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The response by selected rice genotypes to organic ameliorants in tidal swampland which is affected by Fe toxicity

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Abstract. Ferrous Fe toxicity in rice has been reported to be one of several major limitations in terms of wetland rice production. Previous studies have reported a decrease in paddy rice yields of between 12–100% due to this problem. A study was conducted in order to determine the growth and yield factors for selected rice genotypes as a response to the presence of organic ameliorants, and their interaction in controlling ferrous Fe toxicity levels in rice which is grown in tidal swampland. Experiments formed part of this study, with these being conducted in tidal swampland around Danda Jaya village and Belandean village in Barito Kuala Regency, South Kalimantan. The experiment was arranged in a split-plot design to test the organic ameliorant treatments (the control was fresh *Salvinia sp*, with the compost being formed of *Salvinia sp*, plus rice straw, and cow manure as the main plots, and sub-plots being formed of rice genotypes (TOX-4136, Inpara-1, Inpara-2, Inpara-4, and IR-64). Results from the experiments revealed the fact that organic ameliorants could reduce ferrous Fe toxicity levels, as well as Fe content in plant tissues, while plant height and the number of tillers also decreased. Rice genotypes which are medium tolerant or fully tolerant to ferrous Fe toxicity when organic amelioration treatments are added can serve to decrease ferrous Fe toxicity and increase the number of filled grains and yield. Applications of fresh S*alvinia* and S*alvinia* compost were as effective as an application of rice straw and cow manures when it came to successfully increasing the yield of rice grown in tidal swampland. Ferrous iron toxicity in rice which has been produced in tidal swampland can be overcome by using tolerant genotypes (Inpara-1 and Inpara-4), or organic ameliorants (*Salvinia* sp).

Key words: land amelioration, Fe toxicity, rice, *Salvinia* sp, tidal swampland.

INTRODUCTION

There exists approximately 8.92 million hectares of tidal swampland in Indonesia. All of i t has the potential of being converted into agricultural land (BBSDLP, 2015). Productivity levels of rice which is grown in tidal swampland areas is generally low due to high acidity levels and poor soil nutrient conditions, plus Al, Fe, and H_2S toxicities (Sarwani et al., 1994).

Ferrous Fe (Fe^{+2}) toxicity levels in rice have been reported to be one of the single major limitations of wetland rice production, resulting in a decrease in paddy rice yields by between 12–100% (Sahrawat, 2010). Rice plants which experience high ferrous Fe toxicity levels suffer from poor growth and low tillering, resulting in low-to-zero production (Audebert & Sahrawat, 2000). Ferrous Fe toxicity in rice may vary with genotypes, nutrient status, land and water management regimes, temperature, and light intensity levels (Sahrawat, 2010; Audebert & Sahrawat, 2000).

Symptoms of ferrous iron toxicity in rice only occur under specific conditions, where the rice has been subjected to flooding. The occurrence of 'reduction conditions' in flooded lowlands has resulted in the dissolution of all forms of soil Fe into dissolved forms of Fe^{+2} (Beckers & Ash, 2005; Audebert, 2006). The occurrence of ferrous Fe toxicity in plants is not only caused by high concentrations of Fe^{+2} in the soil solution which itself is the result of reduction conditions, it is also caused by low pH levels, low nutrient status, and imbalances in the soil (Dobermann & Fairhurst, 2000).

Ferrous iron toxicity can adversely affect morpho-physiological characteristics, resulting in a disruption to rice plant growth (Nugraha et al., 2016; Turhadi et al., 2018; Onyango et al., 2019; Novianti et al., 2020). Several genotypes which are tolerant to ferrous iron toxicity can grow and produce normally, such as Inpara-2, Inpara-6, Siam Saba, Mashuri, Hawara Bunar, and Pokkali (Nugraha et al., 2016; Turhadi et al., 2018). The mechanism which involves the transition between rice tolerance to iron toxicity is related to the genetic characteristics of the specific varieties of rice which are involved in the process. Ensuring the use of tolerant genotypes is the most economical way for farmers to be able to grow rice in tidal swampland areas. However, levels of tolerance may vary with different rice genotypes and soil conditions.

The use of organic fertiliser for soil amelioration can reduce the need for chemical fertilisers while also providing support for sustainable agriculture (Ningsih et al., 2017). Organic-based agriculture which limits the use of chemical fertilisers and pesticides can reduce environmental burdens, ensure food sustainability, and provide a stable income (Hokazano et al., 2009). Using organic fertiliser can help to improve land quality while also decreasing toxic elements in the soil and increasing plant yield. Results from the use of organic fertiliser decomposition has contributed to macro and micronutrient status, while also having formed complex compounds which contain toxic metal ions (Al, Fe, and Mn), and increasing soil exchange capacity, which itself leads to high levels of soil nutrient retention (Juarsah, 2014). Applications of organic materials such as rice straw and cow manure have been reported to improve the physical properties of soil, but these are not always available on site. Another organic material which has the potential to be able to ameliorate soil conditions is *Salvinia* sp, which is widely grown in tidal swampland areas.

