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Research Article

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Technology Paddy Agriculture with SBSU System on Ultisol Land for Growth, Production and Absorption of Fe^{2+}

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Abstract The purpose of this study was to obtain a method of cultivating rice with the SBSU system on ultisol fields on growth, production and uptake of Fe^{2+}. Increasing rice production, faces increasingly complex challenges. The problem, which is no less important is the limitation of iron stress tolerant varieties and cultivation technology. Experiments on ultisol paddy fields in Koto Baru Sitiung, Dharmasraya Regency, West Sumatra, Indonesia, from March to August 2018, on land containing >104.69 mg kg^{-1} Fe^{2+}. The experiment used a completely randomized design, with five replications. The single factor of rice varieties, namely Mekongga, Inpari 24, Inpari 27 and Inpari 28. The production of milled dry rice (MPD) in all varieties is more than 5.4 Mg ha^{-1} even though iron-clad conditions, because the number of productive tillers formed in the SBSU system is more from 21 stems per clump. The pattern of iron distribution occurs through absorption and translocation in the vegetative and generative phases to roots, stems, leaves, grain, and rice. The difference in iron content in each section shows the ability of each variety to adapt. To get iron-rich rice grains and be able to grow and produce well in iron-clad conditions, it is better that in cultivation activities using the SBSU system with Inpari 27 variety, it can produce iron levels in rice grains more than 27 mg kg^{-1} with produce paddy of 6.83 Mg ha^{-1}.

Keywords Rice, Sistem Bujur Sangkar Utama, Sitiung

Introduction

The projection of Indonesia's rice production in 2018 is estimated to reach more than 56.54 million Mg of paddy, equivalent to 32.42 million Mg of rice with an area of 7.1 million ha of paddy. Indonesia's rice consumption is 111.58 kg $capita^{-1}$ $year^{-1}$. Efforts to increase production continue to be made to increase income and welfare and improve national food security [1, 2]. Increasing rice production in the future, will face many increasingly complex challenges. Competition and land conversion for agriculture with various development needs such as transportation infrastructure, offices, reservoirs, housing and compounded by weather and environmental conditions related to nutrient stress, climate, weeds, pests and diseases.

Another issue that is no less important is the limitation of tolerant rice varieties and cultivation methods to environmental stresses, especially iron stress (Fe^{2+}) [3-5] which are widely found in acid mineral soils (ultisol). In these fields the concentration of dissolved Fe^{2+} varies from 0.1 mg kg^{-1} to 600 mg kg^{-1}, under certain conditions it can reach more than 5,000 mg kg^{-1}. The problem that often arises is the low level of soil fertility due to the binding of nutrients by heavy metals [6].

Fertile land for agriculture is very limited, while available land is marginal land, namely ultisol land with various problems. In ultisol soil iron poisoning often occurs, which causes root damage and low nutrient availability. Efforts to improve root function and neutralize the bad influence of iron are becoming increasingly important, for the growth of rice plants. Overcoming these obstacles is to utilize plants that are tolerant of stress

[7, 8]. Tolerant plants have the ability to develop various mechanisms to adapt. The adaptation mechanisms developed by plants occur morphologically and physiologically [9-11]. Development of iron stress tolerant rice varieties can be done through screening and genetic engineering.

The cultivation method is very helpful in increasing the growth, production and adaptability of rice to iron stress. In cultivation using the Sistem Bujur Sangkar Utama (SBSU) method, the potential of tillers is 3.6 million stems per ha, whereas with conventional methods it is only 1.6 million stems. An increase in the number of tillers by 125% when compared with conventional methods that have often been applied by farmers [12].

Rice germplasm has very narrow genetic variability for iron content in endosperm. Generally, plants use a reduction mechanism to get iron from the soil. The reduction mechanism, which is used by most plant species, involves the production of Ferric Chelate Reductase which reduces Fe^{3+} to Fe^{2+} on the root surface. The dissolved Fe^{2+} is then transported into the root cell by a special transporter, i.e., Iron-Regulated Metal Transporter 1 [13]. Efforts to produce tolerant varieties need to be supported by information on growth, production and distribution patterns of iron in hybrid rice varieties.

Research on the engineering of rice cultivation using the SBSU method on ultisol fields on growth, production and absorption patterns of Fe^{2+} ions in some hybrid rice is still very limited. The results of this study are very important for engineering tolerant rice varieties [14], especially iron stress tolerant. In addition, also to meet the needs of iron-rich rice and increased production through the development of cultivation methods.

