Application of Manganese and Silica through Leaves and Their Effect on Growth and Yield of Rice in Rice Field in Village of Sinar Agung, Sub-district of Pulau Panggung, District of Tanggamus, Lampung Province, Indonesia

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Abstract. **The rice production had declined and been stagnant in the last two decades. One way to increase rice productivity was the application of micro elements such as manganese (Mn) and silicon (Si). On appropriate dose, Mn and Si worked sinergically in increasing rice productivity, but would decrease the productivity when applied excessively. In order to be effective, Mn should be applied through leaf before Si because the ability of Si to inhibit Mn absorption. This research was to investigate the effect of Mn and Si application and their response on growth and yield of rice. The research was conducted on irrigated rice field in Village of Sinar Agung, Sub-district of Pulau Panggung, and District of Tanggamus, Lampung Province, Indonesia from November 2014 to April 2015. The treatment were arranged in 2x5 factorial consisting of two concentrations of Mn (0 and 5 ppm) and five concentrations of Si (0, 50, 100, 150, and 200 ppm). The research was designed in Randomized Complete Block Design with three replications. Homogeneity of variance was tested by Barlett's test and nonadditivity using Tukey's test. The results showed that applications of 5 ppm Mn increased plant growth and yield in all variables, except for plant height. While the application of Si to 200 ppm increased plant height, dry weight, number of productive tillers, filled grain weight, 1000 grain weight, and grain yield. The application of 50 ppm of Si with addition of 5 ppm of Mn showed the best response of rice on the filled grain weight and grain yield.**

Keywords: Oryza sativa, beneficial micronutrients, Mn and Si micronutrients, biosynthesis of chlorophyll.

I. INTRODUCTION

Rice consumption in Indonesian was 97.34 kg per capita per year in 2014 [3] as compared to other countries in the South East Asia such as Malaysia, Brunei Darussalam, and Singapore. It was the highest one [11] and with a big problem. Indonesia high demand of rice consumption was not equal with its ability to supply. The Goverment efforts to increase the rice production was through the intensification of agriculture. The effort with proper cultivation technology contributed only 56.10 % to rice production rate. In the agriculture intensification concept there were two important components, the use of new varieties and the technology of fertilizer application on acidic (ultisol) soil.

Ultisol soil was widespread on the islands of Smatera and Kalimantan in Indonesia. The soil type in Lampung Province was dominated by ultisol having the characteristics of low pH and rich in metal elements such as Al, Fe, Zn, and Mn. The increased pH caused the availability of Mn to be more limited for plant, albeit Mn was an important plant micro element. Rice plant required optimum of Mn to increase productivity. Providing of Mn through the leaves was expected to overcome the limitation of Mn absorption from the soil. However there was cautionto consider on the foliar application of Mn and Si. Silicon could alleviate distribution of Mn throughout the rice plant [26]. Althought Si could consequently reduce the toxicity of excess of Mn [23], the absorption of Mn might not sufficient.

Since the last two decades, the rice production had declined and been stagnant. Increasing macronutrient fertilizer (nitrogen, phosphorus, and potassium) application was not able to increase productivity as expected. Macronutrients commonly were returned to the soil through fertilization, but micronutrients such as zink (Zn), copper (Cu), iron (Fe), manganese (Mn), molibdenum (Mo), boron (B), and silicon (Si) which were also beneficial were not available for plants. The micronutrients were important to increase crop yield and quality in agricultural development programs, and in its growth plants needed enough micronutrients to support productivity [10].

Essential micronutrient such as Mn was beneficial for the growth of rice plants. Mn was needed by plants in a small amount, but its existence could stimulate the growth of plants substantially. According to [10] Mn played a role in the biosynthesis of chlorophyll. Manganese availability maintained the greenness of leaves to delay senescence in photosynthesizing [2]. The application of Mn through leaves could cause excessive accumulation in leaf tissues to result in necrosis. Manganese was immobile in the plant tissue it needed other element such as Si which could alter the distribution of Mn within the leaf tissue more evenly [9].

Monocotyledonous plants of graminae family such as rice, corn and sugarcane in some studies were known to accumulate Si in large amounts and they were considered as Si accumulators (higher than 1 % Si on dry weight) [14]. All plants contained Si in their tissues, albeit a wide variation occurred in the concentration of Si in the above ground tissues, ranging from 0.1 to 10 % of dry weight [23]. The concentration of Si differed in some common crops grown under the same condition. Rice (*Oryza sativa* L.) contained 39.1 mg Si in shoot, but chickpea (*Cicer arietinum* L.) contained only 3.0 mg Si. The different being put aside, the deficiency of Si would reduce the optimum productivity of the plant [24].

