. Symptoms of iron toxicity would decrease again if added to *E. dulcis* compost in straw compost 5 t ha\(^{-1}\). Addition of *E. dulcis* compost to 5 t ha\(^{-1}\) in straw compost 5 t ha\(^{-1}\) would reduce iron toxicity symptoms, but the addition of *E. dulcis* compost to 10 t ha\(^{-1}\) would actually increase iron toxicity symptoms. The Inpara 1 variety showed the mildest symptoms of iron toxicity that were not different from Inpara 2, while IR64 had the worst symptoms of iron toxicity (Table 11).

Decreasing in iron toxicity symptoms due to application of *E. dulcis* compost in straw compost followed quadratic regression equations pattern. The optimum level of *E. dulcis* compost added to straw 5 t ha\(^{-1}\) for Inpara 1, Inpara 2, and IR64 as many as 5.45; 5.55; and 5.55 t ha\(^{-1}\). The minimum
Iron toxicity symptoms of Inpara 1 were relatively lower than that of Inpara 2, while IR64 showed symptoms of relatively higher iron toxicity (Table 13).

| Treatment                                      | Fe toxicity symptom$^*$[20] |
|-----------------------------------------------|-----------------------------|
| **Organic Matter**                            |                             |
| Control                                       | 6.11                        |
| Control with water replaced                    | 5.55                        |
| 5 t ha$^{-1}$ S + 0.0 t ha$^{-1}$ Ed          | 5.00                        |
| 5 t ha$^{-1}$ S + 2.5 t ha$^{-1}$ Ed          | 3.56                        |
| 5 t ha$^{-1}$ S + 5.0 t ha$^{-1}$ Ed          | 2.33                        |
| 5 t ha$^{-1}$ S + 10.0 t ha$^{-1}$ Ed         | 4.33                        |
| **Varieties**                                 |                             |
| Inpara 1                                      | 4.11                        |
| Inpara 2                                      | 4.50                        |
| IR64                                          | 4.83                        |

$^*$Number a column followed by the same letter were not significantly different based on DMRT 0.05.

*S = straw compost; Ed = Eleocharis dulcis compost

Table 11: Symptoms of iron toxicity and grain yield of three rice varieties were added with straw and E. dulcis, greenhouse of ISARI, Banjarbaru, 2010 WS

| Organic matter | Varieties | Average |
|----------------|-----------|---------|
|                | Inpara 1  | Inpara 2 | IR64    |
| Control        | 10.86     | 8.61     | 5.27    | 8.25    |
| Control with water replaced                   | 16.36     | 14.48    | 8.90    | 13.25    |
| 5 t ha$^{-1}$ S + 0.0 t ha$^{-1}$ Ed          | 22.24     | 20.24    | 13.04   | 18.50    |
| 5 t ha$^{-1}$ S + 2.5 t ha$^{-1}$ Ed          | 26.27     | 24.35    | 18.19   | 22.94    |
| 5 t ha$^{-1}$ S + 5.0 t ha$^{-1}$ Ed          | 31.62     | 28.34    | 21.53   | 27.17    |
| 5 t ha$^{-1}$ S + 10.0 t ha$^{-1}$ Ed         | 22.24     | 21.31    | 14.49   | 19.35    |
| **Average**                                    | 21.59     | 19.56    | 13.57   | (-)      |

$^*$Number a column followed by the same letter were not significantly different based on DMRT S = straw compost; Ed = Eleocharis dulcis compost.

Table 12: Grain yield per hill (g) of three rice varieties was applied straw and E. dulcis compost, greenhouse ISARI Banjarbaru, 2010 WS

Substitution of water and addition of straw and E. dulcis compost could increase grain yield per hill. Increased grain yield per hill was greater in addition of 5 t.ha$^{-1}$ straw compost compared to water replacement. The grain yield per hill would increase again if application of 5 t.ha$^{-1}$ straw compost coupled with E. dulcis compost to 5 t.ha$^{-1}$, but the addition of E. dulcis compost to 10 t.ha$^{-1}$ would reduce grain yield per hill. Inpara 1 had the highest average grain yield per hill, which was higher than Inpara 2, while IR64 had the lowest grain yield (Table 12 Figure 4).