Salvinia sp is a water fern which has widely been used as a phytoremediator in order to clean-up water which has been polluted by heavy metals. *Salvinia* is an effective bio sorbent when it comes to removing heavy metals from waste water (Olguín et al., 2005; Dhir & Kumar, 2010). Plants which can be used for phytoremediation must possess characteristics such as being native, and having a rapid growth rate, a high biomass yield, the ability to absorb large levels of heavy metals, the ability to transport metals to those parts of plants which are above ground, and the ability to tolerate the metal toxicity mechanism (tolerant) (Ali et al., 2013; Burges et al., 2018).

The objectives behind these experiments involved the study of growth and yield levels in selected rice genotypes, and the response to organic ameliorants and their interaction in controlling iron toxicity levels in rice which is grown in tidal swamplands.

MATERIAL AND METHODS

Implementation procedure

A field experiment was conducted in the tidal swampland at Barito Kuala, South Kalimantan, on acidic sulphate soil - overflow type B - at two different locations which had differing ferrous Fe toxicity levels: ie. Belandean (with heavy toxicity levels) and Danda Jaya (with medium toxicity levels). The experiment was conducted between February and August 2011.

The experiment was arranged in a split-plot design employing land amelioration as the main plots, and with rice genotypes as the sub-plots. The main plots consists of the following: 1) control plots; 2) the application of one month-old *Salvinia sp* plants, buried under the soil prior to planting; 3) an application of *Salvinia sp* compost at 2.0 t ha^{-1}; 4) an application of rice straw compost at 2 t ha^{-1}; 5) an application of cow manure compost at 2 t ha^{-1}. The subplot (rice genotypes) consist of prospective genotypes TOX4136-5-1-1-KY-3, Inpara-1, Inpara-2, Inpara-4, and IR-64 (an Fe-sensitive genotype which was set as the control).

The treatments were assigned to plots of 4 m × 5 m, with three replications for each treatment. The *Salvinia sp* (treatment 2) source was collected from the River Kambat in Barito Kuala, South Kalimantan. *Salvinia sp* seeds were broadcasted at 100 g m^{-2} (fresh).

Composting was conducted for four weeks by adding decomposing bacteria to speed up the decomposition process. Other compost forms - rice straw and cow manure - were also composted and buried under the soil one week prior to planting. Organic matter with a water content of 35% was applied at a dose of 2 t ha^{-1}. Three week-old rice seedlings were planted 20 cm × 25 cm apart, with two seedlings per plot. Fertiliser was used of N, P, and K types, being applied at 75 kg N ha^{-1}, 37.5kg P_2O ha^{-1}, and 37.5 kg K_2O ha^{-1}. A half dose of N, and full doses of P and K, were applied seven days after planting; the remaining N was applied four weeks later. Weeding, plant protection, and maintenance were conducted according to recommended rice culture practices.

Soil and plant sampling

Measurements were carried out on soil Fe levels and the pH of the main plots before planting took place. This was seven days after the application of organic ameliorant, at the end of the vegetative growth stage, and after the harvest had been completed. Soil samples were taken from each plot using a soil drill at a depth of 20 cm, covering as many as six points. Soil from these six points was then composited, and about 500 g was taken for analysis in the laboratory.

The yield of agronomical characters and other yield components were recorded. The height and number of tillers were observed at the end of the vegetative phase for the plant, covering ten plants (or clumps) in each treatment plot. Observations were carried out for the rice yield component (involving the number of panicle tillers^{-1}, the number of filled grain panicles^{-1}, and the panicle length) by taking samples of six clumps in each treatment plot a t harvest. Grain yield was measured by taking a sample of 2.5 m × 2.5 m per plot.

Readings were taken twice for levels of ferrous Fe toxicity in rice, namely at the age of four weeks after planting and again at eight weeks (at the end of the plant's vegetative phase). Ferrous Fe toxicity was scored according to those methods which had been developed by IRRI-INGER (1996): a score of 1 means highly tolerant; 2–3 is tolerant; 5 is medium tolerant; 7 is sensitive; and 9 is highly sensitive. Plant samples were collected at the end of the vegetative stage for the purpose of tissue Fe analysis.

Soil and plant analysis

A measurement took place of soil pH levels using a digital pH meter, at a ratio of 1:2.5 soil and water. Iron (Fe) was extracted with one mol L^{-1} NH4 OAc (ammonium acetate), and then Fe levels in solution were determined through Atomic Absorption Spectrophotometry (AAS).

Nutrient contents (P, Ca, Mg, K, and Fe) in organic matter (ameliorant) as used in this study were extracted with a mixture of strong acid HNO_3+$HClO_4$. Phosphorus was measured by means of a staining system which used a spectrophotometer. Calcium (Ca), Mg, K, and Fe were measured using Atomic Absorption Spectrophotometry (AAS). Nitrogen (N) contents were determined by means of extraction using H_2SO_4+H_2O_2 (N-kjeldahl), and N levels were measured by means of distillation. The analysis of Fe in paddy plant tissue was the same as for the analysis of nutrient contents in organic matter (ameliorant).

Statistical analysis

The results which were obtained were subjected to an 'Analysis of Variance' (ANOVA), and further means of treatment effects were compared with testing results by using a Duncan Multiple Range Test (DMRT) at a confidence level of 95%. Data analysis was carried out using the SAS V.9 version program.