Silicon in rice improved plant performance such as delaying senescence and increasing the strength of leaves and stem. Also, Si improved the efficiency of water use. It was described by [1] that epidermal cell walls were layered with Si to become an effective barrier against the loss of water by transpiration through cuticles and of fungal infections. Si also could improve plant resistance to pests and diseases [19], [20]. Silicon fertilization might be an option to increase yield in rice fields inherently low on plant-available Si [21] and at the same time to decrease the demand for pesticides [19].

All these roles were expected to increase the production of rice so that Indonesia rice requirement could be fulfilled. Manganese capabilities supported by Si could strengthen leaves and stem to make photosynthesis more effective [17]. Foliar application of Mn and Si at appropriate concentration on rice plant were expected to reach the optimum growth of plant so the yield of rice could increase.

II. MATERIALS AND METHODS

The experiment was conducted on an irrigated rice field in the Village of Sinar Agung, Sub-district of Pulau Panggung, and District of Tanggamus from November 2014 to April 2015. The treatments were arranged in 2x5 factorial. The first factor was two concentrations of Mn (0 and 5 ppm) and the second factor was five concentrations of Si (0, 50, 100, 150, and 200 ppm). The experiment was done in a Randomized Complete Block Design with three replications. The homogeneity of variance was tested with Barlett's test and the non-additivity model with Tukey's test. The difference of means was analyzed with Orthogonal Contrast and Polynomial at $\alpha = 0.05$.

The materials were variety of rice (Ciherang), urea, SP-36, phonska, dolomite, silica (SiO_2), manganese ($MnSO_4.H_2O$), plastic sheet, niclosamide (Kensida 500 SC), isoprothiolen (Fujiwan 400 EC), and methyl tiophanate (Tillo 500 EC). The instruments used in the experiment were analytic scale (Scout pro 400), measuring cups, distilled water, stirer, oven (Memmert UNB 500), seed blower (Seedburo), seed counter (Seedburo 801 Count-A-Pak), 10 and 20 l cans and funnels. The variables observed were plant height, dry weight of plant, number of productive tillers/hill, filled-grains weight/hill, 1000 grain weight, and grain yield/ha as described below:

PLANT HEIGHT (cm). The measurement initiated from the base of the stem to the longest leaves. Measurements were taken at 12 weeks after planting (WAP).

DRY WEIGHT OF PLANT (g). Dry weight of rice plant was measured on 2 plant samples plot^{-1} at the end of the vegetative phase. Plant samples were dried at 70ºC for 3x24 hours then weighed.

PRODUCTIVE TILLERS NUMBER HILL^{-1}. The number of productive tillers was calculated at 13 weeks after planting (WAP) as the number of tillers capable of producing panicles.

FILLED-GRAIN WEIGHT HILL^{-1} (g). The grain weight was measured by weighing all grains hill^{-1}.
1000-GRAIN WEIGHT (g). 1000 grains at 14 % moisture content were randomly sampled and weighed.

GRAIN YIELD HA^{-1} (tons). The measurement was made by weighing the grain at 14 % moisture content harvested from 2 m x 2 m plots and the weights were converted to tons ha^{-1}.

The first application of Mn and Si to the plants were described by [17]. The Si were foliar applied to the plants started at 3 WAP and continued on at 7 and 11 WAP with $MnSO_4.H_2O$ of 0 and 5 ppm. The Si applied at the concentration of 0, 50, 100, 150, and 200 ppm. The formulation of Si in form of SiO_2 and Mn in form of $MnSO_4.H_2O$ solution was calculated as follow:

ppm Mn or Si = $\frac{weight\ of\ SiO2\ or\ MnSO4.H2O\ (mg)}{Vol\ (l)} \times \frac{Ar}{Mr} \times \%\ purity$ of $MnSO_4.H_2O$ or SiO_2

where Ar was atomic weight of Mn or Si and Mr was molecular weight of $MnSO_4.H_2O$ or SiO_2. The concentrations of Mn and Si were obtained at 5 ppm Mn (0.016 g l^{-1}), 50 ppm Si (0.3 g l^{-1}), 100 ppm Si (0.6 g l^{-1}), 150 ppm Si (0.9 g l^{-1}), and 200 ppm Si (1.2 g l^{-1}). The application doses were adjusted as the spray volume used at each application time.

