Indonesian Journal of Agronomy

ISSN 2085-2916 | e-ISSN 2337-3652
Indonesian J. Agron., *51*(2), 269-280, August 2023
DOI: https://dx.doi.org/10.24831/ija.v51i2.48224

Research Article

Control of iron stress in water-saturated tidal land using ameliorant and its impact on rice productivity

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ABSTRACT

Fe stress is a problem in swamp lands that reduces the growth and yield of rice. Providing various types of ameliorants and selecting rice varieties are considered an effort to obtain high rice productivity in tidal land. The research aimed to study the effect of various ameliorants on rice growth and production, and to obtain high productivity of tolerant variety to iron stress at different locations of tidal land. The research was conducted in Karya Bakti Village (1°10'34.8" S and 104°09'31.1" E), Rantau Rasau, East Tanjung Jabung, Jambi. This study adopted a split-plot design with different types and doses of ameliorant as the main plots and several rice varieties as the subplots with three replications. The results showed that the application of ameliorant rice husk ash, coconut husk ash, empty bunch oil palm compost, and goat manure stimulated vegetative and generative growth. Meanwhile, the Inpari 16 Pasundan variety was proven to have better growth and higher production as described through plant height, fresh weight of shoots and roots, dry weight of shoots and roots, root length, number of productive tillers, number of grains per panicle, 1,000 grain weight, and harvested dry grain. The highest rice production was in the Inpari 16 Pasundan variety, 9.3 tons ha^{-1} (low-Fe) and 7.6 tons ha^{-1} (high-Fe). The combination of rice husk ash (0.25 tons ha^{-1}) + coconut husk ash (0.25 tons ha^{-1}) + empty bunch oil palm compost (0.75 tons ha^{-1}) + goat manure (0.75 tons ha^{-1}) was the best combination to increase rice productivity. Inpari 16 Pasundan is considered a tolerant variety on tidal land with high-Fe stress. The interaction between ameliorants and varieties was significant on plant height at ages 2 and 4 weeks after planting at low-Fe, number of productive tillers at high-Fe, root length at low-Fe and high-Fe, 1,000-grain weight, and number of grains per panicle at low-Fe, and harvested dry grain at low-Fe and high-Fe.

Keywords: B-type tidal fields, Fe stress cultivation, organic ameliorant, tolerant rice variety, water-saturated cultivation

Edited by:
Maya Melati

Received:
23 June 2023
Accepted:
9 August 2023
Published online:
25 August 2023

Citation:
Lestari, W., Munif Ghulamahdi, M., & Purwono (2023). Control of iron stress in water-saturated tidal land using ameliorant and its impact on rice productivity. *Indonesian Journal of Agronomy*, *51*(2), 269-280

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food crop in Indonesia. As the population steadily grows, there is a simultaneous increase in the demand for rice, hence necessitating the increase in rice production. Indonesia's average national rice production from 2018 to 2021 was recorded at 55.39 million tons, with an average productivity of 5.17 tons per hectare (ha). However, there were fluctuations in rice production during this period. In 2018-2019, there was a decrease of approximately 7.76% in rice production. Subsequently, in 2019-2020, there was a slight increase of 0.61% in rice production. Despite the slight increase in the last two years, the overall rice production in 2018-2021 still experienced a decrease of around 2.18%. This decline can be attributed to a reduction in the rice land area, which decreased by approximately 2.56% during the same period (Indonesian Central Statistics Agency, 2021). The decrease in rice land area has likely affected the overall production output, despite the productivity improvements observed in certain years.

Rice cultivation can be improved through the optimization of tidal swamp land. The area of tidal land in Jambi province was recorded at 31.4 hectares, indicating that Jambi Province is a potential area for rice plants that have opportunities to increase productivity (Indonesian Central Statistics Agency, 2016). Despite its potential for rice production, tidal lands face challenges in achieving high yields, as evidenced by an average of 2.5 tons ha^{-1} (Irwandi, 2015). This is primarily attributed to unfavorable soil conditions, including high soil acidity, elevated levels of Fe, Al, and persistent waterlogging (Ghulamahdi et al., 2017). These characteristics exhibit plant growth and contribute to the lower productivity level.

Fe stress presents a considerable impediment in wetland ecosystems. Turhadi et al. (2019) underscore the vulnerability of rice cultivation in these regions to decreased productivity caused by Fe stress. The presence of Fe exerts adverse effects on rice plants, hindering nutrient absorption and translocation to the upper plant organs. Consequently, the incursion of Fe into plant tissues disrupts pivotal cellular division processes, as explicated by Harahap et al. (2014).

Mitigating the detrimental effects of Fe stress on rice growth and yield entails implementing various strategies, including the application of ameliorants and the cultivation of tolerant varieties. Numerous ameliorants have proven effective in alleviating the impact of Fe stress. Yusuf and Mukhlis (2020) reported that the inclusion of rice husk biochar as an ameliorant enhances the plant's capacity to attain optimal production. Meanwhile, the application of humic acid (Yartiwi et al., 2023) and rice husk ash (Sagala et al., 2021) as an ameliorant contributes to increased rice and soybean production in areas characterized by high Fe stress.