RESULTS AND DISCUSSION

Soils characteristic

The results of soil analysis at research locations revealed the acidity levels of the soil (pH): this was very acid. Meanwhile, soil pH levels at the Belandean site were lower (3.80) than they were at Danda Jaya (4.10). Toxic elements such as Al-exchangeable (9.70 me per 100 g^{-1}) and Fe which were extracted with Ammonium Acetate pH 4.8 (631 ppm) at the Belandean location were higher than they were at the Danda Jaya Al-exchangeable 6.37 me 100 g^{-1} and 425 ppm Fe. The depth of the pyrites layer ($FeS_2 \geq 2\%$) at Belandean was more shallow (≥ 40 cm) than at Danda Jaya (≥ 54 cm), while level of pyrites at Belandean was also higher (4.37%) than at Danda Jaya (2.48%) (Lubis et al., 2016).

Nutrient content of organic ameliorants

The nutrient content of the organic ameliorants can be seen in Table 1. Levels of organic-C ranged between 15.71–24.92%, while Nitrogen was between 0.87–1.08%, P was 0.09–0.32%, K was 1.35–1.85%, Ca was 0.24–0.35%, Mg was 0.22–0.28%, and C/N was 16–26 (Table 1).

Composts which included *Salvinia sp* had the lowest carbon-nitrogen ratio, whereas variants of rice straw had the highest Potassium levels (1.86%) when compared to the other ameliorants. Variants of cow manure had the highest P level (0.32%). Fresh *Salvinia* had the highest Fe levels (5.23%), followed by *Salvinia* composts, whereas rice straw and cow manure had the lowest levels of Fe (0.25%).

Table 1. The nutrient content of those ameliorants which were used in the research

Nutrient	Rice Straw Compost	Cow Manure Compost	*Salvinia sp.* Compost	Fresh *Salvinia sp.*
C (%)	24.92	16.6	15.71	24.83
N (%)	0.96	0.87	0.98	1.06
C/N	26.0	19.08	16.0	23.4
P (%)	0.19	0.32	0.09	0.11
K (%)	1.86	0.95	1.35	1.75
Ca (%)	0.35	0.18	0.24	0.31
Mg (%)	0.22	0.39	0.28	0.26
Fe (%)	0.62	0.25	1.62	5.23

Changes in soil Fe and pH

Soil analysis which was conducted prior to planting (seven days after soil ameliorant treatmen t had been conducted, at the end of the vegetative stage, and after harvest), demonstrated that soil pH and Fe levels at both experimental sites had changed (Figs 1 and 2). Soluble Fe and soil pH decreased with time; being at their lowest after harvest. Soils at Danda Jaya were more acidic than were those at Belandean in all treatments, whereas soil Fe levels at Danda Jaya were lower than were those at Belandean.

Organic ameliorant treatments did not always change soil pH levels. Soil pH at Belandean before planting was 3.65–3.90 when compared to a reading of 3.50 in the control soil, whereas at Danda Jaya it was between 3.90–4.10 when compared to a reading of 3.90 in the control soil (Fig. 1).

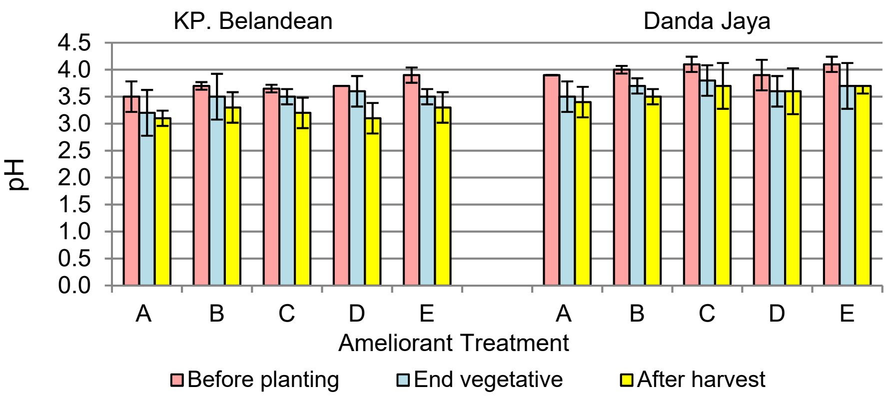

Figure 1. Changes in soil pH content prior to planting, at the end of the vegetative stage, and after harvest, as affected by ameliorant treatment in the tidal swampland of Belandean and Danda Jaya, South Kalimantan, with: a) control; b) *Salvinia sp*, grown; c) *Salvinia sp* compost; d) compost rice straw; and e) compost farmyard manure.

The decrease in soil Fe levels following amelioration treatment was at a figure of 11%, or between 761 ppm (for the control) down to between 525–681 ppm at Belandean. For the Danda Jaya location, the figure was between 9–19%, or from 528 ppm to 428–480 ppm respectively. The decrease in soil Fe levels a t harvest could be related to the waterlogging in this lowland area. Water levels decreased as the plants matured during the start of the dry season; oxidation processes in the soil reduced the levels of soil Fe^{+2} (Fig. 2).

