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Effects of pre-sowing seed treatments on rice yield, grain quality and soil chemical properties in salt-affected soils

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ABSTRACT

This study aimed to evaluate the effects of sowing density and iron (Fe) coated seeds on rice grain yield, grain quality, and soil properties in saline soils in Phuoc Long district, Bac Lieu province, Vietnam. Experimental treatments include: (T_1) Intact dry seed (50 kg seed/ha); (T_2) Hydro-primed seed (120 kg seed/ha); (T_3) Hydro-primed seed (50 kg seed/ha); (T_4) Hydro-primed then sprouted seed (50 kg seed/ha); (T_5) Fe-coated dry seed (50 kg seed/ha); (T_6) Fe-coated hydro-primed seed (120 kg seed/ha); (T_7) Fe-coated hydro-primed seed (50 kg seed/ha); (T_8) Fe-coated hydro-primed seed which was sprouted before sowing (50 kg seed/ha); (T_9) Hydro-primed then sprouted seed (120 kg seed/ha); (T_{10}) Transplanting (50 kg seed/ha). The results indicated that applying Fe-coated seeds significantly increased tiller number at 45 and 60 DAS compared to free-Fe-coated seeds and transplanting treatments. There was no significant difference in tiller number among treatments at harvest stage. The plant height, yield, amylose, protein contents, gel consistency, soil pH, Eh, and Fe content in soil solution among the treatments did not differ significantly. This study demonstrated that reducing seed rate, broadcasting dry seeds, and coating seeds with Fe could reduce production cost while plant growth, yield and grain quality are maintained.

1. INTRODUCTION

The rice-shrimp rotation system is widely practiced throughout the saline-affected areas of the coastal provinces of the Vietnamese Mekong Delta. In this system, rice is cultivated in the wet season when water and soil salinity are low, and shrimp is cultivated in the dry season due to unfavorable conditions of soil and water. These cropping seasons have sometimes overlapped each other. A scarcity of water related to water regulation, water usage, and climate change results in an increase in salinity in water and soil. This causes difficulty in rice production for farmers. In addition, rice variety and cultivation practices also influence the success of the rice-shrimp system. One of the most effective cultivation practices that increase crop yield is the crop density and rate and method of fertilization. Plant competition for nutrients and light due to narrow living space and inadequate light affects rice growth and development, leading to weak stem and development of diseases (Dong et al., 2017).

Traditional seed direct-sowing with a high seed rate (200 kg/ha) and excess application of nitrogen can be a good condition for pest and disease development resulting in a reduction in yield from 38.2% to 64.6%, decrease in the percentage of filled grain from 3.10 to 11.3%, and reduction in weight of 1000 grains 3.70–5.10% (Hai et al., 2006). Thus, sowing with suitable plant density significantly reduces pest development. Recently, farmers have been suggested to apply the row seeding method to reduce the plant density. This seeding method can increase economic benefit about 20% compared to the hand direct-seeding (Giang & Phuong, 2011).

Besides, the irrigation water in the rice cultivation system is mainly from rainy in the wet season. So the rice seeds sowed in the field may be floating due to the water flow. Recently, Fe powder coating on the rice seed surface is intended to increase the specific gravity to minimize the number of floating seeds when the rice seeds are directly seeded in submerged paddy fields (Mori et al., 2012; Deres Molla, 2020). On the other hand, the heavy density of Fe-coated seed stabilizes its contact with soil surface and improves rice yield (Yamauchi, 2017; Deres Molla, 2020). However, this seeding method and plant density have not been studied on the rice-shrimp system in the Vietnamse Mekong Delta. Therefore, this study aimed to assess the effects of sowing density (seed rate) and Fe-coated seeds on the growth, yield components, grain yield, grain quality, and soil properties in the rice-shrimp system.