Although the highest grain yield per hill of Inpara 1 was highest (Table 12), the largest percentage of grain yield increase of IR64 (Table 13). This means that IR64 was more responsive to the addition of straw and E. dulcis compost in acid sulfate soils which had potential for iron toxicity. This could be understood because IR64 was a variety that was also responsive to fertilization. Thus the application of straw and E. dulcis compost could increase yield of IR64 grain higher, although grain...
yield was still lower than Inpara 1 as tolerant and Inpara 2 which avoid to iron toxicity. Increased grain yield per hill due to *E. dulcis* compost in straw compost followed the quadratic regression equation pattern. The optimum level of *E. dulcis* compost added to straw compost 5 t.ha\(^{-1}\) for Inpara 1, Inpara 2, and IR64 as many as 5.14; 5.29; and 5.31 t.ha\(^{-1}\). Grain yield per hill maximum in Inpara 1 was higher than Inpara 2, whereas IR64 had the lowest maximum grain yield per hill (Table 14).

| Organic Matter                          | Varieties        |
|-----------------------------------------|------------------|
|                                         | Inpara 1 | Inpara 2 | IR64  |
| Control                                 | -        | -        | -     |
| Control with water replaced              | 50.7     | 68.2     | 68.8  |
| 5 t ha\(^{-1}\) S + 0.0 t ha\(^{-1}\) Ed | 104.8    | 135.0    | 147.3 |
| 5 t ha\(^{-1}\) S + 2.5 t ha\(^{-1}\) Ed | 142.0    | 182.8    | 245.1 |
| 5 t ha\(^{-1}\) S + 5.0 t ha\(^{-1}\) Ed | 191.2    | 229.2    | 308.4 |
| 5 t ha\(^{-1}\) S + 10.0 t ha\(^{-1}\) Ed | 104.9    | 147.5    | 174.8 |

Table 13. Percentage increasing in grain yield per hill (%) of Inpara 1, Inpara 2, and IR64 due to application of straw and *E. dulcis* compost, greenhouse of ISARI, Banjarbaru, 2010 WS

| Variable                  | Regression equation | X optimum | Y maximum |
|---------------------------|---------------------|-----------|-----------|
| Fe toxicity symptom       |                     |           |           |
| Inpara-1                  | y = 0.089x\(^2\) – 0.970x + 4.721 | 5.45      | 2.08      |
|                           | R\(^2\) = 0.717     |           |           |
| Inpara-2                  | y = 0.084x\(^2\) – 0.932x + 5.127 | 5.55      | 2.54      |
|                           | R\(^2\) = 0.706     |           |           |
| IR64                      | y = 0.084x\(^2\) – 0.932x + 5.460 | 5.55      | 2.87      |
|                           | R\(^2\) = 0.810     |           |           |
| Grain yields/hill          |                     |           |           |
| Inpara-1                  | y = -0.331x\(^2\) + 3.402x + 21.58 | 5.14      | 47.80     |
|                           | R\(^2\) = 0.811     |           |           |
| Inpara-2                  | y = -0.276x\(^2\) + 2.921x + 19.83 | 5.29      | 43.02     |
|                           | R\(^2\) = 0.826     |           |           |
| IR64                      | y = -0.295x\(^2\) + 3.132x + 12.81 | 5.31      | 37.75     |
|                           | R\(^2\) = 0.905     |           |           |