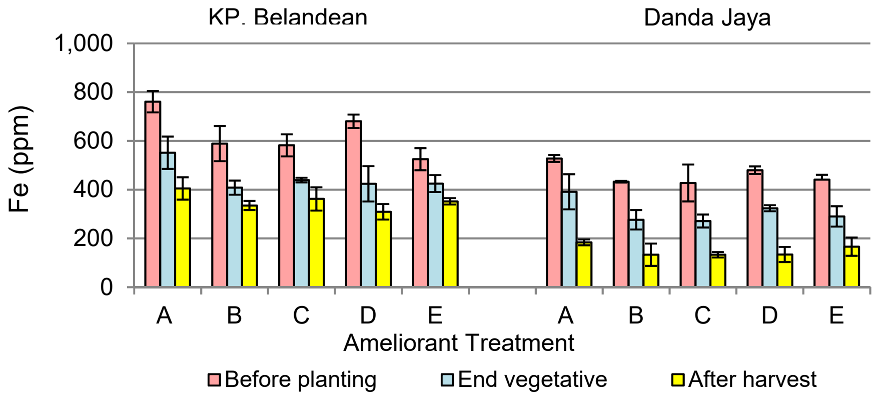

Figure 2. Changes in soil Fe levels prior to planting, at the end of the vegetative stage, and after harvest as affected by ameliorant treatment in the tidal swampland at Belandean and Danda Jaya, South Kalimantan: a) the control; b) *Salvinia sp*, grown; c) *Salvinia sp* compost; d) rice straw compost; and e) farmyard manure compost.

The results revealed that soil iron content in both locations was quite high, with a very low pH level. Ferrous iron toxicity in rice plants was due to the high Fe^{+2} content in the soil, something which occurs in flooded conditions (being known as reduction), where ferric iron (Fe^{+3}) is converted into ferrous iron (Fe^{+2}). The reaction which involved the reduction of ferric iron to ferrous iron occurs in flooded conditions (known as reduction), which involves anaerobic microbes which utilise electrons from NO^{-3}, MnO^{+4}, Fe^{+3}, and $SO4^{-2}$ (Emerson & Moyer, 1997). The Fe oxidation-reduction reaction can be described as follows (Dent, 1986):

$$Fe(OH)_3 + 3H^+ + e- \Leftrightarrow Fe^{2+} + 3H_2O$$

Acidity (soil pH) triggers the dissolution of ferric iron (Fe^{+3}) into a ferrous form (Fe^{+2}), which can be absorbed by plants and can subsequently result in toxicity. The results have shown that low soil pH levels could encourage iron toxicity in rice plants (Dobermann & Fairhurst, 2000; Sahrawat & Diatta, 1995). Fe levels of 100 ppm at pH 3.7 and 300 ppm Fe at pH 5.0 causes iron toxicity in rice (Sahrawat et al., 1996), while Fe levels of 250–500 ppm with a pH of between 4.5–6.0 causes iron toxicity in rice (Majerus et al., 2007; Mehraban et al., 2008).

The ameliorant application of organic matter in soil can decrease the Fe content in that soil (Fig. 2), and decrease the Fe content in the same soil due to the act of chelating organic matter with Fe. The decrease of Fe content in the soil is also a result of the reduction of Fe content which is absorbed by the plant due to the ameliorant application of organic matter in that soil. According to Bernal et al. (2007), organic matter has to control the mobility of heavy metals in soils by decreasing available concentrations through precipitation, adsorption, or complexion processes.

The results from research which was undertaken by Mardalena et al. (2018), revealed that aquatic plants such as water hyacinth (*Eichornia crassive*), water lettuce (*Distia stratiotes*), and floating fern (*Salvinia natans*) can be used as materials for phytoremediation in terms of water which has been contaminated by coal waste due to the ability of these plants to be able to absorb heavy metals such as Fe and Mn.

Fe toxicity levels in plants

The symptoms of iron toxicity vary with rice genotypes. The most common visual symptoms are bronzing or yellowing in rice, tiny brown spots on the lower leaves of plants, spreading towards the leaf base, or the entire leaf colour turning an orange-brown and drying out (Peng & Yamauchi, 1993).

Organic amelioration treatments and rice genotypes significantly affected the levels of ferrous Fe toxicity in rice at four and eight weeks after planting. There was no significant interaction between organic ameliorants and rice genotypes. Organic amelioration treatments could be seen to reduce ferrous Fe toxicity levels in rice (see Table 2).

Table 2. The effect of land amelioration and rice genotypes on ferrous Fe toxicity levels in rice grown in the tidal swampland at Belandean and Danda Jaya in South Kalimantan

Treatment	Belandean		Danda Jaya	
	Fe toxicity Scores (4 weeks)	Fe toxicity Score (8 weeks)	Fe toxicity Scores (4 weeks)	Fe toxicity Scores (8 weeks)
	Soil Ameliorant			
Control	3.93 a	4.32 a	3.33 a	3.42 a
Fresh *Salvinia sp*.	2.53 c	3.06 b	3.00 ab	2.68 b
Salvinia sp. compost	3.00 b	3.28 b	2.73 b	2.58 b
Rice straw compost	3.13 b	3.40 b	3.20 ab	2.88 b
Cow manure compost	3.00 b	3.14 b	3.07 ab	2.72 b
	Rice Genotypes			
TOX4136	2.87 b	3.34 b	2.80 b	3.02 b
Inpara-1	2.33 c	2.74 bc	2.00 c	1.80 c
Inpara-2	3.20 b	3.32 b	3.20 b	3.14 b
Inpara-4	2.20 c	2.26 c	2.07 c	1.60 c
IR 64	5.00 a	5.54 a	5.27 a	4.72 a

Note: Values which are followed by letters within a column are significantly different according to DMRT at $\alpha = 5\%$.