2. MATERIALS AND METHODS

2.1. Experimental site and treatments

The field trial was conducted in the Winter-Spring 2016-2017 on salt-affected alluvial soils at Phuoc Long district, Bac Lieu province, from 09/2016 to 01/2017. The soil at the field site was classified as Salic Tropaquepts according to The United States Department of Agriculture (USDA-NRCS, 2014).

Top soil (0–20 cm depth) was slightly acidic (pH 5.50). Soil EC value was 4.60 mS/cm. This high value in EC is because the experimental site was affected by ingression of salinity. Soil organic carbon (6.48%) was ranged in a medium level for paddy rice (Metson, 1961). The other characteristics of experimental soil are presented in Table 1.

Table 1. Soil properties at the experimental site at the beginning of study

Depth (cm)	$pH_{1:2.5}$	$EC_{1:2.5}$ (mS/cm)	CEC $cmol_{(+)}$/kg	SOC (%)	NH_4^+-N (mg/kg)	Total N (%N)	Olsen-P (mg/kg)	Exchange K ($cmol_{(+)}$/kg)	Total Fe (%)
0–20	5.50	4.60	18.3	6.48	17.1	0.35	4.73	1.74	0.86

The experiment was laid out in a randomized complete block design with four replications. Ten experimental treatments, including different combinations of pre-sowing seed methods and seed rates (shown in parentheses, as dry seed) were as follows.

(T_1) Intact dry seed (50 kg seed/ha)

(T_2) Hydro-primed seed (120 kg seed/ha)

(T_3) Hydro-primed seed (50 kg seed/ha)

(T_4) Hydro-primed then sprouted seed (50 kg seed/ha)

(T_5) Fe-coated dry seed (50 kg seed/ha)

(T_6) Fe-coated hydro-primed seed (120 kg seed/ha)

(T_7) Fe-coated hydro-primed seed (50 kg seed/ha)

(T_8) Fe-coated hydro-primed seed which was sprouted before sowing (50 kg seed/ha)

(T_9) Hydro-primed then sprouted seed (120 kg seed/ha)

(T_{10}) Transplanted (50 kg seed/ha)

Hydro-priming: soaking the seed in water for one night. Sprouting: incubating seed under wet condition for two days. The seeds of T_1–T_9 were sown on field by hand broadcasting. T_{10} (transplanting): hydro-primed then sprouted seeds were sown on the field, then after crop standing, the seedlings were transplanted.

2.2. Method of Fe-coating on rice seed

The material has been commercialized for the preparation of Fe-coated seeds was Fe powder for agricultural use, and the mean particle size of 53 µm from The JFE Steel Corporation, Tokyo, Japan (JFE Steel Corporation, 2016). The process of Fe-coating on rice seeds was recommended by JFE Steel Corporation (2016). 1000g of dry rice seeds were coated by a mixture of Fe powder (550 g), and 25 g calcined gypsum ($CaSO_4 \cdot 0.5H_2O$). Process of Fe-coating on rice seed was conducted as follows (1) granulation, (2) Fe-coating, and (3) drying. (1) Granulation: Rice seed and KONABIJIN™ were mixed with water spray adequately. The KONABIJIN™ should be added little by little until uniform coating. Then calcined gypsum was added to the seed and mixed until uniform coating, satisfactory appearance without unevenness can be observed. After granulation, the seeds were spread out in trays in a thin layer (<10 mm) and air-cooled for one night. (2) Fe-coating: The granulated seed was water-sprayed and repeatedly dried until enough Fe-coating. (3) Drying: After Fe-coating, the seeds were kept in a cool and dry area as thin layers.

2.3. Field management

Each experimental plot had an area of 42 m2 (6 m × 7 m), separating by the bunds (30 cm wide × 30 cm high). Rice cultivar used for this experiment was OM5451.

