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Effects of Land Preparation and Iron-coated Rice Seeds on Yield, Growth Parameters, and Soil Properties in the Mekong Delta, Vietnam

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Abstract

The objective of this study was to evaluate the effects of land preparation methods and iron-coated (Fe-coated) rice seeds on the growth, yield, and Fe uptake of rice in alluvial soils in the Mekong Delta region. The experiment was conducted in the 2020 summer-autumn cropping season under the triple rice cultivation system in Chau Thanh district, An Giang province. The field experiment was designed as a randomized complete block design (RCBD) with six treatments and four replications. The treatments were: (T_1) puddled + water seeding + Fe-coated seeds; (T_2) non-puddled + dry seeding + Fe-coated seeds; (T_3) zero-tillage + non-puddled + dry seeding + Fe-coated seeds; (T_4) puddled + water seeding + sprouted + non-Fe-coated seeds; (T_5) puddled + wet seeding + sprouted + non-Fe-coated seeds; and (T_6) puddled + transplanting + sprouted + non-Fe-coated seeds. The results showed that changes in the land preparation, planting method, and Fe-coated seeds did not significantly affect the number of tillers, plant height, yield components, soil chemical properties, grain yield, or Fe uptake of the rice plants and grains. However, the T_3 and T_6 treatments tended to have higher grains yields (5.86-5.90 tons ha^{-1}), and higher total Fe content in grains (93.0-94.3 mg kg^{-1}) and rice plants (83.1-84.0 mg kg^{-1}). The findings from this study confirmed that the new planting method using zero-tillage + non-puddled + dry seeding + Fe-coated seeds can maintain the germination rate, growth, and grain yield of rice.

Keywords

Dry seeding, iron-coating, rice quality, water seeding, zero-tillage

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Introduction

The Mekong Delta, one of the two major rice granaries in Vietnam, is responsible for over 50% of rice production and 90% of rice exports for the whole country (GRiSP, 2013). In 2019, the rice production of the entire delta reached about 24.8 million tons with a planting area of about 4.02 million hectares, accounting for 2/3 of the total sowing area in the country (FAOSTAT, 2019). However, in recent years, the profits from rice cultivation have been declining due to the influence of many factors such as market price, input costs, land preparation, labor cost, and climate change (Phuong *et al.*, 2016). Therefore, to increase the farmers' profits, it is necessary to reduce the input costs in rice cultivation. According to the farmers' cultivation practices, the land is always plowed carefully before sowing rice seeds. However, this process also has many disadvantages, such as requiring much labor, especially in the dry season (Carter & McKyes, 2005), and having a limited impact in reducing the risks of pests (Saeidirad, 2020). As an alternative, minimum tillage has been reported to maintain soil properties and save land preparation time over puddling in paddy soil (Haque *et al.*, 2016; Hossen *et al.*, 2018). However, in areas with sloping land, plowing will make the area more vulnerable to erosion by wind and water, leading to increased soil loss and reduced soil fertility (Carter & McKyes, 2005). Even if farmers apply dry sowing practices, when it rains, the seeds are buried down or float to the surface, which can greatly affect the sowing area and economic profit of the farmers. A previous study suggested that sowing rice seeds on non-cultivated land would give a higher profit than land under preparation because land preparation costs are usually expensive (Phuong *et al.*, 2016). For this method, although productivity may be maintained in the first to two crop plantings, productivity decreases in the following seasons compared to the traditional planting method, resulting in a decrease in the framer's profit. Recently, Fe powder coating on the rice seed surface has been used 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, 2020). On the one hand, the heavy seed density of Fe-coated seeds stabilizes their contact on the soil surface even if the seeds are under irrigation water flow and improves crop standing by lowering the seeding rate (Yamauchi, 2017). However, a study applying Fe-coated rice seeds combined with land preparation has not occurred in the Mekong Delta region in Vietnam.