Materials and Method

Experiments on the ultisol openings were recently seized with Fe^{2+} in Koto Baru, Dharmasraya Regency, West Sumatra, Indonesia, from March to August 2018. The single factor experiment used a Completely Randomized Design with five replications. These factors are hybrid rice varieties, namely: Mekongga, Inpari 24, Inpari 27, and Inpari 28. One week before the paddy fields are plowed, commemorated for seven days and added 10 Mg ha^{-1} cow manure. The paddy fields are incubated for two weeks, after which they are plowed back and continued with harrowing until the land is ready for planting. The plot size used in this experiment are 6 m x 3 m.

Before germinating, rice seeds were immersed in the deltametrin solution, with the concentration of 3 g L^{-1} for 20 minutes, rinsed thoroughly and soaked 24 hours. Germination is carried out by wrapping the rice seeds using wet opaque paper placed in the tray. Planting is carried out in accordance with established treatments. Maintenance is done is fertilizing Urea 1/3 dose, SP 36 and KCl at the beginning of planting. Urea fertilization is then 1/3 dose when the plant is 6 weeks old and 1/3 when entering the generative phase. Weeding is done at the age of 2 and 6 weeks after planting. Watering is carried out alternately and water is cultivated to stagnate when primordial flowers.

Observations were made on each experimental unit, three samples per unit on agronomic and physiological characters. Rice samples were dried in an oven, then blended to analyse Fe^{2+} levels in roots, stems, leaves, grain and rice grains. The sample was weighed as much as 0.5 gram then it was destructed with H_2SO_4, $HClO_4$, and concentrated HNO_3 and heated until the extract was clear. The sample was diluted to 50 ml, then analysed Fe^{2+} levels with the AAS Farian AA 240 tool with SNI 6989.4.2009 method, at the LLDikti Region X Laboratory.

Results and Discussion

The results of the analysis of the parameters of plant height, number of tillers, productive tillers, percentage of productive tillers, panicle length, number of branches, 1000 grain weigh, weight of $clump^{-1}$ grain, grain weigh ha^{-1}, Fe^{2+} content (roots, stems, and leaves in the vegetative phase and generative), Fe^{2+} levels in (grain and rice) engineering rice cultivation with the SBSU in ultisol paddy fields are respectively presented in Tables 1, 2, 3, and 4.

The height of rice plants (Table 1) ranges from 64 to 71 cm, lower than the description, which is 81-106 cm. This shows that the high growth of rice varieties is hampered due to the presence of Fe^{2+} stress. The stunted growth of rice plant height is thought to be due to obstacles, translocation of photosynthesis results, and growth hormones that function to encourage rice plant growth [5, 8, 15].

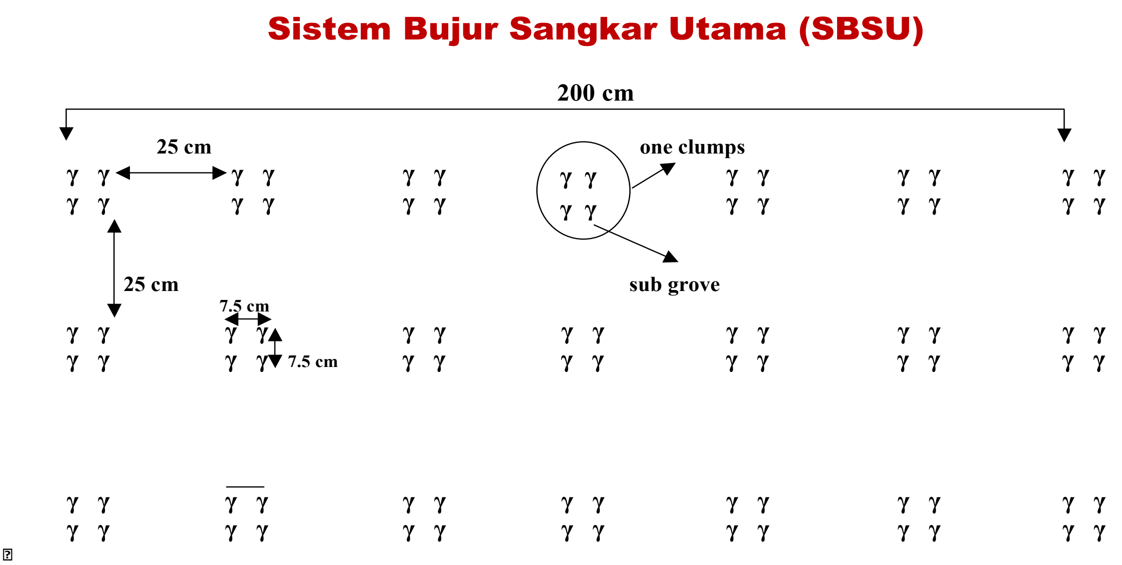
Table 1 shows, the growth of tillers with the SBSU system is able to increase the number of tillers by 62-76% (45-65 stems) with a percentage of productive tillers 34-49% (21-24 stems), whereas in conventional cultivation methods, the number of tillers formed 13-16 sticks [16]. Productive tillers formed in the SBSU system are more numerous because there are four sub-clumps that allow plants to avoid early competition in the vegetative phase so that each sub-clump can develop well [12].