Utilizing Fe-tolerant rice varieties represents a strategic approach to enhance rice production in tidal swamp regions. Ratmini et al. (2021) have substantiated the indispensability of Fe-tolerant varieties in facilitating favorable growth and yield outcomes. Notably, several rice varieties have demonstrated optimal performance, including Indica (Kar et al., 2021), Inpara 4 (Yartiwi et al., 2023), CK801 and Suakoko8 (Dorothy et al., 2020), and Pokkali (Turhadi et al., 2019).

Several rice varieties, including IR64, Sertani, Inpari 16 Pasundan, and Inpara 2, are renowned for their high productivity. However, the extent of their tolerance to Fe levels still requires comprehensive testing. To further enhance the growth and optimal productivity of these selected rice varieties, implementing different ameliorants can be considered complementary measures. These ameliorants can help create a supportive environment for the growth and development of rice plants.

The research aimed to study the effect of various ameliorants on rice growth and production, and to obtain high productivity of tolerant variety to iron stress at different locations of tidal land.

MATERIALS AND METHODS

The research was conducted in Karya Bakti Village (1°10'34.8" S and 104°09'31.1" E), Rantau Rasau, East Tanjung Jabung, Jambi. The study began in October 2022 and ended in February 2023. The study site includes type B tidal land with a tropical climate. The study was carried out in two experiments, i.e. low-Fe (3,400 ppm) and high-Fe (6,200 ppm) land conditions.

The study adopted a split-plot design. Different types and doses of amelioration were designated as the main plot, while the rice variety was as sub-plots. The type and dose of ameliorant consisted of no ameliorant (A0), rice husk ash (0.25 tons ha^{-1}) (A1), rice husk ash (0.25 tons ha^{-1}) + coconut husk ash (0.25 tons ha^{-1}) (A2), rice husk ash (0.25 tons ha^{-1}) + coconut husk ash (0.25 tons ha^{-1}) + empty bunch oil palm compost (0.75 tons ha^{-1}) (A3), rice husk ash (0.25 tons ha^{-1}) + coconut husk ash (0.25 tons ha^{-1}) + empty bunch oil palm compost (0.75 tons ha^{-1}) + goat manure (0.75 tons ha^{-1}) (A4), and dolomite (2 tons ha^{-1}) (A5). Rice varieties were IR64, Sertani, Inpari 16 Pasundan, and Inpara 2 symbolized as V1, V2, V3, and V4, respectively. The 24 treatment combinations were repeated 3 (three) times, resulting in a total of 72 experimental units.

The certified rice seeds were used in the study. Rice seedlings were prepared before planting. Seeds were soaked in water for 8-9 hours to achieve full imbibition, and then the seeds were drained for 24 hours to stimulate root growth. The nursery beds were 1 m wide and 4 m long with a height of 20-40 cm. The seeds were put into the seedling holes, then the rice husks were spread on the beds to ease uprooting. Soil moisture was maintained by irrigation. Seedlings were transplanted at the age of 21 days.

Rice seedlings were planted in plots measuring 2 m (length) x 3 m (width). The plot was equipped with water channels measuring 30 cm (wide) and 25 cm (depth). The water level was maintained ± 10 cm below the ground surface to maintain water saturation conditions. Before planting, ameliorants in accordance with the treatment were applied in each experimental plot. Ameliorant was spread evenly on the surface of the plot. Ameliorant was incubated for 1 week in the experimental plot, before transplanting.

Rice seedlings were planted on each experimental plot with a planting distance of 25 cm x 25 cm. Two seedlings were planted at a depth of 1-1.5 cm from the base of the roots. Water irrigation was maintained from planting to harvest at a level of ± 10 cm above the bottom of the trench.

Inorganic fertilizers were applied with the recommendation rate of 300 kg urea ha^{-1}, 200 kg KCl ha^{-1}, and 300 kg SP-36 ha^{-1}. The fertilizer application was carried out in three stages, namely all SP-36 was applied before planting. Urea and KCl were applied twice, first at 14 and secondly at 35 days after planting (DAP) with a 50% recommended dose for each fertilizer application. Pest and disease control used pesticides according to the field situation in accordance with the recommended dose.

Rice was ready to be harvested at the age of ± 100 days after planting (DAP) which was characterized by rice grains and flag leaves turning 95% yellow, brownish-yellow leaf color, hard and filled rice grains, and ducked stalks. Each rice variety was harvested according to predetermined ripening criteria.

The data collected was divided into plant growth data, plant yield, and plant tissue Fe content. Plant growth consisted of plant height, root length, root fresh weight, root dry weight, shoot fresh weight, and shoot dry weight. Plant production data consisted of the number of productive tillers, the number of grains per panicle, 1,000 grain weight, and harvested dry grain (HDG).

Observation of plant height was carried out non-destructively at intervals of 2 weeks. Meanwhile, other parameters were observed destructively at the end of the study. The observed dry weight of plant organs was obtained through drying using an oven with a temperature of 80 °C for 48 hours. Meanwhile, Fe content was determined using Atomic Absorption Spectrometry (AAS) (Agilent 200 Series AA Systems, Agilent Technologies, Inc, USA).