The soluble Si was sprayed onto the entire lower leaf surface of rice plants using a knapsack sprayer. The application of Si and Mn solutions were performed on the same day, Mn being applied first. This was because Si coated the leaf tissue and prevented Mn to be absorbed into the leaf tissue if Si was applied first.

III. RESULTS

RESPONSES OF PLANT GROWTH

The observation on rice growth components included plant height, dry weight, and number of productive tillers. The results showed that the response of rice growth to increased concentration of Si did not depend on the addition of Mn as shown by all variables of growth (Table 1).

Table 1. Recapitulation of the effect of an increase in the concentration of Si and the addition of Mn on rice growth.

Comparison	Variable		
	PH	PW	PT
	-----------------% difference-----------------		
Manganese (M)			
P1 : M_0 vs M_1	ns	11.45*	4.79*
Silica (S)			
P2 : S-Linier	*	*	*
P3 : S-Quadratic	ns	ns	ns
P4 : S-Cubic	ns	ns	ns
P5 : S-Quartic	ns	ns	ns
Interaction			
P6 : P1xP2	ns	ns	ns
P7 : P1xP3	ns	ns	ns
P8 : P1xP4	ns	ns	ns
P9 : P1xP5	ns	ns	ns

Notes: M_0= 0 ppm Mn; M_1= 5 ppm Mn; PH= plant height; PW= dry weight of plant; PT= number of productive tillers. *significant at α= 0.05; ns= not significant.

PLANT HEIGHT. The results showed that the application of Mn did not contribute significantly on plant height (Table 1). Plant height increased in a linear fashion with the increase of Si concentration. The maximum concentration of Si application, 200 ppm, resulted in the plant height of 102.29 cm (Figure 1).

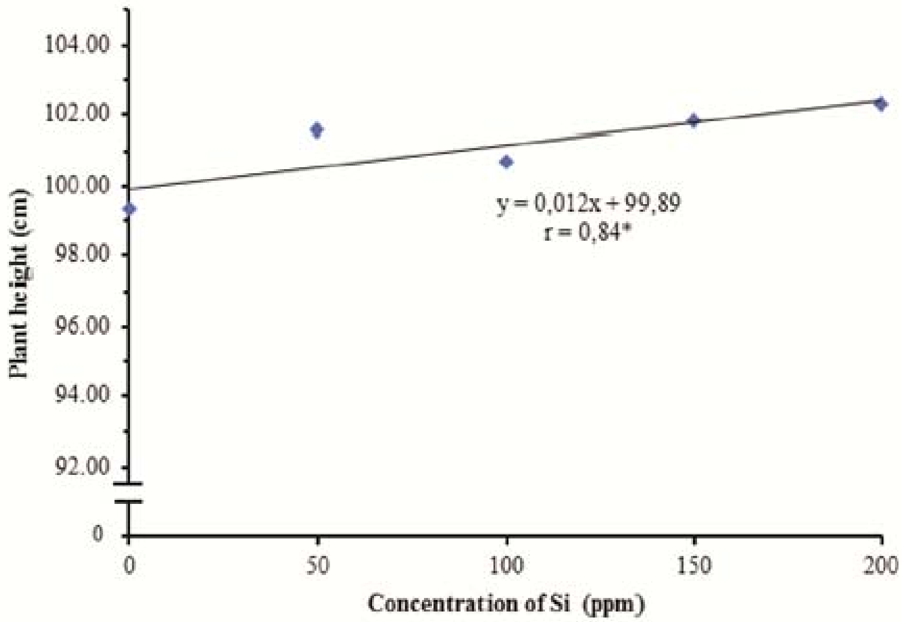

Figure 1. Response curve of the increasing concentration of Si on plant height

DRY WEIGHT OF PLANT. The addition of 5 ppm Mn increased dry weight of plant 11.45 % higher than without Mn (Table 1). At the concentration of 0 ppm Si, the dry weight was 71.15 g with increase of 0.105 g for every 1 ppm addition of Si (Figure 2).