Table 1: Data parameters for plant height, tillers number, productive tillers, and percentage of productive tillers

Rice Cultivars	Plant Height (cm)	Tillers Number (clum)	Productive Tillers (clum)	Productive Tillers (%)
Mekongga	71a	65a	22a	34b
Inpari 24	71a	63a	23a	39ab
Inpari 27	64b	59ab	24a	42ab
Inpari 28	64b	45b	21a	49a

The numbers followed by different letters on the same parameters in each treatment showed significantly different at the 5% level of the LSD test

Potential tillers formed by the SBSU method reached 3.6 million tillers rods^{-1}, while the conventional method was only 1.6 million tillers^{-1} tillers. An increase of 125%, compared to conventional methods that have often been applied by farmers (Figure 1). The advantages of this system are: 1) more sapling growth, 2) there is no competition for growth in the vegetative phase due to the distance between seedlings in one sub-family, 3) higher population per hectare, 4) increasing production per hectare, 5) Age faster harvests around 90 days, and 6) are cultivated with the System of Rice Intenfication [1].



Explanation:

Distance between clumps : 25 cm or 30 cm
Seedling distance in 1 clump : 7.5 cm or 10 cm
The number of clumps per ha : 90.000 clumps
Potential number of tillers : 60 s/d 120 tillers
Total population per ha : 90.000 clumps x 4 = 360.000 clumps x 10 tillers = 3.600.000 tillers
Productive tillers : 30-60 tillers
Conventional : 160.000 clumps x 10 tillers = 1.600.000 tillers

Figure 1: Schematic of rice cultivation method using the SBSU System, in each cluster there are four sub-clumps of rice

The longest panicle length was in the Inpari 24 (24 cm) variety, Inpari 27 (23.8 cm), Inpari 28 (23.3 cm) and Mekongga (22.2 cm), while the number of panicle branches in each variety did not show any significant difference, which was between 8.2 to 8.6 fruit. Panicle formation is an important stage in rice productivity related to grain formation [17]. The weight of grain per clump in the four rice varieties ranges between 58-67.3 g. In theory, with the cultivation of the SBSU system, around 90,000 clusters per ha will be obtained [11], then the grain weights range from 5.22 to 6.06 Mg ha^{-1}. This, not different from the production obtained in the production parameters grain weigh ha^{-1} (Table 2).

The grain weight of 1,000 varieties of rice (Mekongga, Inpari 24, Inpari 27 and Inpari 28) were cultivated under 26.5 g of iron, 28.0 g, 27.5 g and 28.1 g respectively. The weight of the grain is higher than the description except for the Mekongga variety. According to the description, Mekongga (27-28 g), Inpari 24 (26 g), Inpari 27 (26.7 g) and Inpari 28 (27.4 g). The high 1,000 grain weight indicates that the rice variety is able to adapt to stress, through a mechanism of greater iron translocation to the roots in the generative phase so that the growth of panicles and grains can develop properly (Table 2). The highest grain weight production is Inpari 27, which is 6.83 Mg ha^{-1}, then Mekongga (6.34 Mg ha^{-1}), Inpari 28 (5.93 Mg ha^{-1}) and Inpari 24 (5.36 Mg ha^{-1}). The production is higher when compared with the description, which is 5.7-7.7 Mg ha^{-1}[16]. The high grain weight production in experiments because in cultivation with the SBSU system is able to produce higher productive tillers compared to conventional methods [18].