The applied fertilizer formula was 80N–60P_2O_5–15K_2O (kg/ha), which fertilizer rate for rice in the rice-shrimp system was recommended by Qui *et al*. (2016). Urea, superphosphate, and potassium chloride as a single chemical fertilizer for nitrogen, phosphorous, and potassium, respectively, were applied at different times of the rice crop. The whole phosphorus fertilizer amount was applied once at sowing time as the basal application. Nitrogen applied at 10, 22, and 45 days after sowing (DAS) were 20%, 40%, and 40%, respectively. Potassium fertilizer was split into two equal doses at 22 DAS and 45 DAS.

2.4. Collected parameters

During the experimental time, soil samples were taken at seedling (10 DAS), tillering (20 DAS), panicle initiation (45 DAS), heading (60 DAS), and maturity stages (95 DAS) to determine basic characteristics of the soil including pH, soluble and total Fe. Soil redox potential (Eh) was also measured at these stages. The number of tillers and plant height were monitored at four different growth stages (20, 45, 60, and 95 DAS). Rice yield components (the number of filled grains, ratio of filled grains/unfilled grains, weight of 1,000 grains, and the number of filled grains/panicle) were calculated from samples harvested in an area of 0.25 m^2 (0.5 m × 0.5 m). The grain quality, including amylose, protein contents, and gel consistency, was analyzed at harvest stage.

2.5. Analysis

Soil pH was determined by extracting the soil with deionized water at a ratio of 1:2.5 and measured using a pH meter. Soil Eh was measured with Platinum electrodes permanently installed in 0–20 cm soil depth. The Fe content in the soil was determined in the extract by atomic absorption spectroscopy (Van Reeuwijk, 2002).

The rice yield components were hand-threshed. After threshing, these parameters were determined and weighed. Grain yield was harvested on an area of 5 m^2 of each plot. Grains were separated, treated, air-dried, and then weighed. Grain moisture was also determined at weighing time by a grain moisture tester. The final grain yield at 14% of the moisture was then calculated based on the weight and the determined moisture. The gel consistency of the rice grains was determined according to the method illustrated by Rayee *et al*. (2021). The grain protein content was calculated by multiplying grain N content with 5.95 (Yasui and Tsutsumi, 1982). Amylose content was measured according to the methodology proposed by Juliano *et al*. (1971).

Germination and the germination rate were calculated according to the following equations (Yamauchi and Winn, 1996):

Germination (%) = the number of seeds germinated (at day 1, 2, 3, and 4)/the number of seeds tested × 100

2.6. Statistical analysis

The data collected from the experiment were statistically analyzed with Minitab v.16 using the Tukey HSD test for multiple comparisons. A p-value < 0.05 was considered as a statistically significant difference.

3. RESULTS AND DISCUSSION

3.1. Effects of sowing density and Fe-coating on rice growth

3.1.1. The emergence rate of the rice seeds

The germination of OM5451 variety is shown in Figure 1. The result showed that the number of germinated seeds of OM5451 variety in the no Fe-coated treatments (T_2, T_3, T_4, and T_9) was significantly higher than that of the Fe-coated treatment (T_5, T_6, T_7, T_8) at 1 and 2-day incubation. However, on day 3 and 4, there was no significant difference between the treatments. According to Mori et al. (2012), Fe coating on the rice seed surfaces could reduce the speed of germination rate due to the Fe barrier physically inhibiting the rice seeds to some extent. Similarly, our results indicated that coating rice seeds with Fe did not affect rice seed germination rate, but these Fe-coated seeds need longer time to enable them to germinate. Seed germination, which is a complex process, is controlled by many factors, including water, light, temperature, and phytohormones (Kucera et al., 2005; Huang et al., 2018). Some previous studies showed that the seeds treatments did not significantly affect the rice germinated rate (Adhikari et al., 2013; Hao et al., 2016; Sarkar et al., 2019). In normal conditions, the germination rate of rice depends mainly on the variety (Ju et al., 2000; Dung et al., 2021)