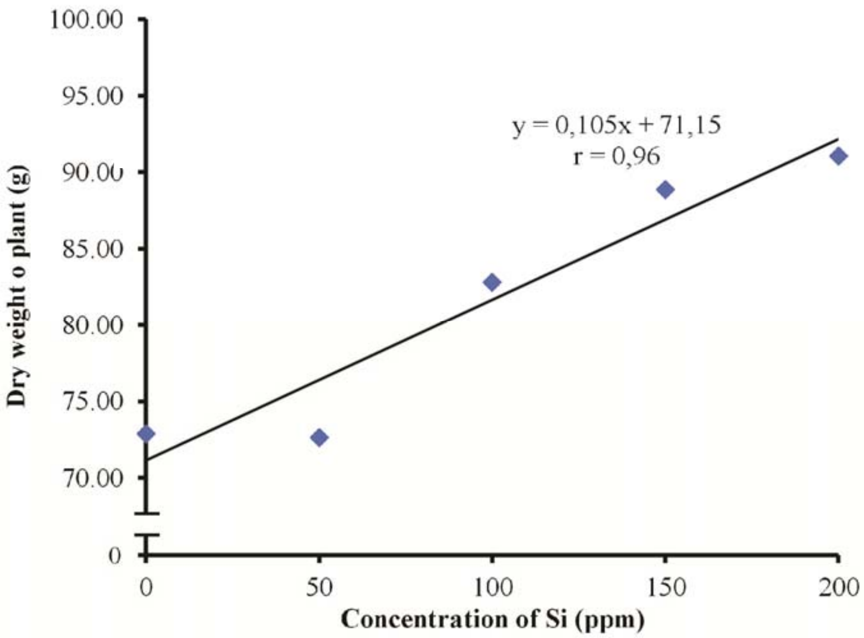

Figure 2. Response curve of the increasing concentration of Si on dry weight of plant

PRODUCTIVE TILLERS NUMBER. The addition of 5 ppm Mn increased number of productive tillers 4.79 % higher than without Mn (Table 1). The application of Si increased the number of productive tillers in a linear fashion. The maximum concentration of Si application, 200 ppm, resulted in the number of productive tillers of 17.31 hill^{-1} (Figure 3).

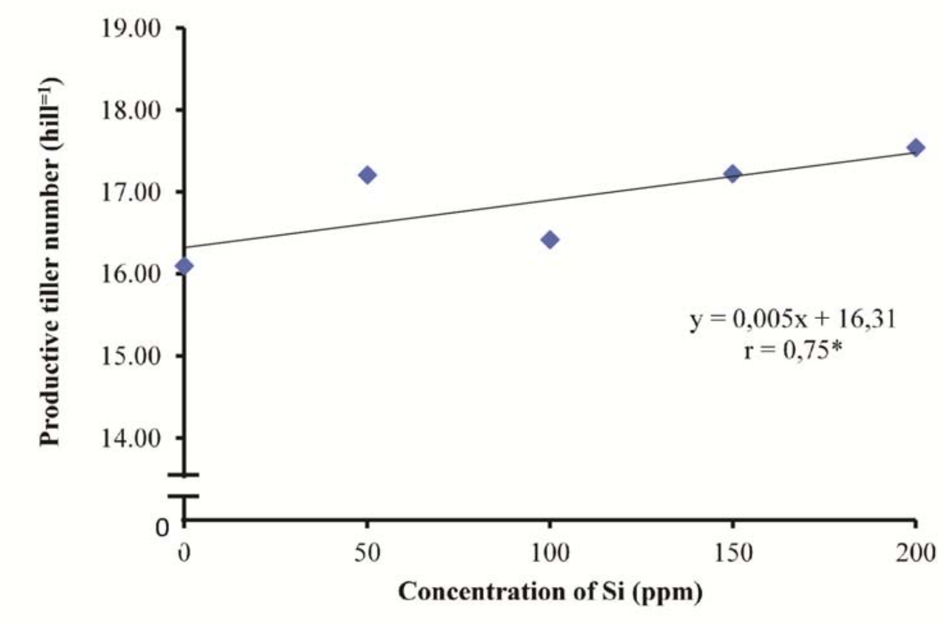

Figure 3. Response curve of the increasing concentration of Si on number of productive tillers hill^{-1}

RESPONSES OF PLANT YIELD

The observations on grain yield components included filled-grain weight, 1000-grain weight, and grain yield. Increasing concentration of Si to 200 ppm with addition of 5 ppm Mn was able to increase rice yields as indicated by the filled-grain weight and grain yield increase (Table 2).

Table 2. Recapitulation of effect of an increase in the concentration of Si and the addition of Mn on the grain yield.