The underlying hypothesis of this study was that the combination of puddled soil with Fe-coated rice seeds would result in yields comparable to the traditional rice cultivation system without reducing the rice growth and soil characteristics. Therefore, the objective of this study was to evaluate the effects of different combined treatments of land preparation, seed treatment with or without an Fe-coating, and sowing method on rice growth, rice yield, grain Fe uptake, and soil chemical properties in the alluvial soils in An Giang province, Vietnam.

Materials and Methods

Experimental site and soil characteristics

The trial was located at Binh An 2 hamlet, An Binh village, Chau Thanh district, An Giang province, Vietnam (10°29'31.0"N, 105°19'52.8"E), from April 3rd to July 3rd, 2020. The average monthly temperature in the area varied between 28.3°C and 30.4°C, and the total rainfall during the cropping period was 439mm (An Giang Hydro Meteorological Station). In general, the temperature was suitable for rice growth and development.

The experimental soil was classified as Dystric Fluvisols, according to the International Union of Soil Sciences Working Group World Reference Base for Soil Resources (WRB, 2014). The topsoil (0-20cm) was slightly acidic (pH 5.97), the redox potential (Eh) was around 198mV, total Fe was around 3.11%, and soil organic carbon (1.69%C) had a very low level range for paddy rice fields (Metson, 1961).

Experimental design and treatments

The experiment was conducted in the 2020 spring-summer cropping season under the triple rice cultivation system in Chau Thanh district. It was laid out in a randomized complete block design (RCBD) with four replicates. Six treatments were applied, namely: (T_1) puddled + water seeding + Fe-coated seeds; (T_2) non-puddled + dry seeding + Fe-coated seeds; (T_3) zero-tillage + non-puddled + dry seeding + Fe-coated seeds; (T_4) puddled + water seeding + sprouted + non-Fe-coated seeds; (T_5) puddled + wet seeding + sprouted + non-Fe-coated seeds; and (T_6) puddled + transplanting + sprouted + non-Fe-coated seeds.

For puddled/water seeding method: Land was hoed by hand and then puddled under wet conditions. The puddled land was flooded to a depth of approximately 5cm for four days, and then the Fe-coated seeds were sown. The field water was kept for two more days then drained out so that the seeds could germinate well. Once the seeds had germinated, irrigation water was supplied intermittently for critical growth stages such as panicle initiation, heading, and flowering, as water needs to be kept in flooding conditions during these stages.

For non-puddled/dry seeding method: The land was hoed but not puddled. The Fe-coated seeds were sown on the dry soil surface. After sowing, irrigation water was supplied to a depth of 5cm and kept for two days, then drained out so that the seeds could germinate well. Water was applied intermittently as needed.

For zero-tillage/non-puddled/dry seeding method: Land preparation was not applied, but dry seeding was tested. For this method, rice stubble was kept in the field but was cut to a uniform height of approximately 10cm above the soil surface. At sowing time, the field was maintained in drought conditions without water. Instead, seeds coated with Fe were sown on the dry soil surface but with the presence of the stubble. Right after sowing, water was supplied to a depth of 15cm for two days, and then the water was drained out so that the rice seeds could germinate. Again, water was intermittently applied afterward.

Method of Fe coating for rice seeds

The materials for making Fe-coated seeds were 1000g of dry rice seeds, KONABIJIN^{TM} (S91 pre-mix, a mixture of Fe powder (550g)), and 25g calcined gypsum ($CaSO_4 \cdot 0.5H_2O$) (JFE Steel Corporation). The process of Fe-coating rice seeds was conducted as following (1) granulation, (2) rusting, and (3) drying. (1) Granulation: Rice seeds and KONABIJIN^{TM} were mixed with water spray adequately. The KONABIJIN^{TM} was added little by little until the seeds were coated uniformly. Then calcined gypsum was added to the seeds and mixed until coated uniformly. After granulation, the seeds were spread out on trays in a thin layer (<10mm) and air-cooled for one night. (2) Rusting: The granulated seeds were water-sprayed and dried repeatedly until oxidation was apparent. (3) Drying: After rusting, the seeds were kept in a cool, dry area as thin layers.