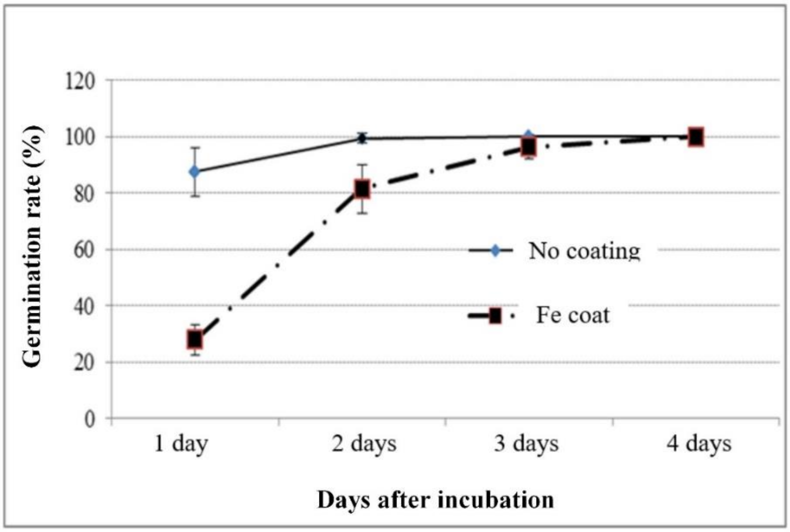

Figure 1. The germination rate of rice seeds under different seeds incubation duration

3.1.2. The number of tillers

The number of rice tillers/m^2 is one of the important factors contributing to rice yield (Moldenhauer and Gibbons, 2003). The results showed that the number of rice tillers/m^2 at 20 DAS was significantly different among treatments (Figure 2). The lowest number of tillers was in the treatment of 50 kg seed/ha (276–411 tillers/m^2), and the highest number of tillers was recorded in the 120 kg seed/ha treatment (394–589 tillers/m^2). At the stage of panicle initiation and flowering, the treatment of 50 kg seed/ha had the lowest number of tillers, while the other treatments were not different in the number of tillers. Our results indicated that the number of tillers tends to be high in the treatment of 120 kg rice seed/ha compared with the treatments applied 50 kg rice seed/ha at the 20, 45, and 65 DAS. However, the number of tillers ranged from 386 to 481 tillers/m2 and was not significantly different among treatments at the harvesting (Figure 2). In general, the number of tillers tended to increase in the Fe-coated rice seeds treatments compared with the treatments without Fe-coated in the 45 and 60 DAS but did not differ significantly at the harvest stage.

The study was implemented in one cropping season, explaining why the different pre-sowing seed treatments have not influenced the number of tillers. Deres Molla (2020) studied the effect of Fe-coated seeds rate on the rice growth in Japan reported that the number of tillers did not differ significantly at the rice growth stages.

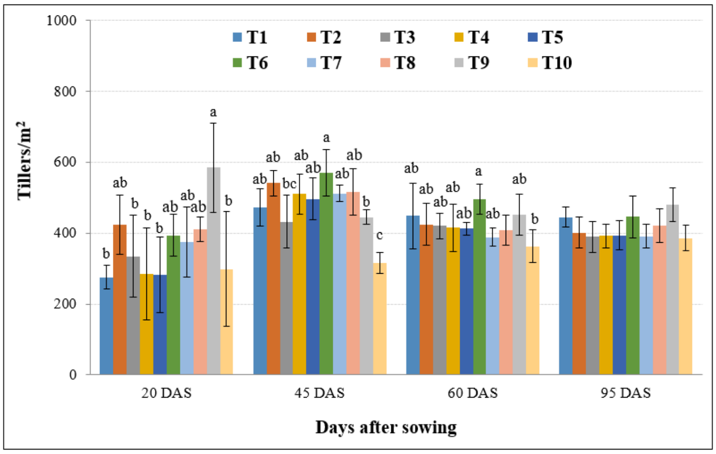

Figure 2. Effects of sowing density and Fe-coating on rice tillers over productive stages

Bars on chart show data mean and standard deviation (n=4); at the same timing of measurement, the different letters on bars show a significant difference (5%); DAS: day after sowing; T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, and T_{10} are explained in the text.