The significant differences among data were determined by analysis of variance (ANOVA). Furthermore, the significance value between treatments was tested with Tukey's honestly significance difference (HSD) test at the level of α = 5%. All data were analyzed using DSAASTAT for Windows (developed by the University of Perugia). Furthermore, combined analyses were carried out to determine the varietal response, the influence of amelioration, and the interaction of both on land with different Fe stresses.

RESULTS AND DISCUSSION

Plant vegetative growth

As the plants age, their height steadily increased, reflecting their vegetative growth. Moreover, comparing the height of rice plants cultivated in low-Fe soil and those in high-Fe soil revealed discernible disparities. The cultivation of rice in low-Fe soil resulted in higher plants in comparison to those grown in high-Fe soil (Figure 1).

Each ameliorant had no significant effect on rice plant growth every two weeks on the low-Fe fields (Figure 1). On the contrary on the high Fe field, the ameliorants had a significant effect at measurements of 2, 4, and 6 weeks after planting (WAP). Nevertheless, it is worth noting that ameliorant rice husk ash, coconut husk ash, empty bunch oil palm compost, and goat manure demonstrates a potential to stimulate the height growth of rice, particularly in high Fe soil condition. The increase in plant height is thought to be the effect of giving rice husk ash which can increase soil pH (Nurhayati, 2014). Goat manure has complex bonds so it can improve the life of micro-organisms in the soil because it contains very good organic matter as a result of which nutrient availability increases (Ghulamahdi et al., 2023). This suggests that optimizing the specific components and their proportions in amelioration can result in superior stimulation of plant height during rice cultivation.

The selected rice varieties did not exhibit a significant difference among ameliorants in terms of plant height, but the Sertani variety showed higher growth in plant height than IR64. This distinct characteristic of Sertani was observed consistently in both low Fe and high Fe soil conditions. This indicated that the Sertani variety shows a consistent ability to increase plant height regardless of the Fe content in the soil.

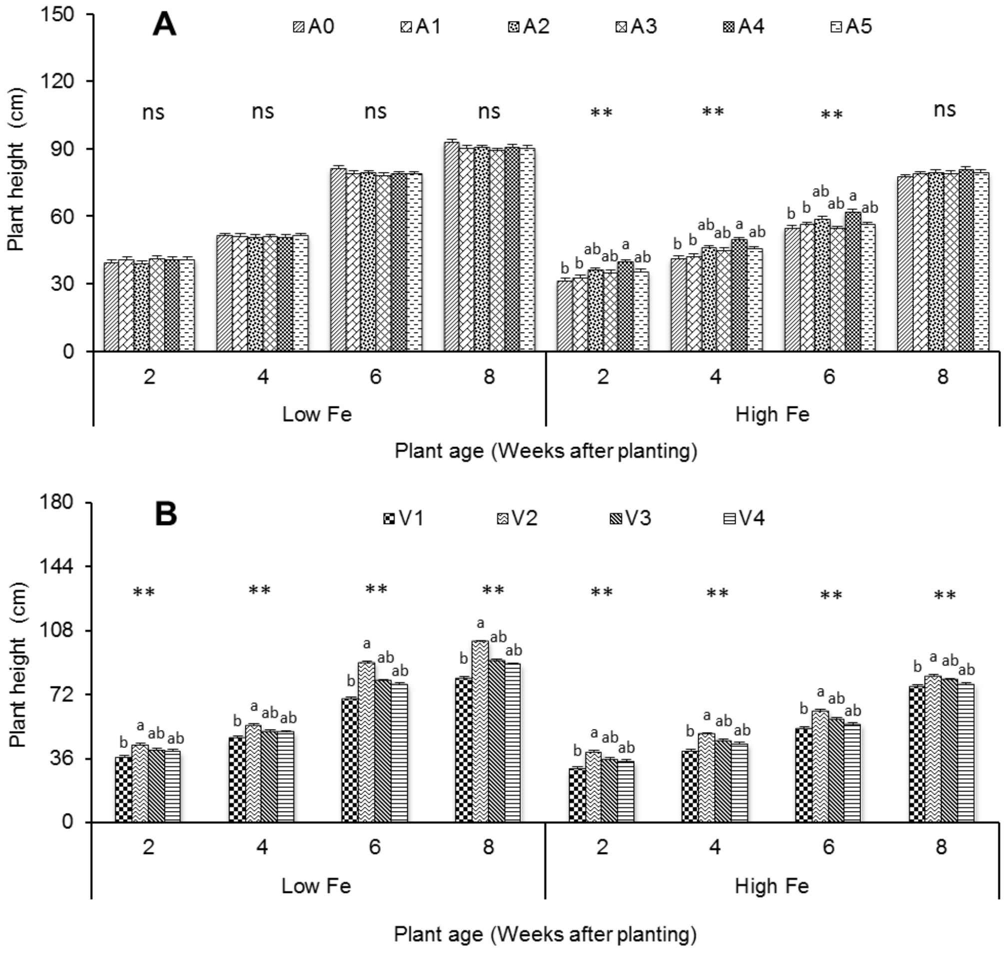

Figure 1. Biweekly plant height of rice plant under different applications of ameliorants (A) consisted of no ameliorant (A0), rice husk ash (A1), rice husk ash + coconut husk ash (A2), rice husk ash + coconut husk ash + empty bunch oil palm compost (A3), rice husk ash + coconut husk ash + empty bunch oil palm compost + goat manure (A4), and dolomite (A5). Rice varieties (B) to test are IR64 (V1), Sertani (V2), Inpari 16 Pasundan (V3), and Inpara 2 (V4) in low-Fe and high-Fe locations.