Table 14: Quadratic regression equations of Fe toxicity symptoms, and grain yield of three varieties of rice given *E. dulcis* compost, greenhouse of ISARI, Banjarbaru, 2010 WS
Decrease in soil Fe concentrations up to level of 5 t ha\(^{-1}\) E. dulcis compost was thought to be related to depletion of Fe by organic matter through organic acids released during humification process. Organic acids play an important role in suppressing the solubility of metal ions by forming organic or chelate complexes. Organic acids suppress activity of Fe\(^{3+}\) through formation of organo-metal compounds (Pulford et al., 1989; Pitchel et al., 1989) which dissociate to produce -COO- and -O- and form chelate bonds with Fe\(^{3+}\) [19]; [20]. Carboxyl and hydroxy groups are main functional groups of organic acids that play a role in forming these complex compounds [21].

Nevertheless E. dulcis compost would increase concentration of Fe in soil again if it was given in higher amounts, ie 10 t ha\(^{-1}\), especially in Inpara 1 and IR64 varieties, whereas in Inpara 2 increasing was not significant. This is presumably because application of high-level organic matter, in Inpara 1 and IR64, would release Fe it contains into soil also higher. As a result, AH and AF released by organic matter, in addition to chelating Fe in soil solution also chew additional Fe from organic matter into soil which was quite high, so that soil Fe becomes increased again. Humic acid had an average negative charge of 670 cmol (+) kg\(^{-1}\) and fulvic acid around 1,030 cmol (+) kg\(^{-1}\) (Teng, 1986). In Inpara 2 which was indicated to have an exclusion-avoidance mechanism was suspected to had root oxidation power so that soil Fe concentration was also lower than planted with Inpara 1 and IR64. One type of organic acid with carboxyl and hydroxy groups were fulvic acid (AF) and humic acid (AH). The phenolic-COOH and OH groups had advantages through acidic properties and interaction effects of electronic attraction, chelate formation, and complex [22].

4. Conclusions
It could be concluded that:
1. Application of 5 t ha\(^{-1}\) straw compost + 5.0 t ha\(^{-1}\) purun tikus (E. dulcis) compost could show the best physiological properties of rice plants, namely root length, root surface area, relative water content, width of stomata opened, stomatal density, transpiration rate, enzymatic activities (peroxidase and polyphenol oxidase), and chlorophyll content.
2. Application of straw and E. dulcis compost would decrease Fe toxicity symptoms, but increase grain yield per hill of rice.
3. Grain yield per hill at the treatment 5 t ha\(^{-1}\) straw + 5.0 t ha\(^{-1}\) E. dulcis compost was 27.17 g.
4. Inpara 1 was more tolerant to iron toxicity, the best performane of phsiological traits, Fe toxicity symptoms, and grain yield followed by Inpara 2, whereas IR64 was more susceptible to iron toxicity and showed all the lowest variables.

5. Increasing *E. dulcis* compost rate up to 5 t ha\(^{-1}\) could increase traits of rice physiology and grain yield, but decrease Fe toxicity symptoms.

References

[1] Tanaka A and S Yoshida 1970 Nutritional disorders of the rice plant in Asia. Int. Rice Res. Inst. Tech. Bull. 10 51p Int. Rice Res Inst Los Banos, The Philippines

[2] Dobermann A and T. Fairhurst 2000 Rice nutrient disorders & nutrient management. Handbook series Potash & Phosphate Institute (PPI) Potash & Phosphate Institute of Canada (PPIC) and International Rice Research Institute

[3] Fairhurst T, A Dobermann, C Quijano-Guerta and V Balasubramanian 2002 Mineral deficiencies and toxicities. In T Fairhurst and C Witt (eds). Rice, a Practical Guide to Nutrient Management. Potash & Phosphate Institute (PPI). Potash & Phosphate Institute of Canada (PPIC) and International Rice Research Institute

[4] Abifarin, A O 1988 Grain yield loss due to iron toxicity. WARDA Technical Newsletter 8(1):1-2