Field management

Each experimental plot was 49m^2 (7m × 7m), and separated by bunds (30cm width × 40cm height). The bunds were covered with a plastic sheet installed to a depth of 20 cm below the soil surface to minimize seepage between adjacent plots and the surrounding field. The rice variety used for this experiment was OM5451. The rate of sowing was 50 kg ha^{-1} as dry seed.

The fertilizer formula was 80N-45P_2O_5-15K_2O (kg ha^{-1}), which is the recommended rate from the Cuu Long Rice Research Institute, Vietnam. Urea, superphosphate, and potassium chloride were used as chemical fertilizers for nitrogen, phosphorous, and potassium, respectively. The whole phosphorus fertilizer amount was applied once at sowing time as a basal application. Nitrogen was applied at 7, 15, and 45 days after sowing (DAS) at the rates of 20%, 40%, and 40%, respectively. Potassium fertilizer was split into two equal doses at 15 and 45 DAS.

Collected parameters and analyses

During the experimental time, soil samples were taken before sowing and harvesting (95 DAS) to determine the soil pH, redox potential (Eh), soil organic carbon, and total Fe in soil. 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 at a soil depth of 0-20cm. The Fe content in the extracted soil was determined by atomic absorption spectroscopy (Van Reeuwijk, 2002).

The number of tillers and plant height were monitored at three different growth stages (20, 40, and 60 DAS). Rice yield components were calculated from samples harvested in an area of $0.25m^2$ (0.5 × 0.5m). Grain yield was harvested on an area of $5m^2$ of each plot. Grains were separated, treated, air-dried, and then weighed. Grain moisture was also determined at weighing by using a grain moisture tester. The grain was dried to a 14% moisture content, and then the final grain yield was calculated based on the weight and the determined moisture. The yield components were the number of panicles, filled and unfilled grains/panicle, filled grain weight, filled grain percentage, 1000-grain weight, and grain moisture. The rice yield components were hand-threshed. After threshing, these parameters were determined.

Statistical analysis

The data collected from the experiment were statistically analyzed with Minitab 16 using analysis of variance (one-way ANOVA). Only treatments with significant differences were submitted to the Tukey comparison test at the 5% significance level.

Results and Discussion

Soil chemical properties

Soil pH

Soil pH values at harvesting time ranged from 5.70 to 5.85 (**Table 1**). The results showed that there were no significant differences in soil pH under the different land preparation methods combined with seed treatments and sowing methods. In general, these pH values were still in a normal range for the development of rice plants. In a conventional rice production system, puddling has been shown to result in the destruction of macrospores, breakdown of soil aggregates, and the formation of a hardpan at a shallow depth, affecting the soil pH and electrical conductivity (Kumar & Ladha, 2011; El-Henaway, 2013). However, the results from this study indicated that the land preparation methods did not significantly affect soil pH, and it agrees with the results of El-Henawy (2013). El-Henawy (2013) reported that soil pH was not significantly affected by puddling in two experimental field crops, which were conducted in Egypt in the 2007 summer season.

Soil Eh

The soil Eh values were measured at harvesting time and ranged between 193mV and 241mV (**Table 1**). Since the field water was drained out for some days before the rice was harvested, the topsoil was under aeration conditions, resulting in positive Eh values. There were no significant differences in the soil Eh values among the treatments. The soil redox potential, an important chemical characteristic, is related to soil aeration conditions and is made up of the reduction and oxidation states of the chemical elements (Weil & Brady, 2017). Soil Eh is most affected by the drainage of gravitational water and tillage. In an intensive rice system, both short-term and long-term tillage results in soil aeration condition changes (Weil & Brady, 2017). However, the soil in this study was collected from the topsoil at harvesting time, which was the same as well-aerated conditions, and this explains why the soil Eh values were not significantly different among the land preparation treatments.