The stunted growth of plant height was caused by excessive absorption of Fe nutrients. The excessive of Fe found within the cultivation site influences plants' physiological function and molecular mechanism, consequently leading to a decline in plant growth performance (Aung et al., 2020). Food crops, including rice, are cultivars sensitive to excess Fe. The growth of other food crops, such as soybeans, has also been found to be inhibited due to an excess of Fe (Lapaz et al., 2020). The implementation of ameliorants and the careful selection of tolerant varieties have been scientifically validated as effective strategies to address growth impediments in plants induced by an excessive concentration of Fe (Mahender et al., 2019; Ratmini et al., 2023).

The fresh weight of each rice plant organ serves as an indicator of the rice plant's capacity to uptake water and nutrients. Typically, the fresh weight of the shoot and root in rice plants cultivated in low-Fe soil conditions surpasses that of plants grown in high-Fe soil conditions. The presence of Fe stress in high-Fe soil adversely affects the plant's ability to absorb water and nutrients, consequently impacting the fresh weight of both the shoot and root (Figure 2).

Treated soil with ameliorants plays an important role in establishing a more sufficient growth environment, enabling efficient absorption of water and nutrients. This positive effect of ameliorants is evident in both low-Fe and high-Fe soil conditions. Notably, among the various ameliorant treatments, a combination of rice husk ash, coconut husk ash, empty bunch oil palm compost, and goat manure demonstrated a significant increase in the fresh weight of shoot and root when compared to other treatments. This suggests that a combination of rice husk ash, coconut husk ash, empty bunch oil palm compost, and goat manure exhibited a distinct ability to facilitate the effective uptake of water and nutrients by the plants, thereby promoting their growth.

The application of ameliorants is able to improve the roots of rice plants because it further expands the area reached by the roots to absorb elements of N, P, Si, Ca, Mg, Na, and K (Suwardi & Wijaya, 2013). The increase in root weight has an effect on the increase in shoot weight. The higher the fresh weight of the roots, the higher the fresh weight of the shoots (Telaumbanua et al., 2023).

The response of each rice variety to Fe stress, particularly in terms of root growth, has been verified to be distinct. Significant differences were observed among the tested varieties, particularly in root fresh weight. However, no significant differences were observed in shoot growth. This is in line with the results of research by Dewi et al. (2021) that the height and low of fresh shoot weight is influenced by plant physiological activities such as photosynthesis.

However, the Inpari 16 Pasundan variety had good adaptation and a greater ability to absorb water and nutrients compared to the other tested varieties. This adaptive trait was evident in both low-Fe and high-Fe soil conditions, emphasizing the exceptional performance of the Inpari 16 Pasundan variety.

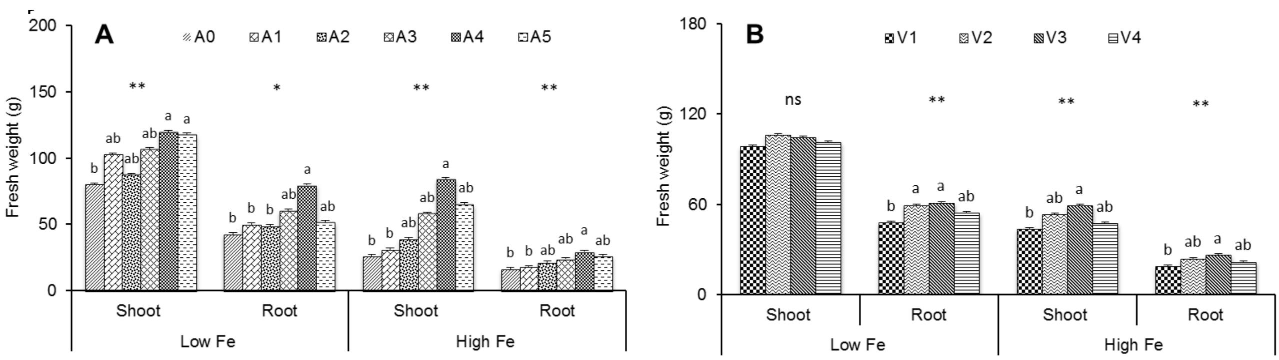

Figure 2. Fresh weight of shoot and root of rice plant under different applications of ameliorants (A) and rice varieties (B) in low Fe and high Fe locations.

The capacity of plants to uptake water and essential nutrients becomes hindered when they are cultivated under conditions of Fe excess (Severo et al., 2020). This is primarily attributed to root damage, which impedes their ability to efficiently transport both components to various plant tissues (Saikia et al., 2019). The aforementioned condition significantly impacts plant metabolism, consequently leading to suppressed plant growth, as reported by Zahra et al. (2021). This assertion is further supported by observable alterations in the fresh weight of both roots and shoots. This phenomenon arises due to the fundamental requirement of plants for a well-balanced provision of water and nutrients to achieve an optimum fresh weight for the shoot and root growth (Mazhar et al., 2022).