3.1.3. Plant height

The results showed that rice plant height was not significantly different among all treatments over growing stages (20, 45, 60, and 95 DAS). Therefore, the sowing density and Fe-coating did not affect the rice plant height after one cropping season (Figure 3). In this study, the field was managed in the same way throughout the experiment. Besides, the rice can grow in the water scarcity condition, except for the essential stages such as tillering and flowering (Liao et al., 2020). This study indicated that the seeding methods with Fe-coated/non-Fe-coated or change in sowing density did not affect rice plant height.

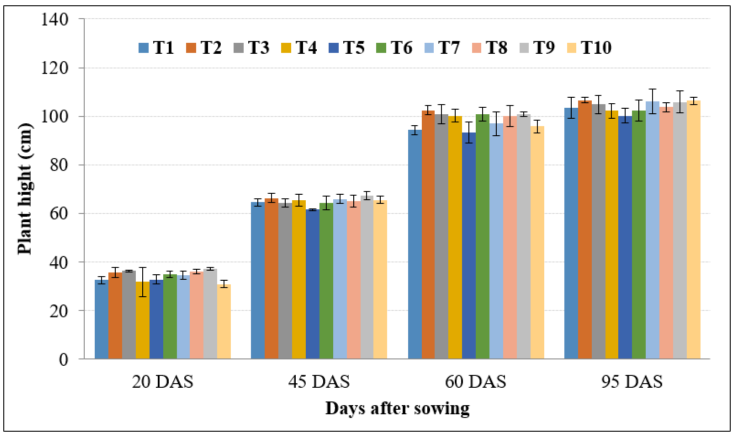

Figure 3. Effects of sowing density and Fe-coating on rice height

Bars on chart show data mean and standard deviation (n=4); DAS: day after sowing; T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, and T_{10} are explained in the text.

3.2. Effects of sowing density and Fe-coating on rice yield components and grain yield

The number of filled grains varied from 4,596 to 6,018 grains/0.25m^2, and there was no significant difference among all treatments (Table 2). Similarly, other yield components such as the filled grain/un-filled grain ratio, the weight of 1,000 grains, and the number of filled grains/panicle were not significantly different. This finding showed that the sowing density (seed rate) and Fe-coating did not significantly affect rice yield components after one cropping season in the rice-shrimp system.

Table 2. Effects of sowing density and Fe-coating on rice yield and yield components

Treatments	No. of filled grain (/0.25m2)	Ratio of filled grain/un-filled grain	Weight of 1,000 grain (g)	Number of filled grain/panicle
T1	4,929±588	4.6±0.8	24.4±0.3	44.3±5.1
T2	4,596±609	2.7±1.2	25.6±0.5	46.5±11.1
T3	5,846±1,095	3.6±1.1	25.2±0.8	60.6±13.9
T4	5,974±1,434	5.5±0.8	24.8±0.3	61.9±18.3
T5	5,975±429	3.4±0.7	24.4±0.2	60.8±2.7
T6	5,127±962	2.3±0.9	25.1±0.2	46.0±5.9
T7	5,359±925	3.4±1.2	25.2±0.5	55.2±10.3
T8	6,018±639	3.6±1.1	25.7±0.3	57.4±5.7
T9	4,721±582	2.0±0.5	25.1±0.7	39.6±6.6
T10	5,773±375	3.5±1.0	24.5±0.4	60.1±4.6
F-test	ns	ns	ns	ns
CV (%)	14.1	35.5	1.7	15.9

ns: not significantly different; ± standard deviation (n=4); T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, and T_{10} are explained in the text.