The iron toxicity levels in four-week-old plants which had been grown in ameliorant-treated plots in Belandean was lower - at between 2.53–3.13 - than in the control plots (where the reading was 3.93). Similar results were obtained at Danda Jaya, with readings of between 2.73–3.20 in ameliorant-treated plots and 3.33 in the control plots. Plants which had been treated with *Salvinia sp* compost showed the lowest toxicity symptoms.

The results which are shown in Table 2 revealed the fact that TOX 4136, Inpara-1, Inpara-2, and Inpara-4 varieties are more tolerant when it comes to iron toxicity than is IR-64. Inpara-1 and Inpara-4 plants revealed the lowest symptoms of toxicity in both experimental sites, and at four and eight weeks. The ratings for Danda Jaya were at 1.80 and 1.60 for Inpara-1 and Inpara-4 respectively, in contrast to a reading of 4.72 for IR-64. Similarly, ratings at Belandean were at 2.74 and 2.26 for Inpara-1 and Inpara-4 respectively, in contrast to the figure of 5.54 for IR-64 (Table 4).

Inpara-1 and Inpara-4 show low iron toxicity symptoms both with and without ameliorant applications, indicating the fact that both of these varieties are tolerant of iron toxicity in tidal swampland. According to Becker & Ash (2005), rice plants have a mechanism of avoidance and/or morphological and physiological tolerance when it comes to being able to overcome and survive adverse conditions in soils which contain toxic Fe elements and large amounts of Fe in plants. This mechanism is important in the selection of adaptive or tolerant rice genotypes.

The tolerance of rice genotypes to ferrous Fe toxicity is related to the biosynthesis and lignification processes in root cell walls. Increased lignin concentration in root cell walls and changes of Fe permeability increase the capacity to avoid excessive Fe uptake (Stein et al., 2019). According to Saikia & Baruah (2012), iron toxicity tolerance in rice is related to anti-oxidative enzyme activity. There was an exclusion mechanism here which was determined by its root architecture to be conducive to air transport giving it, therefore, the ability to oxidise Fe^{2+} in the rhizosphere, while there was also a tolerance mechanism which was mainly related to shoot-based mechanisms (a tolerance-inclusion mechanism) (Wu et al., 2014).

Iron levels in plants

Ameliorant treatments significantly reduced Fe levels in rice plant tissues (Fig. 3). The Fe levels were found to be at a figure of 1,299 ppm in the control, and between 759–1,096 ppm in ameliorant-treated plants which were being grown at Belandean. Similar results were obtained from plants which had been grown at Danda Jaya, with a figure of 939 ppm in the control and figures of between 622–703 ppm in ameliorant-treated plants (Fig. 3).

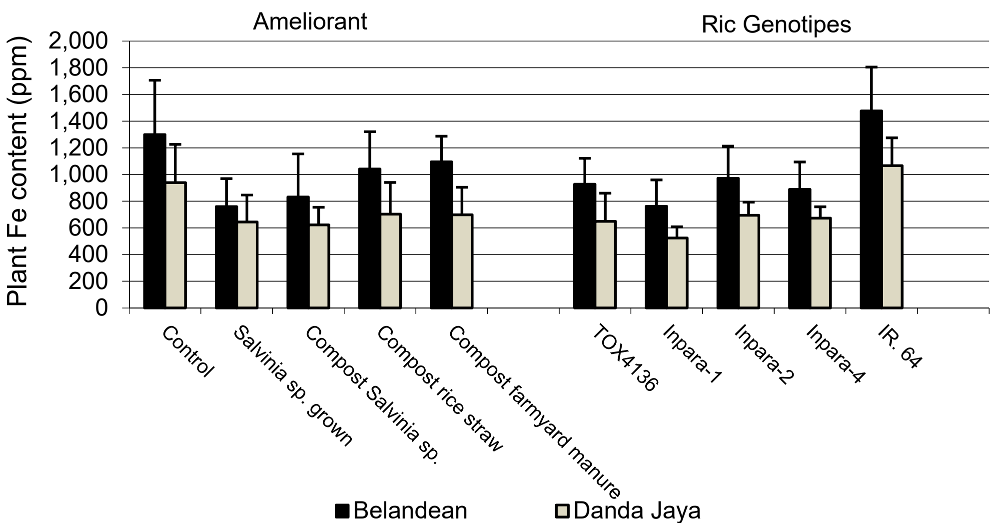

Figure 3. Average iron content in rice under land ameliorant and rice genotype treatments in tidal swampland: Belandean and Danda Jaya, South Kalimantan.

Rice genotype IR-64 is susceptible to iron toxicity, so this genotype could be seen to possess higher iron levels in the plant tissues. Iron levels in IR-64 which was rown at Belandean was at 1,477 ppm, which was higher than the comparative readings for other genotypes (TOX, Inpara-1, Inpara-2, and Inpara-4), which ranged between 762–971 ppm. Similar results were obtained from Danda Jaya, with a reading of 1,066 ppm Fe in IR-64, and only 524–694 ppm Fe in other genotypes.