Soil organic carbon

The total organic carbon content in the soil at harvesting time was highest in T_5 (1.56%C) and lowest in T_2 (1.41%C), which was the same as that in T_4 (1.41%C). There were no significant differences in soil organic carbon content among the treatment methods. Soil organic carbon is a complex and varied mixture of organic substances in soil, and decomposition depends on several factors, such as the aerobic or anaerobic conditions, soil pH, plant community, and soil fauna (Weil & Brady, 2017; Santos *et al.*, 2019). The findings of this study confirmed that the combination of land preparation methods and Fe-coated rice seeds did not affect soil organic carbon.

Total Fe

The results showed that the highest total Fe content in the soil was found in T_5 (3.20%) and

Table 1. Effects of land preparation and rice seed methods on soil chemical properties

Treatments	pH	Eh (mV)	SOC (%C)	Total Fe (%)
T_1	5.79	241	1.44	2.87
T_2	5.70	214	1.41	2.88
T_3	5.78	193	1.49	2.84
T_4	5.72	211	1.41	3.05
T_5	5.85	228	1.56	3.20
T_6	5.83	235	1.46	3.04
F	ns	ns	ns	ns
CV (%)	1.98	26.7	8.77	12.0

Note: ns: not significantly different (P >0.05); T_1, T_2, T_3, T_4, T_5, and T_6 are explained in the text.

the lowest was obtained from T_3 (2.84%) (**Table 1**). These results indicated that the treatment methods did not cause significant differences in the total Fe contents in the soil of all the treatments. This might be because the Fe powder used to coat the rice seeds may have led to enhancing the solubility of Fe due to the reducing reaction under flooded soil conditions and thus, increased the Fe content in the soil. However, the amount of Fe powder used in this study did not appear to significantly affect the total Fe content in the soil at harvesting time.

Fe uptake in rice plants and grains

The analysis results indicated that the highest Fe content in the plants was found in T_1 (88.4 mg kg^{-1}), followed by T_3 with a content of 84.0 mg kg^{-1}, and the lowest Fe content was obtained from T_5 at 76.2 mg kg^{-1} (**Table 2**). The results indicated that the Fe contents in the rice plants were not significantly different among the treatments. In this study, Fe powder coated on the rice seeds could have increased solubility in the sowing time in the water/wet seedings (T_1, T_4, T_5) and transplanting treatments (T_6), and decreased solubility in the dry seeding treatments (T_2, T_3). However, the paddy fields had the same water management throughout the experiment after sowing, causing the availability of Fe^{2+} cations which did not differ among the land preparation treatments. This may be because the rice plants absorbed the same nutrients under the same field conditions.

The analysis results indicated that T_3 had the highest content of Fe (94.3 mg kg^{-1}) in the rice grains (**Table 2**). The lowest content was observed in T_2 (89.7 mg kg^{-1}). Similarly, the differences in the Fe content in the rice grains did not differ significantly due to the same field conditions. This study demonstrated that the combination of land preparation and Fe-coated rice seeds did not significantly affect the Fe content in the rice plants or grains.

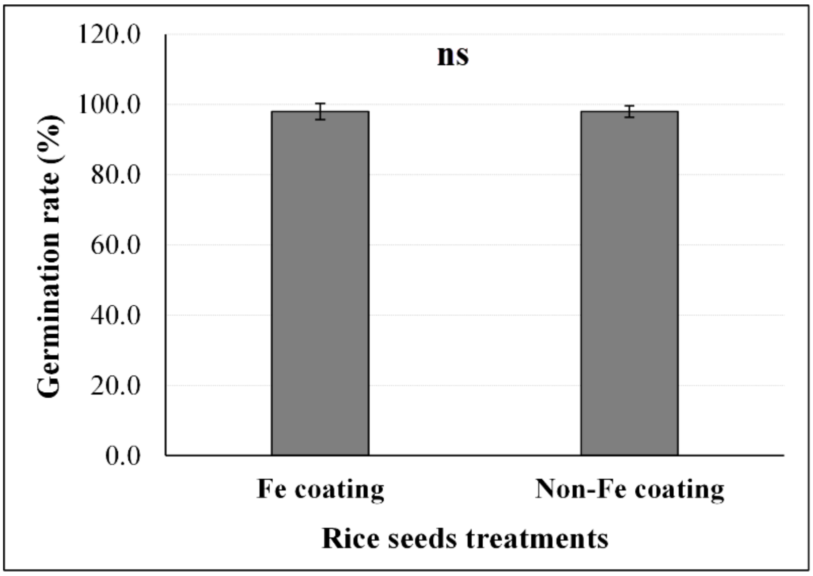
Rice seed germination under different rice seed methods