Grain yield of OM5451 variety under different seed rates and Fe-coating conditions is shown in Figure 4. The results showed that the rice yield in the field trial varied from 5.5 to 6.3 tons/ha, and there was no significant difference among treatments. In addition, the effect of Fe-coating on rice yield in the rice-shrimp system after one cropping season was also not found. A previous study also reported no significant difference in grains yield between no Fe-coated and Fe-coated rice seeds in experimental fields (Yamauchi, 2017). Similarly, Ottis and Talbert (2005) also reported that that rice yield was not decreased with decreased seeding rates. This result indicated that the application of 50 kg rice seed/ha in the rice-shrimp system could reduce the production cost while maintaining the grain yield.

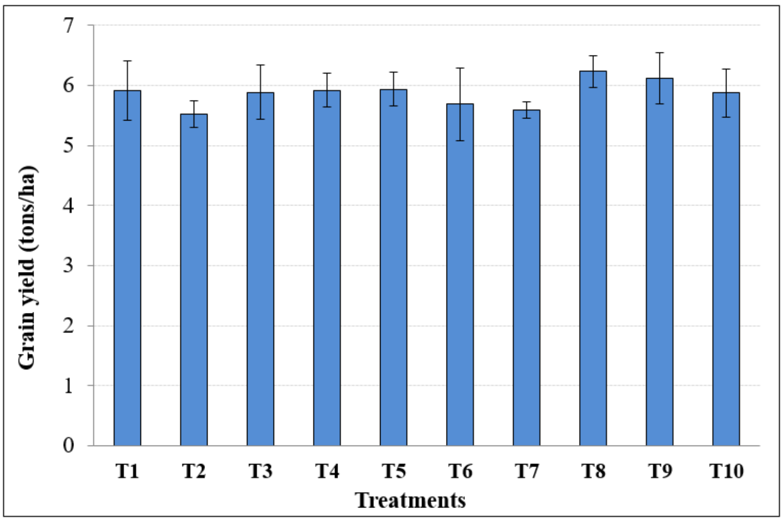

Figure 4. Effects of sowing density and Fe-coating on grain yield

Bars on chart show data mean and standard deviation (n=4); DAS: day after sowing; T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, and T_{10} are explained in the text.

3.3. Effects of sowing density and Fe-coating on rice grain quality

Rice grain quality depends on specific variety and other parameters such as environment, harvesting system, and post-harvesting technology. Change of production process can alter the rice grain quality and cost-benefit of rice production. In this study, the rice grain quality was evaluated for amylose content, protein content, and gel consistency. However, there was no difference among treatments (Table 3). In the rice production system, grain quality is dependent on some internal factors such as genetic differences, management practices (Tsukaguchi *et al.*, 2016), or the external factors such as fertilization, irrigation, and meteorology (Blumenthal *et al.*, 1998; Ozturk and Aydin, 2004). According to Ata-Ul-Karim *et al.* (2017), it is difficult to improve rice grain quality because these parameters do not change in the same field conditions. This indicated that the sowing density and Fe-coating did not influence rice quality after one cropping season.

Table 3. Effects of sowing density, pre-sowing seed treatment and Fe-coating on rice quality

Treatments	Amylose content (%)	Protein content (%)	Gel consistency (mm)
T_1	12.3±0.2	6.5±0.2	71.6±0.8
T_2	13.6±0.7	6.8±0.2	72.3±3.0
T_3	13.2±1.6	6.3±0.4	63.8±1.6
T_4	14.3±0.6	6.5±0.1	69.4±5.6
T_5	12.7±0.1	6.5±0.1	71.6±0.8
T_6	13.6±0.5	6.8±0.3	72.3±3.0
T_7	13.5±1.3	6.5±0.2	70.4±4.9
T_8	14.2±0.7	6.4±0.1	69.4±5.6
T_9	12.6±0.5	7.0±0.2	71.6±0.8
T_{10}	14.3±0.6	6.9±0.8	72.3±3.0
F-test	*ns*	*ns*	*ns*
CV (%)	*5.0*	*3.8*	*4.1*

ns: not significantly different; ± standard deviation (n=4); T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, and T_{10} are explained in the text.