Previous studies reported that levels of iron toxicity tend to vary with plant varieties and susceptibility. Iron toxicity occurs if the Fe intake by plants is more than 300 ppm (Yamauchi & Peng, 1995), whereas Sulaiman et al. (1997) reported that the figure was 200 ppm Fe for IR-64 which had been grown in tidal swampland areas. The soil Fe content which was used in this particular experiment was somewhat high (at 1,626 ppm Fe), in soil with a high Fe content which can cause iron toxicity in plants. The research results by Noor et al. (2012) showed that FE concentrations in a solution which was set at ≥ 325 ppm Fe caused symptoms of severe iron toxicity in IR-64 rice varieties, which resulted in the presence of a level of inhibition of rice plant growth and which decreased the plant's dry weight to 85.5%.

The level of Fe in rice tissue (Fig. 2) was associated with the iron toxicity figures (Table 2), and Fe levels in the soil (Fig. 2). The result of research by Turhadi et al. (2018), showed that leaf bronzing figures correlated with Fe content levels in the shoots themselves. The research results also showed that IR-64 (sensitive) absorbs high levels of Fe in plant tissues when compared to Hawara Bunar and Pokkali (tolerant), and Indragiri, Inpara-2, and Inpara-6 (moderately tolerant).

Plant growth

Ameliorant treatments significantly affected plant growth heights at the Balandean site, whereas the effects of rice genotypes were significant both at Balandean and Danda Jaya. There was no interaction between amelioration and rice genotypes in terms of affecting plant growth at the two sites (Table 3).

Table 3. The effects of land ameliorants and rice genotypes on plant height and the number of tillers in tidal swampland at Belandean and Danda Jaya in South Kalimantan

Treatment	Belandean		Danda Jaya	
	Plant Height (cm)	Number of tillers	Plant Height (cm)	Number of tillers
	Soil Ameliorant			
Control	76.6 b	12.9 b	76.9 a	14.8 b
Fresh *Salvinia sp.*	85.4 a	15.0 a	79.5 a	16.1 ab
*Salvinia*sp. compost	82.4 a	14.8 a	79.4 a	17.1 a
Rice straw compost	82.3 a	13.9 ab	78.6 a	15.8 ab
Cow manure compost	80.9 ab	13.5 b	81.6 a	15.5 b
	Rice Genotypes			
TOX4136	91.6 a	11.9 c	84.9 b	14.2 c
Inpara-1	89.0 a	14.3 b	89.9 a	16.3 b
Inpara-2	92.3 a	13.5 b	94.0 a	14.3 c
Inpara-4	65.6 b	17.0 a	64.8 c	20.6 a
IR 64	69.2 b	13.4 b	62.3 c	13.8 c

Note: Values which are followed by letters within a column are significantly different according to DMRT at $\alpha = 5\%$.

An application of fresh *Salvinia*, plus *Salvinia* compost, and various types of rice straw all served to increase plant height; this was noted as being between 82.3–85.4 cm in treated plants, compared to a figure of 76.6cm in the control. At both experimental sites, TOX-4136, Inpara-1, and Inpara-2 plants were taller than were those of Inpara-4 and IR-64 (Table 3).

Land ameliorants significantly affected the number of tiller clumps^{-1} at both sites. Belandean's plants, when treated with fresh *Salvinia* and *Salvinia* compost, had the greatest number of tillers, reaching figures of 15.0 and 14.8 respectively. Similar results were obtained at Danda Jaya, with readings of 17.1 for plants which had been treated with fresh *Salvinia*. The number of tillers between genotypes was variable, being at its highest in Inpara-4, with a reading of 17.0 at Belandean and 20.6 at Danda Jaya.

TOX-4136 had the lowest number of tillers at both sites, providing a reading of 11.9 at Belandean and 14.2 at Danda Jaya. Treatment with fresh *Salvinia* and *Salvinia* compost significantly increased the number of tillers, whereas treatment with various forms of rice straw and cow manure did not (Table 3).

Yield and the yield component of rice

Land ameliorants significantly affected grain yields at both sites, along with the number of panicles per tiller, and the number of filled grains per panicle. Similarly, plant genotypes significantly affected yield and yield components, and there were no interactions between land ameliorant treatments and plant genotypes when it came to affecting yield and yield components (Tables 4 and 5).

Table 4. The effects of land ameliorants and rice genotypes on dry grain yield (t ha^{-1}), the number of panicles per tiller, the number of filled grains per panicle, and panicle length (cm) in tidal swampland in Belandean, South Kalimantan

Treatment	Belandean			
	Grain (t ha^{-1})	Number of panicle tiller^{-1}	Number of filled grain panicle^{-1}	Panicle length (cm)
	Land Ameliorant			
Control	3.15 b	9.5 c	112.0 b	21.6 a
Fresh *Salvinia* sp.	3.81 a	12.3 a	127.5 a	21.8 a
Salvinia sp. compost	3.54 a	11.2 ab	131.5 a	22.5 a
Rice straw compost	3.73 a	11.0 b	126.4 a	22.3 a
Cow manure compost	3.60 a	10.8 b	136.6 a	21.9 a
	Rice Genotypes			
TOX4136	2.97 b	9.0 c	125.1 c	22.9 a
Inpara-1	4.08 a	11.0 b	140.6 b	23.3 a
Inpara-2	3.91 a	9.8 b	125.8 c	21.8 b
Inpara-4	4.13 a	12.5 a	170.7 a	21.6 b
IR 64	2.67 b	12.4 a	71.6 d	20.5 c

Note: Values which are followed by letters within a column are significantly different according to DMRT at α = 5%.