The germination estimation results showed that both Fe-coated seeds and non-Fe-coated seeds had the same germination rate of 98% after four days of inoculation (**Figure 1**). The results showed that the germination rate of rice seeds in the treatment with Fe applied to the seed coat was not significantly different compared with the control treatment. Seed germination, a complex process, is controlled by many factors, including water, light, temperature, and phytohormones (Kucera *et al.*, 2005; Huang *et al.*, 2018). However, the germination rate depends mainly on the variety in normal conditions (Ju *et al.*, 2000). Fe-coated primed dry rice seeds, a technology developed in 2004, and untreated rice seeds have both been sown onto paddy fields for comparison studies (Yamauchi, 2004). Some previous studies have shown that a change in the seed inoculation methods did not significantly affect the germination rate of rice seeds (Mori *et al.*, 2012; Adhikari *et al.*, 2013; Hao *et al.*, 2016; Sarkar *et al.*, 2019; Dung *et al.*, 2021; Dung *et al.*, 2022). Mori *et al.* (2012) tested the germination rate of Fe-coated rice seeds under

Table 2. Effects of land preparation and rice seed methods on the Fe uptake in plants and grains

Treatments	Fe uptake in plants (mg kg^{-1})	Fe uptake in grains (mg kg^{-1})
T_1	88.4	90.7
T_2	77.5	89.7
T_3	84.0	94.3
T_4	77.9	92.0
T_5	76.2	92.0
T_6	83.1	93.0
F	ns	ns
$CV_{(\%)}$	9.62	4.94

Note: ns: not significantly different (P >0.05); T_1, T_2, T_3, T_4, T_5, and T_6 are explained in the text.



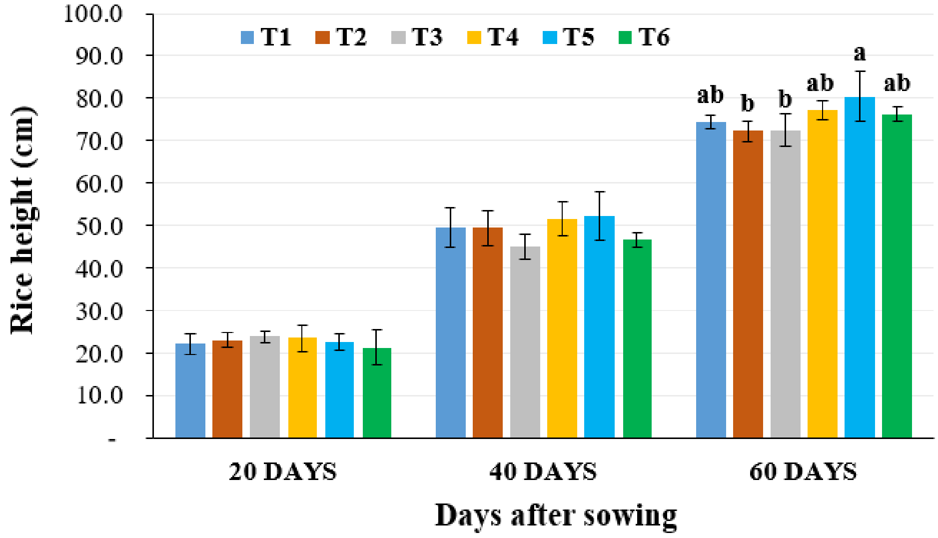
Note: Vertical bars represent the standard deviation of the mean of four replications.