3.4. Effects of sowing density and Fe-coating on soil properties

3.4.1. Soil pH

Soil pH varied between 5.6 and 6.9 from 10 DAS to 60 DAS, and this pH range is suitable for rice growth and development (Figure 5). At the harvesting stage (95 DAS) soil pH slightly decreases (4.5–5.1) compared to that in the previous stages. The result showed that there were no statistical differences among the soil pH of the different sowing density and Fe-coating of rice seeds treatments.

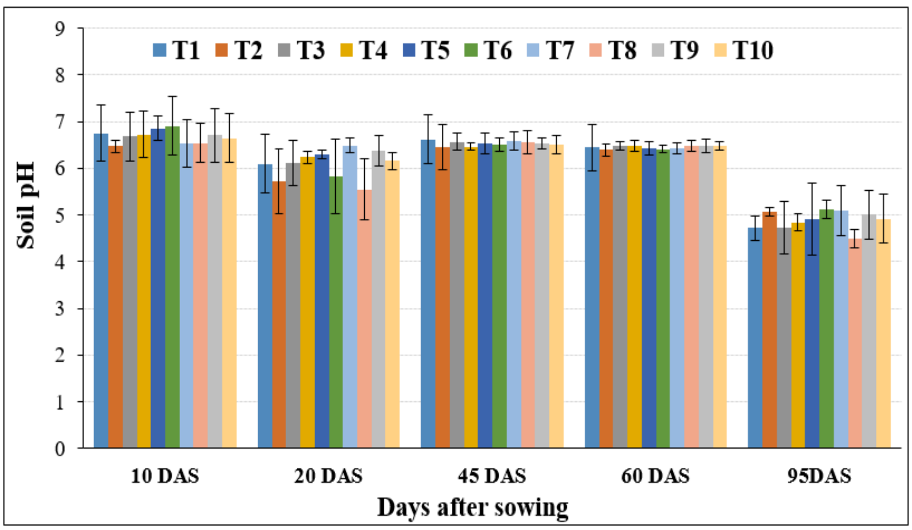

Figure 5. Effects of sowing density and Fe-coating on soil pH

Bars on chart show data mean and standard deviation (n=4); DAS: day after sowing; T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, and T_{10} are explained in the text.

3.4.2. Soil Eh

Soil Eh is used to evaluate soil oxidation and reduction status and also to determine the ability of soil in supplying nutrients for plant growth and development. In this trial, soil Eh had variation from -306 to -12 mV although they were not different in all treatments (Figure 6). Before sowing rice seed, soil was flooded causing negative Eh and this affected rice growth because rice can be poisoned by heavy metals in soil and lowered soil nutrient availability and rice yield. In addition, comparing between the Fe-coat and non-Fe-coat treatment, soil Eh was not different. It is concluded that Fe-coating for rice seeds did not alter soil Eh or soil reduction status. According to Weil and Brady (2017), soil Eh is most affected by the drainage of gravitational water and tillage in the paddy field. However, the soil in this study was the same field management after sowing, and it explained why soil Eh was not significantly different among the Fe-coated/no-Fe coated or rice seeds density treatments.