Organic ameliorant treatments increased dry grain yields, from 3.15 t ha^{-1} in the control to between 3.54–3.81 t ha^{-1} at Belandean. Fresh *Salvinia*, plus *Salvinia* compost, various forms of rice straw, and cow manure all increased yields by 21%, 12%, 18%, and 14% respectively (Table 4). Dry grain yields at Danda Jaya increased from

3.94 t ha^{-1} in the control to between 4.50–4.73 t ha^{-1}. Fresh *Salvinia*, plus *Salvinia* compost, various forms of rice straw, and cow manure all served to increase yields by 15%, 20%, 14%, and 17% respectively (Table 5).

Table 5. The effects of land ameliorants and rice genotypes on dry grain yield (t ha^{-1}), the number of panicles per tiller, the number of filled grains panicles^{-1}, and panicle length (cm) in tidal swampland at Danda Jaya, South Kalimantan

Treatment	Danda Jaya			
	Grain (t ha^{-1})	Number of panicle tiller^{-1}	Number of filled grain panicle^{-1}	Panicle length (cm)
	Land Ameliorant			
Control	3.94 b	12.8 b	115.3 b	23.0 a
Fresh *Salvinia* sp.	4.55 a	14.5 a	125.6 ab	22.7 a
Salvinia sp. compost	4.73 a	15.2 a	135.5 a	22.8 a
Rice straw compost	4.50 a	13.9 ab	131.4 a	23.0 a
Cow manure compost	4.63 a	14.0 ab	124.6 ab	23.2 a
	Rice Genotypes			
TOX4136	3.70 c	11.6 d	120.8 b	24.1 ab
Inpara-1	5.59 a	15.4 b	152.0 a	24.4 a
Inpara-2	4.50 b	12.5 cd	127.1 b	23.5 b
Inpara-4	5.61 a	17.8 a	158.9 a	21.6 c
IR 64	2.95 d	13.5 c	73.6 c	21.2 c

Note: Values which are followed by letters within a column are significantly different according to DMRT at $\alpha = 5\%$.

Organic ameliorant treatment increased the number of panicle tillers^{-1}, from 9.5 in the control to between 11.0–12.3 at Belandean, and from 12.8 for the control to between 13.9–15.2 at Danda Jaya. Inpara-1 and Inpara-4 at Danda Jaya had results of 14.8 and 17.8, which was significantly more than for IR-64 (which produced a reading of 13.5). *Salvinia*-treated plants, both fresh and composted, had more panicles than did the control plants, whereas those which had been treated with various forms of rice straw and cow manure were similar to the control treatment at Danda Jaya (Tables 4 and 5).

Organic ameliorant treatment increased the number of filled grain panicles^{-1} from 112.0 for the control to between 126.4–136.6 at Belandean, and from 1,115.3 for the control to between 124.6–135.5 at Danda Jaya. Inpara-1, Inpara-2, Inpara-4, and TOX-4136 all produced significantly higher readings than did IR-64 at both locations (Tables 4 and 5).

Organic ameliorant treatment at both locations did not affect panicle length. The average panicle length at Belandean was between 21.6–22.5 cm, while at Danda Jaya it was between 22.7–23.0 cm. At both locations, the genotype which had the longest panicle was Inpara-1 (which produced readings of 23.3 cm at Belandean and 24.4 cm at Danda Jaya), and the shortest was IR-64 (at 20.5 cm for Belandean and 21.2 cm for Danda Jaya).

Fresh *Salvinia* increased grain yields by 21% at Belandean, whereas *Salvinia* compost increased yields by 20% when compared to results for other ameliorant treatments. These results demonstrated that, just like various forms of rice straw and cow manures, *Salvinia*, both fresh and as compost, can be used as organic ameliorants in tidal swampland areas. Aquatic plants have the potential to be used for the phytoremediation of water which has been contaminated with inorganic (such as nutrients or heavy metals), and also organic pollutants due to their ability to absorb and bind elements which solute in the water (Wani et al., 2017; Mardalena et al. 2018; Ali et al., 2020; Ansari et al., 2020). The technology which was used in the phytoremediation of metal which had contaminated environments should be effective, cost-effective, and environmentally friendly (Sharma et al., 2015; Ashraf et al., 2018).

Organic ameliorant treatment and the use of tolerant genotypes increased rice yields through their roles in preventing or reducing ferrous Fe toxicity in rice (Tables 4 and 5). The use of tolerant genotypes at Belandean increased grain yields to 4.13 t ha^{-1} at Belandean, whereas the yield of the susceptible IR-64 was only 2.67 t ha^{-1}. Similarly, the use of tolerant genotypes at Belandean increased grain yields to 5.61 t ha^{-1}, whereas the yield of the susceptible IR-64 was only 2.95 t ha^{-1}. The yields of tolerant-genotypes (TOX-4136, Inpara-1, Inpara-2, and Inpara-4) at Belandean were between 11.20–54.70% higher than the figures for IR-64. Similarly, the yields were between 25.4–90.2% higher than those for IR-64 at Danda Jaya. Inpara-1 and Inpara-4 had grain yields of 4.08 and 4.13 t ha^{-1} at Belandean respectively, whereas at Danda Jaya the results were 5.59 t ha^{-1} and 5.61 t ha^{-1}.