Figure 1. The germination rate of rice seeds in the Fe-coated and non-Fe-coated treatments after four days of inoculation

submerged conditions and reported no difference in the percentage of seed germination in the Fe-coated rice seeds compared to the treatment without the Fe coating.

Plant height

The heights of the rice plants measured at various growth stages are presented in **Figure 2**. At 20 DAS, the rice heights varied between 21.4 and 24.0cm. The highest and lowest heights were found in T_3 and T_4 as 24.0cm and 23.5cm, respectively. At 40 DAS and 60 DAS, the plant heights were highest in T_5 as 52.3cm and 80.5cm, respectively. However, land preparation, planting, and seeding methods resulted in no significant differences in plant heights over the three observation periods (20, 40, and 60 DAS). According to Yamauchi (2017), pre-germinated seeds are usually used in water seeding and wet seeding because they germinate faster than in dry seeding. In this study, the field was managed in the same way as dryland crops in terms of land preparation and then flooded thereafter. After the seeds germinated, the watering after seeding the Fe-coated seeds was evenly controlled in all the treatments. Twenty days after sowing, rice can grow in water-scarce conditions, except during the essential stages such as tillering and



Note: Vertical bars represent the standard deviation of the mean of four replications; bars having different letters are significantly different (P <0.05); T_1, T_2, T_3, T_4, T_5, and T_6 are explained in the text.

Figure 2. Plant heights at various growth stages of the treatments.

flowering (Liao *et al.*, 2020). This study indicated that the seeding methods under Fe-coated or non-Fe-coated conditions did not affect the rice heights at various growth stages.

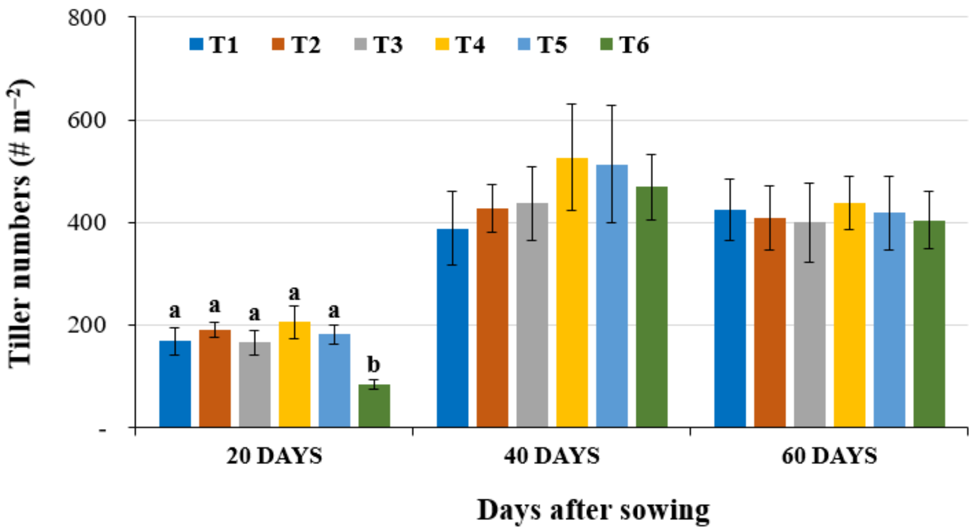
The number of tillers

The results showed that the highest tiller numbers were found in T_4 over the three various growth stages of 20 DAS, 40 DAS, and 60 DAS and were 206, 527, and 439 tillers m^{-2}, respectively (**Figure 3**). At 20 DAS, the lowest tiller number (84.0 tillers) was found in T_6, which was significantly lower than those of the other treatments. For this treatment, since the seedlings were transplanted at 15 days, the rice plants needed to have time to acclimate before producing tillers compared to the other treatments. At 40 DAS, the lowest tiller number was found in T_1 (389 tillers m^{-2}). However, T_3 had the lowest tiller number (400 tillers m^{-2}) at 60 DAS. Although treatment T_4 produced the highest tiller numbers at the three observed rice growth stages, the values were not significantly different in comparison with the other treatments. Similarly, Deres (2020) studied the effects of Fe-coated seeds on the rate of rice growth in Japan and reported that the number of tillers did not significantly differ at some rice growth stages.