The distribution of photosynthetic yield to vegetative organs is manifested through the dry weight of both the shoot and root. The presence of high-Fe stress has a significant negative impact on photosynthetic yield. This effect is observed in the reduced dry weight of both the shoot and root under the high-Fe condition in comparison to the low-Fe condition. The elevated Fe content in the cultivated soil hinders plant metabolism, including the process of photosynthesis, consequently resulting in a decline in the overall dry weight of the plants (Figure 3).

The tested ameliorants have demonstrated their capability to establish an environment conducive to plant metabolism, particularly in terms of photosynthetic allocation to vegetative organs. This effect is more prominent in land affected by high-Fe stress. Among the various ameliorants, the combination of ameliorant rice husk ash, coconut husk ash, empty bunch oil palm compost, and goat manure has shown good stimulation of photosynthesis compared to other treatments. This enhanced photosynthetic activity is reflected in the increased dry weight of both the shoot and root. Therefore, a combination of rice husk ash, coconut husk ash, empty bunch oil palm compost, and goat manure exhibited a good ability to promote photosynthetic efficiency and subsequent growth in plants, as evidenced by the dry weight of the shoot and root.

Each tested rice variety showed a distinct response in terms of photosynthetic allocation to vegetative organs. However, there is no significant influence observed on the dry weight of the shoot for any of the varieties, regardless of whether they are grown in low Fe or high Fe soil conditions. On the other hand, there are significant differences in root growth, as indicated by the dry weight of the root, among the varieties in both low iron Fe and high Fe soil conditions. However, the Inpari 16 Pasundan variety shows a higher allocation of photosynthetic yield compared to other varieties, both in low Fe and high Fe soil conditions. This finding suggests that the Inpari 16 Pasundan variety possesses a notable ability to cope with Fe stress, particularly in terms of root growth.

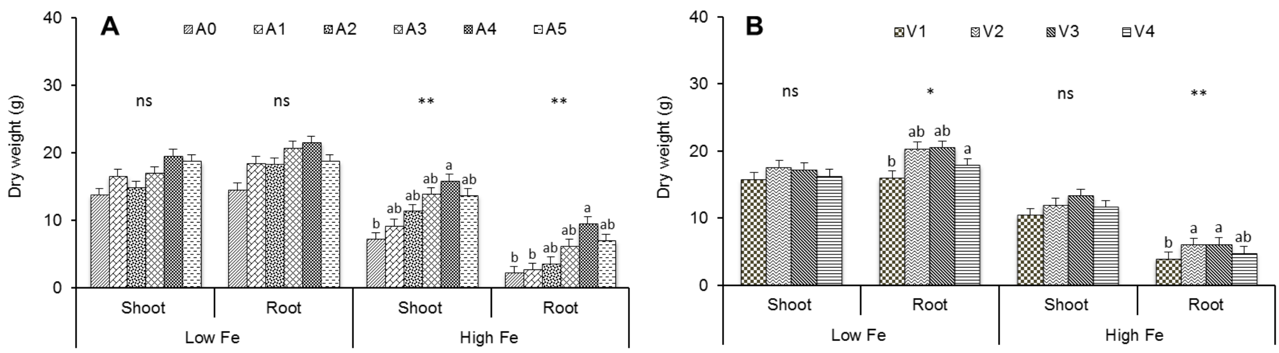

Figure 3. The dry weight of the shoot and root of rice plants under different applications of ameliorants (A) and rice varieties (B) in low Fe and high Fe locations.

The higher the fresh weight of the roots produced, the higher the dry weight of the plant roots (Suryadi, 2012). The results of research by Risnah et al. (2013) showed that the administration of coconut husk ash increased K uptake so that elemental K could increase growth by increasing the rate of photosynthesis in the rice shoot.

Root growth in rice, as indicated by the dry weight, is accompanied by root elongation. The application of the tested combination of rice husk ash, coconut husk ash, empty bunch oil palm compost, and goat manure has stimulated root elongation. This dominance in root elongation highlights the capability of a combination of rice husk ash, coconut husk ash, empty bunch oil palm compost, and goat manure to facilitate improved root growth. Conversely, in plants without ameliorant application, root elongation is significantly inhibited. This consistent pattern is observed in both low-Fe and high-Fe conditions (Figure 4).

Each rice variety exhibited a unique and significant response to root elongation, observed in both low-Fe and high-Fe soil conditions. Despite the Inpari 16 Pasundan variety having the highest dry weight, it does not display dominance in root elongation. Instead, this variety tends to produce more root branching or hair roots rather than extensive root elongation. This suggests that the Inpari 16 Pasundan variety focuses on developing a dense network of fine roots, which aids in nutrient and water absorption, rather than relying on elongated roots for nutrient acquisition.