Table 2: Parameters of panicle length, spikelet number, 1000 grains weight, grain weight clump^{-1} and grain weight ha^{-1}

Rice Cultivars	**Panicle Length (cm)**	**Spikelet Number**	**1000 Grain Weight (g)**	**Grain Weight Clump^{-1} (g)**	**Grain Weight (Mg ha^{-1})**
Mekongga	22.2b	8.5a	26.5a	59.1a	6.34a
Inpari 24	24.0a	8.3a	28.0a	67.3a	5.36a
Inpari 27	23.8a	8.2a	27.5a	58.0a	6.83a
Inpari 28	23.3ab	8.6a	28.1a	67.3a	5.93a

The numbers followed by different letters on the same parameters in each treatment showed significantly different at the 5% level of the LSD test

Ultisol paddy field used in the experiment contained 104.69 mg kg^{-1} Fe^{2+}, this concentration caused poisoning in plants. Poisoning occurs after paddy fields are flooded, which causes the Fe^{3+} oxide process to be reduced to Fe^{2+} compounds. In paddy fields that are subjected to iron poisoning, will cause stunted growth and development of plants, especially in sensitive varieties. In acid soils with high levels of organic matter and heavy oxides can produce ferrous concentrations up to toxic levels in ultisol, oxisol, acid sulphate, and tidal peat soils [18, 19].

The results of the analysis of iron content in the roots, stems, leaves, grain, and rice showed diversity in each variety and plant parts. The diversity shows, differences in tolerance of rice plants to iron stress (Tables 3 and 4) [8]. Plants use a reduction mechanism to get iron from the soil. The reduction mechanism used by plant species involves the production of Ferric Chelate Reductase which reduces Fe^{3+} to Fe^{2+} on the root surface. The dissolved Fe^{2+} substance is then transported into the root cell by a special transporter namely Iron-Regulated Metal Transporter 1 [13]. Rice germplasm has very narrow genetic variability for iron content in endosperm.

Table 3: Iron content in the roots, stems and leaves of several rice varieties in the vegetative and generative phases

Rice Cultivars	**Iron Content (%)**					
	Roots		**Stems**		**Leaves**	
	Vegetative	**Generative**	**Vegetative**	**Generative**	**Vegetative**	**Generative**
Mekongga	2.86ab	6.89bc	0.051ab	0.042a	0.027b	0.054b
Inpari 24	3.42a	7.23b	0.046ab	0.031b	0.040a	0.065a
Inpari 27	2.51b	9.59a	0.054a	0.033b	0.032b	0.059ab
Inpari 28	2.61b	6.52c	0.044b	0.040a	0.026b	0.039c

The numbers followed by different letters on the same parameters in each treatment showed significantly different at the 5% level of the LSD test

In Table 3 we can see that the iron content in the roots of the generative phase has increased compared to the vegetative phase. Iron levels increased in the Mekongga, Inpari 24, Inpari 27, and Inpari 28 varieties, respectively 1.41, 1.11, 2.82, and 1.50 times compared to iron levels in the vegetative phase. Ferrous content in Inpari 27 and 28 increased more than in Mekonggga and Inpari 24, especially in the generative phase. The results of studies on iron-coated transgenic rice plants also showed that more iron was transplanted to roots and leaves. This is thought to be a mechanism developed by plants to adapt to iron stress. Roots respond by modulating metabolism, gene expression and protein activity that results in changes in cell wall composition, transportation processes, cell size and shape, and root architecture [20]. Increasing iron content is a plant mechanism to influence the adaptability of rice varieties to iron stress [21, 22].

Figure 2: Planting with SBSU system using 2-week-old (A) seedlings, and root growth of rice plants experiencing Fe^{2+} *stress (B)*

Figure 2A shows 4 rice seeds planted according to the SBSU System with a spacing of 7.5 x 7.5 cm each with a spacing of 25 cm in clumps. Rice cultivation with this system can produce seedlings of around 60-120 stems [11]. This happens because rice plants avoid competition in the vegetative phase, especially in the formation of tillers so that they are able to produce higher numbers of tillers even in iron-clad conditions.

The uptake of iron in the generative phase of the stem section decreased when compared to the vegetative phase, this occurred in all rice varieties used in this experiment. The decrease of iron content in Mekongga, Inpari 24, Inpari 27, and Inpari 28 rice varieties were 0.18, 0.33, 0.39, and 0.09 times, respectively (Table 3). This is inversely proportional to the iron content in the roots. Iron accumulation in the roots of rice plants increases higher in the generative phase. The roots of rice plants which are gripped with iron still actively grow, this can be seen in Figure 2B. The root portion of rice plants contains the most iron compared to other parts such as stems, leaves, grain and grains of rice (Tables 3 and 4).

In the leaves parameter, the levels of iron absorbed by plants when entering the generative phase increase compared to the vegetative phase. Increased iron content varied in Mekongga rice varieties (100%), Inpari 24 (63%), Inpari 27 (84%), and Inpari 28 (50%) compared to iron levels in the vegetative phase (Tables 3 and 4). The difference in absorption pattern of vegetative to generative phase of iron content shows that the adaptation mechanism of each rice variety is different in dealing with iron stress [23].