Grain yield components and grain yield

The yield components of the treatments are presented in **Table 3**. It can be seen that T_4 had the highest number of panicles per m^2 (566), while T_2 had the lowest number of panicles per m^2 (417). The results showed that T_6 had the highest number of filled grains per panicle (47.9). Though T_3 had a low number of panicles, it had the highest filled grain percentage (one of the essential yield components) of 75.3%. Similarly, T_2 had the lowest number of panicles (417), but it had a high filled grain percent (75.2%). There were no significant differences in the yield components among the treatments, however, the results indicated that coating the seeds with Fe (T_2 and T_3) tended to increase the number of filled grains and the filled grain percentage (**Table 3**). In short, the above results revealed that the land preparation combined with the Fe-coated rice seeds did not affect the rice growth and development, as measured through the plant height and number of tillers, which explains why the rice components did not significantly differ in all the treatments.

The grain yield ranged from 5.35 to 5.90 tons ha^{-1} (**Table 3**). This study showed that transplanting non-Fe-coated seeds into puddled soil (T_6) resulted in the highest yield (5.90 tons ha^{-1}). On the other hand, the results indicated that



Note: Vertical bars represent the standard deviation of the mean of four replications; bars having different letters are significantly different (P <0.05); T_1, T_2, T_3, T_4, T_5, and T_6 are explained in the text.

Figure 3. The number of tillers at various growth stages of the treatments

Table 3. Effects of land preparation and rice seed methods on yield components and grain yield

Treatments	Number of panicles per m^2	Number of filled grains per panicle	Filled grain percentage (%)	1000-grain weight (g)	Yield (tons ha^{-1})
T_1	446	46.7	71.5	23.2	5.38
T_2	417	47.5	75.2	22.9	5.35
T_3	451	47.1	75.3	23.0	5.86
T_4	566	42.5	68.3	22.8	5.73
T_5	454	46.4	65.2	22.7	5.82
T_6	473	47.9	74.4	23.3	5.90
F	ns	ns	ns	ns	ns
CV (%)	17.2	10.2	10.9	1.72	14.5

Note: ns: not significantly different (P >0.05); T_1, T_2, T_3, T_4, T_5, and T_6 are explained in the text.

sowing the Fe-coated seeds in non-treated soil (zero-tillage, dry seeding) provided a slightly higher yield (5.86 tons ha^{-1}) than those of the other treatment methods. Previous research has shown that Fe-coated rice seeds result in improved growth and rice yield (Mori *et al.*, 2012; Yamauchi, 2017). However, the findings of this study showed that Fe-coated rice seeds combined with different land preparation methods did not significantly affect the grain yield. The soil in the study field was alluvial soil, which has a slightly higher fertility, so the soil may have supplied available nutrients as needed by the rice. On the other hand, the results indicated that changing the land preparation in combination with using Fe-coated rice seeds did not significantly affect the soil properties of pH, soil organic matter, Eh, and total Fe. This explains why the rice yield components and grain yield were not significantly different among the treatments.

Conclusions

This study examined Fe-coated rice seed growth and development under changes in land preparation and seeding methods conditions in the dystric fluvisols. The results indicated that the various combinations of seed and land preparation methods had the same seed germination rates and maintained the rice height, number of tillers, yield components, grains yield, and soil chemical properties. In order to comprehensively assess the impact of land preparation and the Fe-coating method on the physico-chemical properties of soil, as well as on rice growth and grain yield, it is imperative to conduct more extensive research, including longer-term studies of rice fields and plants, as well as studies of various soil types.

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