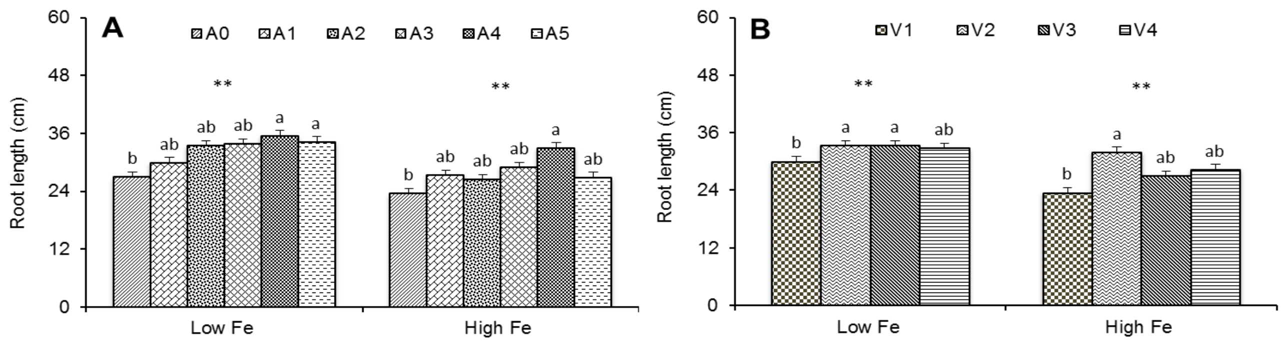

Figure 4. Root length of rice under different applications of ameliorants (A) and rice varieties (B) in low Fe and high Fe locations.

Fe stress causes the root system to be unable to develop and in poisoning conditions, the root surface will be coated with iron oxide (Fe_2O_3) which is dark brown to black in color (Harahap et al., 2014). It is proven in the results of Onyango et al. (2019) that high Fe stress disrupts the morphological performance of root length. Plants that have long roots and a wide distribution are thought to be able to maximize nutrient absorption (Mustikarini et al., 2021).

Crop production

The number of productive tillers in rice plants serves as an indicator of their potential yield. In general, high-Fe soil conditions are associated with a lower number of productive tillers compared to low-Fe soil conditions. This trend suggests that high-Fe stress impedes the growth and development of productive tillers in rice plants. As a result, the overall yield potential of rice crops may be negatively affected under high-Fe soil conditions (Figure 5).

The application of various types of ameliorants has a significant impact on increasing the number of productive tillers. Rice husk ash, coconut husk ash, empty bunch oil palm compost, goat manure and dolomite (A1, A2, A3, A4, and A5) application have increased the number of productive tillers compared to the absence of ameliorant application (A0). Ameliorants containing high levels of N, P, K, Ca, Mg, and high organic matter are very effective in increasing soil pH and soil fertility which is very important in the formation of tillers (Telaumbanua et al., 2023). This finding indicates that all the tested ameliorants can enhance the development of productive tillers in rice plants.

Several tested rice varieties exhibited variations in the number of productive tillers. Among these varieties, the Inpari 16 Pasundan variety stands out as it consistently demonstrates more productive tillers compared to other varieties. This characteristic is observed in both low-Fe and high-Fe soil conditions, highlighting the superior tillering capacity of the Inpari 16 Pasundan variety regardless of iron stress levels in the soil.

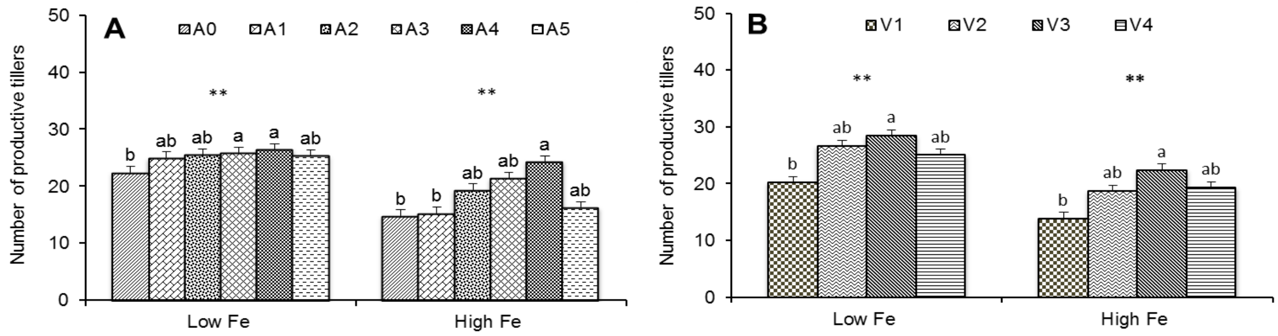

Figure 5. Productive tillers under different applications of ameliorants (A) and rice varieties (B) in low Fe and high Fe locations.

The number of productive tillers that are balanced with panicle length has a strong genetic relationship with the character of the number of panicles, total grain number, number of filled grains (Safrida et al., 2019), and yields (Mustikarini et al., 2021). Differences in the number of tillers of different types of rice are influenced by genetic factors and environmental factors, such as plant spacing and nutrients (Shafi'ie & Damanhuri, 2018).