The results which have been gathered together under this study have revealed that levels of iron toxicity tended to vary with soil characteristics and rice genotypes. The toxicity levels at Belandean were higher than those at Danda Jaya, something which may be related to differences in soil characteristics between the two sites (Table 2). The soil at Belandean was more acidic and had higher levels of exchangeable Al and Fe.

Ferrous Fe toxicity in plants is caused by high levels of soil-soluble Fe. Most mineral soils are rich in Fe, and ferrous Fe toxicity in plants generally occurred in flooded areas where a reduction process involving microbes converted insoluble Fe^{3+} to soluble Fe^{+2} (Beckers & Ash, 2005).The critical concentration, according to Sulaiman et al. (1997), using extraction methods with 1 N NH_4OAC in tidal swampland areas was 260 ppm. The toxicity level in IR-64 plant tissue was 200 ppm.

Research results from Lubis et al. (2016) regarding tidal swampland in South Kalimantan with a soil Fe content of 631 ppm, involved paddy IR-64 (sensitive varieties) which showed severe symptoms of iron toxicity (the ferrous Fe toxicity score was 7.0), but Inpara-4 (tolerant varieties) showed only light symptoms of iron toxicity (the ferrous Fe toxicity score was 3.0). In conditions of elevated iron toxicity, the individual rice plant experienced a decrease in morpho-physiological performance as indicated by a decrease in plant height, length, and width, the number of leaves, and the contents of chlorophyll and carotenoids (Novianti et al., 2020). According to Onyango et al. (2019), iron toxicity also affects several characteristics of rice, such as the length of the roots, increased bronzing of leaves, photosynthesis, transpiration, soluble sugars, proteins, and starch.

Organic ameliorant treatments at both sites served to reduce ferrous Fe toxicity and increased rice yields. The application of organic matter will improve soil quality and reduce phytotoxicity. Some organic acids - both naturally and as a result of the decomposition of organic matter - can bind to metal ions and reduce their solubility in the soil. Organic acids are abundantly released by the plants, and can be used as the natural chelators of metal ions (Montiel-Rozas et al., 2016), Research results from

Herviyanti et al. (2011) revealed that the application of humic matter from rice straw compost with a dose of 600 kg ha^{-1} on rice fields which have always flooded can reduce the concentration of Fe^{2+} in the soil, from 694 ppm to 476 ppm, and increase grain yield by 51.4% when compared to soil which does not contain humic materials. Research results from Mowidu et al. (2019) revealed that the application of straw compost at 5 t ha^{-1} increased the grain yield of Inpari-1 genotypes by 20.83% when compared to using no straw compost at all.

An application of fresh or composted *Salvinia sp* was comparably effective to cow manure or various forms of rice straw. This result demonstrated the potential use of *Salvinia sp* as organic matter, and this species is widely available in the tidal swampland. Four week-old *Salvinia* produced 225 kg of fresh weight 100 $(m^2)^{-1}$, or about 22.5 t ha^{-1} at Belandean, and a 186 kg $plot^{-1}$ or about 18.6 t ha^{-1} at Danda Jaya. The time taken to multiply *Salvinia sp* at Belandean and Danda Jaya was 5.1 and 5.9 days respectively.

There are several mechanisms in environmental phytoremediation which can be useful in remediating heavy metals from contaminated soils, with phytoextraction and phytostabilisation being used as the most promising and alternative methods (Mahar et al., 2016; Sarwar et al., 2017). Several environmental factors, such as pH, solar radiation, nutrient availability, and salinity, all greatly serve to influence the phytoremediation potential and growth of the plant (Reeves et al., 2018; Tewes et al., 2018).

Salvinia sp plants have been reported to contain major nutrients (N, P, K, Ca, and Mg), along with growth regulators, particularly cytokine and IAA (Arthur, 2007). In addition, *Salvinia sp* biomass has the ability to bind heavy metals. Begum & Hari Krishna (2010) reported that *Salvinia sp* bound 88.8% Fe from a 5 ppm solution after ten days. Sanchez-Galvan et al. (2008) reported that *Salvinia sp* has a wide specific surface ($264 m^2 g^{-1}$), one which is rich in carbohydrates (48.5%) and carboxyl (0.95 mmol g^{-1}).

CONCLUSION

1. Organic ameliorant treatments reduced soil Fe, ferrous Fe toxicity scores, and Fe content in plant tissues, and increased plant height and the number of tillers in selected rice grown under medium and high levels of ferrous Fe toxicities in tidal swampland.

2. Rice genotypes which have medium levels of tolerance or which are fully tolerant to iron toxicity and organic ameliorants treatments tend to decrease iron toxicities and increase the number of filled grains and yields of rice grown in tidal swampland. An application of fresh *Salvinia sp* and *Salvinia sp* compost were as effective as an application of various forms of rice straw and cow manure compost when it came to increasing yields.

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