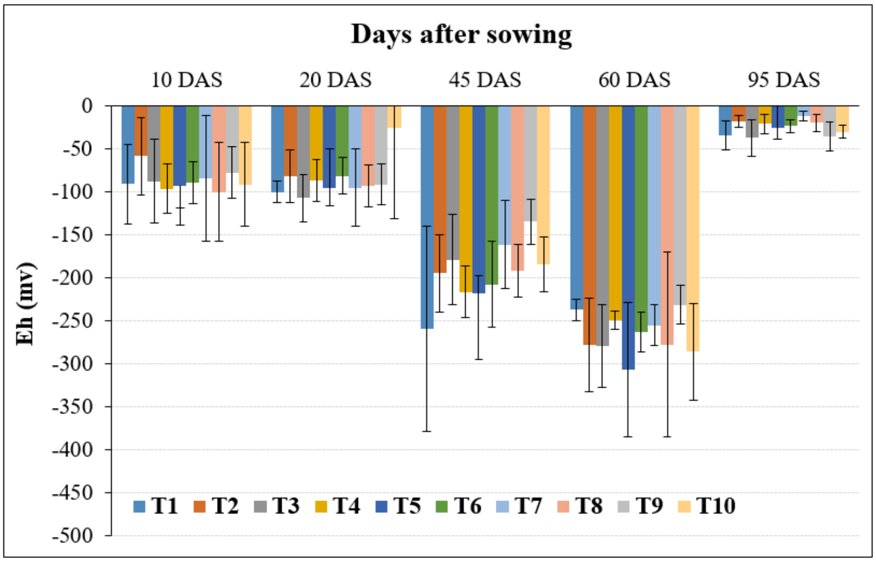

Figure 6. Effects of sowing density and Fe-coating on soil Eh

Bars on chart show data mean and standard deviation (n=4); DAS: day after sowing; T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, and T_{10} are explained in the text.

3.4.3. Soluble Fe content in soil solution

Soluble Fe content (ppm) in soil solution was not different among experimental treatments over the duration of rice growth. The soluble Fe content at the seedling stage (10 DAS) ranged from 18.7 to 212 ppm in the soil solution and the reason for this result was soil flood during shrimp crop leading to Fe reduction to Fe^{2+}. However, the soluble Fe content decreased in the later stage of the rice growth as soil aerated and Fe^{2+} precipitated while rice was grown (Figure 7). Similar to the other soil parameters such as pH or Eh, the results showed that the soluble Fe content in the Fe-coated seeds treatments did not differ significantly compared with the treatments without applied Fe-coated seeds. The reason may be the amount of Fe powder coating rice seed is low, and it was not enough to change the soluble Fe in soil.

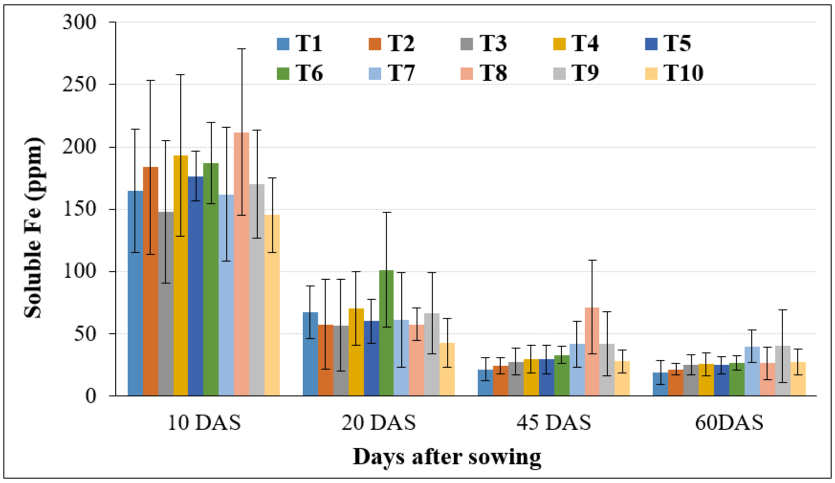

Figure 7. Effects of sowing density and Fe-coating on soluble Fe content in soil solution

Bars on chart show data mean and standard deviation (n=4); DAS: day after sowing; T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, and T_{10} are explained in the text.

4. CONCLUSIONS

The application of Fe-coating on seeds did not affect the germination rate of rice seeds after four days of incubation. This study indicated that applying Fe-coated seeds and reducing the sowing density of rice seeds have not been effective on rice yield, grains quality, soil pH, Eh, and the soluble Fe in the rice production system in the salt-affected soil. After one cropping trial, the recommendation of seed rate for rice production in the rice-shrimp system is 50 kg seed/ha. Further investigation is recommended for various cropping seasons and regions to get precise assessment of effects of the sowing density and Fe-coating method on the growth and grain yield.

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