The application of ameliorants has shown nonsignificant effectiveness on low-Fe soils in increasing grain yield per panicle. Among the ameliorants tested, a combination of rice husk ash, coconut husk ash, empty bunch oil palm compost, and goat manure stands out because it causes a higher yield of rice grains than other ameliorants. The use of a combination of rice husk ash, coconut husk ash, empty bunch oil palm compost, and goat manure shows its potential to increase overall rice productivity and yield. The ameliorant role of rice husk ash, coconut husk ash, empty bunch oil palm compost, and goat manure has a more complex bond so that it can provide nutrients for plants when filling rice seeds (Ghulamahdi et al., 2023) (Figure 6).

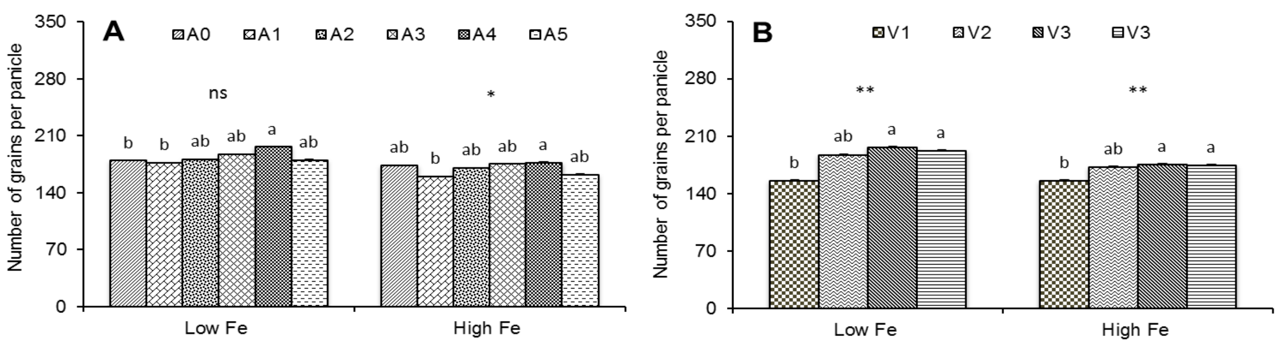

Figure 6. Number of grains per panicle of rice plant under different applications of ameliorants (A) and rice varieties (B) in low Fe and high Fe locations.

The total number of grains per panicle has a positive correlation with the number of productive tillers (Andrew et al., 2020) and grain weight (Fatimaturrohmah et al., 2016) so that a large number of total grain will be in line with the increase in grain yield. Plants that lack element N will result in grain being empty (Arinta & Lubis., 2018). Results from Azalika et al. (2018) that a good rate of photosynthesis helps the process of filling the grain optimally by transferring photosynthesis.

The weight of 1,000 grains of rice serves as a representative measure of the actual yield of the plant in the field, without undergoing any drying process. When comparing the effects of Fe stress, both in low-Fe and high-Fe conditions, a similar trend is observed in terms of the weight of 1,000 grains. This consistent pattern holds for both ameliorant-treated plants and different rice varieties. Ameliorants can increase soil pH and affect the availability of nutrients because nutrients can affect normal pH (Nurhayati, 2014). Therefore, regardless of the presence of ameliorants or the specific rice variety, the impact of Fe stress on the weight of 1,000 grains remains consistent (Figure 7).

The application of ameliorants has not resulted in significant stimulation of the weight of 1,000 grains of rice. However, there is a positive trend observed about this parameter specifically with ameliorant rice husk ash, coconut husk ash, empty bunch oil palm compost, and goat manure. On the other hand, among the tested rice varieties, significant differences have been observed in the weight of 1000 grains. The IR64 variety has been found to have the lowest weight of 1,000 grains, while the other varieties have not shown significant differences in this parameter.

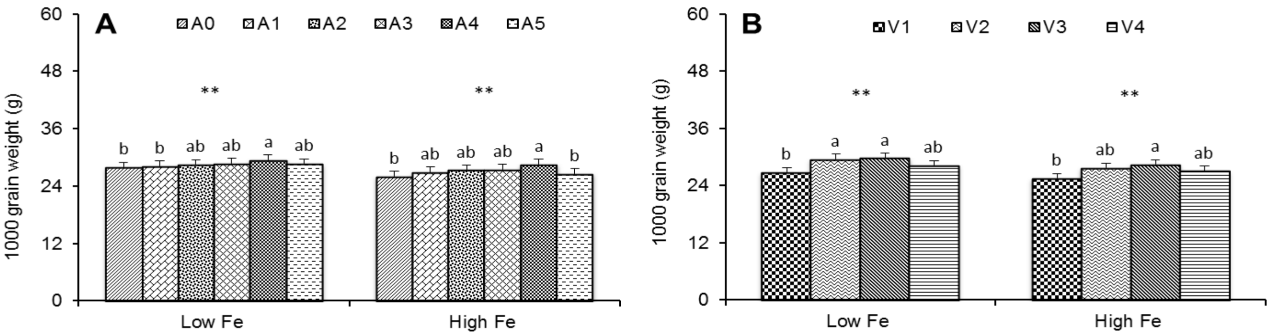

Figure 7. 1,000-grain weight of rice plant under different applications of ameliorants (A) and rice varieties (B) in low Fe and high Fe locations.