Table 4 shows all rice varieties absorbing iron to be transplanted to the grain and grains of rice. In the grain parameter, the highest iron content of Mekongga variety is 56.40 mg kg 11, whereas the lowest iron content in Inpari 24 is 40.33 mg kg 11 significantly different from other varieties (Table 4). In Inpari 24, iron uptake in grain was lower than in other varieties, which was 40.33 mg kg^{-1}, but iron uptake was higher in grains of rice which was 29.47 mg kg^{-1}, except Mekongga 44.78 mg kg^{-1} and was not significantly different from Inpari 27 and 28 27.60 and 23.42 mg kg^{-1}, respectively.

Table 4: Patterns of iron content distribution in unshelled paddy and rice of several paddy varieties in the generative phase

Rice Cultivars	**Iron Content (mg kg^{-1})**	
	Grains	**Rice Grains**
Mekongga	56.40a	44.78a
Inpari 24	40.33b	29.47b
Inpari 27	51.30a	27.60b
Inpari 28	54.56a	23.42b

The numbers followed by different letters on the same parameters in each treatment showed significantly different at the 5% level of the LSD test

The highest iron content in the rice parameter occurred in the Mekongga variety which was 44.78 mg kg^{-1} significantly different from other varieties such as Inpari 24 (29.47 mg kg^{-1}), Inpari 27 (27.60 mg kg^{-1}) and Inpari 28 (23.42 mg kg^{-1}). The highest absorption of iron content in rice grains and grains was in the Mekongga variety, namely 56.40 mg kg^{-1} and 44.78 mg kg^{-1} (Table 4). The mechanism of all rice varieties adapting to iron stress in the vegetative and generative phases lies in its ability to regulate iron distribution patterns in the roots, stems, leaves, grain, and rice. The distribution pattern of Fe increased from vegetative to generative phases, mainly in root and leaf parameters but decreased in stem parameters (Tables 1, 2, 3, and 4).

Internal mechanisms occur by regulating the absorption and translocation of iron to roots, stems, leaves, grains and grains of rice. In tolerant plants, nutrient stress is more often transplanted to the roots [20], especially in the generative growth phase. Adaptation through external mechanisms requires avoidance mechanisms, whereas internal mechanisms require high tissue tolerance to iron stress or avoidance of high iron concentrations in the tissue [24].

The results of several tolerant plant varieties such as maize, soybean, wheat, ground cover legumes, and rice show the ability of plant roots to continue to grow and develop well even in conditions gripped by nutrients. The main difference in the adaptation mechanism is the binding site whether it is simplified or apoplast. These mechanisms can occur simultaneously although in different degrees according to plant type and adaptability [25, 26].

The root dry weight variable is an important indicator, to see tolerance to stress and adaptability to acid soils. Damage to root cap cells, occurs because plants have a Ca deficiency which plays an important role in the development of cell walls [20]. Tolerant plant species, which have a mucilage layer that has the role of absorbing most of the iron in the rhizosphere so that plants avoid root damage. The results showed that, in rice plants there was a similar mechanism of tolerance to environmental stress, such as Fe^{2+} stress.

The mechanism is thought to be used by rice plants to adapt to iron stress by detoxifying stress, externally and internally. Tolerant varieties have genetic ability in managing nutrition and environmental influences to be able to adapt to nutrient stress [5]. Iron has an important role in the formation of proteins, especially to help plant metabolic activities. It is suspected that proteins play a different role in detoxification that is encoded and localized to all root cells [27].This research is very important for the development of breeding engineering technology for stress, especially the varieties cultivated on iron-grabbed land in the context of rice extensification and intensification as a food source. The genetic engineering approach targets an increase in iron absorption, translocation, and storage in rice endosperm.

Conclusions and Suggestions

Grain weight production in all varieties is more than 5.4 Mg ha^{-1} even in iron-clad conditions, because the number of productive tillers formed in the SBSU system is more than 21 stems per family. The pattern of iron distribution in four hybrid rice varieties occurs through absorption and translocation in the vegetative and generative phases of the roots, stems, leaves, grain, and rice. The difference in iron content in each section shows the ability of each variety to adapt to iron stress. To get rice grains that are rich in iron and able to grow and produce well, it is better to use SBSU with Inpari 27 varieties that are able to produce iron levels in rice grains more than 27 mg kg^{-1} with grain weight production of 6.83 Mg ha^{-1}.

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