[5] Ponnamperuma F.N and JL Solivas 1982 Field amelioration of an acid sulfate soil for rice with manganese dioxide and lime. p 213-222 In: H. Dost and N. Van Breemen (eds.). Proc of the Bangkok Symposium on Acid Sulfate Soils Second Int‘t Symposium on Acid Sulphate Soils, Bangkok Thailand January 18-24 1981 ILRI, Wageningen The Netherlands

[6] Pitchtel JR, WA Dick, and EL McCoy 1989 Binding of iron from pyritic mine spoil by water soluble organic materials extracted from sewage sludge. Soil Sci. 148:140-148

[7] Jumberi A, A Supriyo, dan S Raihan 1998 Penggunaan bahan amelioran untuk meningkatkan produktivitas tanaman pangan di lahan pasang surut. M. Sabran et al. Prosiding Seminar Nasional Hasil Penelitian Menunjang Akselerasi Pengembangan Lahan Pasang Surut Balittra Banjarbaru

[8] Ponnamperuma FN 1977 Screening rice for tolerance to mineral stresses. IRRI Research Paper Series 6. Int Rice Res Ins, Los Banos The Philippines

[9] Van Egmond F and M Akts 1977 Iron-nutritional aspect of the ionic balance of plants. Plant and Soil 48:685-703

[10] Makarim AK, O Sudarman, dan H Supriadi 1989 Status hara tanaman padi berkeracunan besi di daerah Batumarta, Sumatera Selatan. Penelitian Pertanian Vol 9(4) : 166-170.

[11] Widjaja-Adhi IPG, DA Sutriadi, MT Satri, IGM Subiksa, and IW Suastika 2000. Pengelolaan, pemanfaatan, dan pengembangan lahan rawa. h 127-164. *Dalam: Adimihardja, A, LI Amien, F Agus, and D Jaennudin (eds.). Sumberdaya Lahan Indonesia dan Pengelolaannya. Pusat Penelitian Tanah dan Agroklimat Bogor.*

[12] Mehraban P, AA Zadeh, and HR Sadeghipour 2008. Iron toxicity in rice (*Oryza sativa* L.) under different potassium nutrition. Asian Journal of Plant Sciences, 2208 : 1-9.

[13] De Datta SK 1981 Principles and Practices of Rice Production. pp 41-45, 345-419. John Wiley and Sons New York.

[14] Yamanouchi M and S Yoshida 1981 Physiological mechanisms of rice’s tolerance for iron toxicity Paper presented at the IRRI Saturday Seminar June 6, 1981. Int Rice Res Inst Los Banos The Philippines

[15] Gupta AS, RP Webb, AS Holaday and RD Allen 1993 Over expression of superoxide dismutase protecs plants from oxidatives stress. Plant Physiol 103:1067-1073

[16] Bode K, O Doring, S Luthje, and M Bottger 1995 Introduction of iron toxicity symptoms in rice (*Oryza sativa* L.) Hamburg, Mitt. Inst. Allg Bot 25:35-43

[17] Quijano C and R Mendoza 1994 Mineral toxicities in rice Breeding Flood-Prone Rice IRRI, Los Banos The Philippines
[18] Becker M and F Asch  2005 Iron toxicity – condition and management concepts, J. plant Nutr. Soil Sci, 168:558-573.
[19] Aida, S. N., D. Widianto, dan R. Sutanto. 2004. Pengaruh pemberian asam-asam organik terhadap kelarutan Fe (besi) di tanah sulfat masam. Agrosains 17(1):99-109
[20] IRRI 1996 Standard evaluation system for rice. Int. Ric Res Inst, Los Banos The Philippines
[20] Stevenson F J 1994 Humus chemistry, Genesis, Composition and Reactions. John Wiley & Sons Inc, New York.
[21] Iyemuremye F, RP Dick, and J Baham 1996 Organic amendements and phosphorus dinamics I. Phosphorus Chemistry and Sorption, Soil Sci. 161:426-442.