Conditions after flowering for example, the availability of photosynthates, weather, and the number of leaves affect the 1,000 grains' weight (Fatimaturrohmah et al., 2016). The grain weight of rice types has different characteristics due to differences in grain size and shape which are determined by the genetic factors of each rice variety and environmental factors such as nutrition (Pradipta et al., 2017).

The harvested dry grain serves as an indicator of the commercial yield in rice production. The grain yield is lower in the high-Fe condition compared to the low-Fe condition. This finding suggests that high Fe stress negatively affects the commercial yield of rice plants. The inhibitory effects of high-Fe stress on rice production can reduce rice productivity (Figure 8).

The application of the tested ameliorants has a significant impact on increasing the grain yield. Specifically, the combination of ameliorant rice husk ash, coconut husk ash, empty bunch oil palm compost, and goat manure has resulted in a higher grain yield compared to other ameliorants. This suggests that a combination of rice husk ash, coconut husk ash, empty bunch oil palm compost, and goat manure can enhance grain filling, leading to higher yields of dry grain compared to other ameliorants.

Rice husk ash can increase soil pH and neutralize soil acidity (Nurhayati, 2014) and can reduce the availability of iron in the soil (Severo et al., 2020). Coconut husk ash is a stabilizing agent for improving soil characteristics (Jagwani & Jaiswal., 2019). Application of oil palm empty fruit bunches compost will increase organic matter. The application of goat manure will increase organic C and micronutrients, and lime contains calcium elements to reduce soil acidity (Ghulamahdi et al., 2023). This is very supportive to increase rice productivity.

Among the tested rice varieties, significant differences have been observed in the yield of harvested dry grain. Specifically, the Inpari 16 Pasundan variety has been confirmed to have the highest weight of harvested dry grain compared to other varieties. This indicates that the Inpari 16 Pasundan variety exhibits better grain filling and higher overall yield. On the other hand, the IR64 variety is indicated to have a higher percentage of empty grains, which consequently leads to a lower weight of harvested dry grain. This suggests that the IR64 variety may have limitations in grain filling and yield potential compared to other varieties in the study.

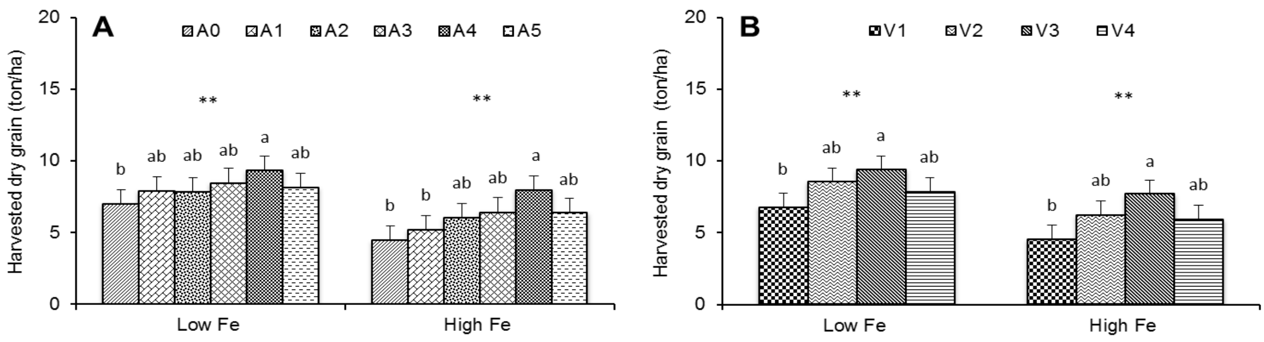

Figure 8. Harvested dry grain of rice plant under different applications of ameliorants (A) and rice varieties (B) in low Fe and high Fe locations.

The higher the yields obtained, the higher the productivity of the land uses increases (Arinta & Lubis., 2018). Ameliorant application is effective for increasing rice yield (Noor, 2022). Environmental conditions influenced the toxicity level of Fe and the yield of harvested dry grain and also depended on the sensitivity or tolerance of several planted varieties.

CONCLUSIONS

The response of rice plants during the vegetative phase to high-Fe stress was evident in the symptoms, namely stunted plants, reduced root length growth, low plant biomass, and decreased plant production. However, low-Fe stress had lower negative impacts on the plants. The results showed that the application of rice husk ash (0.25 tons ha^{-1}) + coconut fiber ash (0.25 tons ha^{-1}) + empty bunch oil palm compost (0.75 tons ha^{-1}) + goat manure (0.75 ton ha^{-1}) as ameliorants significantly triggered vegetative and generative growth. Meanwhile, the Inpari 16 Pasundan variety was proven to have better growth and higher production as described through plant height, fresh weight of shoots and roots, dry weight of shoots and roots, root length, number of productive tillers, number of grains per panicle, 1,000 grain weight, and harvested dry grain. Therefore, rice husk ash (0.25 tons ha^{-1}) + coconut fiber ash (0.25 tons ha^{-1}) + empty bunch oil palm compost (0.75 tons ha^{-1}) + goat manure (0.75 tons ha^{-1}) is the best combination, and Inpari 16 Pasundan is a tolerant variety, especially on tidal land with high-Fe stress.

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