Comparison	Variable		
	FG	**1000G**	**GY**
	------------------% difference-----------------		
Manganese (M)			
P1: M_0 vs M_1	19,74*	2,76*	18,86*
Silica (S)			
P2: S-Linier	*	*	*
P3: S-Quadratic	*	ns	*
P4: S-Cubic	ns	ns	ns
P5: S-Quartic	*	ns	*
Interaction			

P6: P1xP2	ns	ns	ns
P7: P1xP3	ns	ns	ns
P8: P1xP4	ns	ns	ns
P9: P1xP5	*	ns	*
The response of Mn			
S_0: M_0 vs M_1	25,77*	-	22,58*
S_1: M_0 vs M_1	30,06*	-	30,14*
S_2: M_0 vs M_1	9,59*	-	10,06*
S_3: M_0 vs M_1	25,29*	-	18,85*
S_4: M_0 vs M_1	14,48*	-	13,88*
The response curve of Si			
M_0: S-Linier	-	-	-
M_0: S-Quadratic	-	-	-
M_0: S-Qubic	-	-	-
M_0: S-Quartic	*	-	*
M_1: S-Linier	-	-	-
M_1: S-Quadratic	-	-	-
M_1: S-Qubic	-	-	-
M_1: S-Quartic	-	-	-

Notes: M_0= 0 ppm Mn; M_1= 5 ppm Mn; S_0= 0 ppm Si; S_1= 50 ppm Si; S_2= 100 ppm Si; S_3= 150 ppm Si; S_4= 200 ppm Si; FG= filled-grain number; 1000G = 1000-grain weight; GY= grain yield. * significant at $\alpha = 0.05$; ns= not significant.

*FILLED GRAIN WEIGHT***.** The results showed that the addition of 5 ppm Mn with increased concentration of Si to 200 ppm affected filled-grain weight significantly. The applications of 50 ppm Si with addition of 5 ppm Mn showed the best response, 30.06 % better than without Mn followed by 150, 200, and 100 ppm Si with addition of 5 ppm Mn which were 25.29, 14.48, and 9.59 % better, respectively (Figure 4).

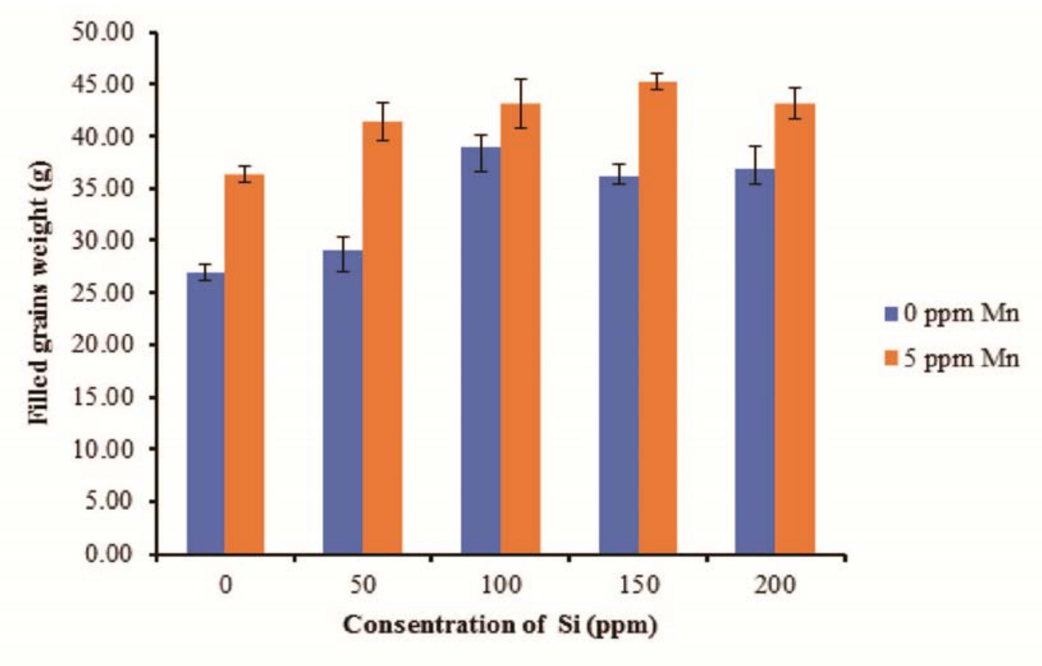

Figure 4. Response of the increasing concentration of Si with and without Mn on filled grain weight

*1000 GRAIN WEIGHT***.** The addition of 5 ppm Mn increased 1000 grain weight 2.76 % higher than without Mn (Table 2). The maximum concentration of Si application, 200 ppm, resulted in the weight of 1000 grains of 26.68 g (Figure 5).

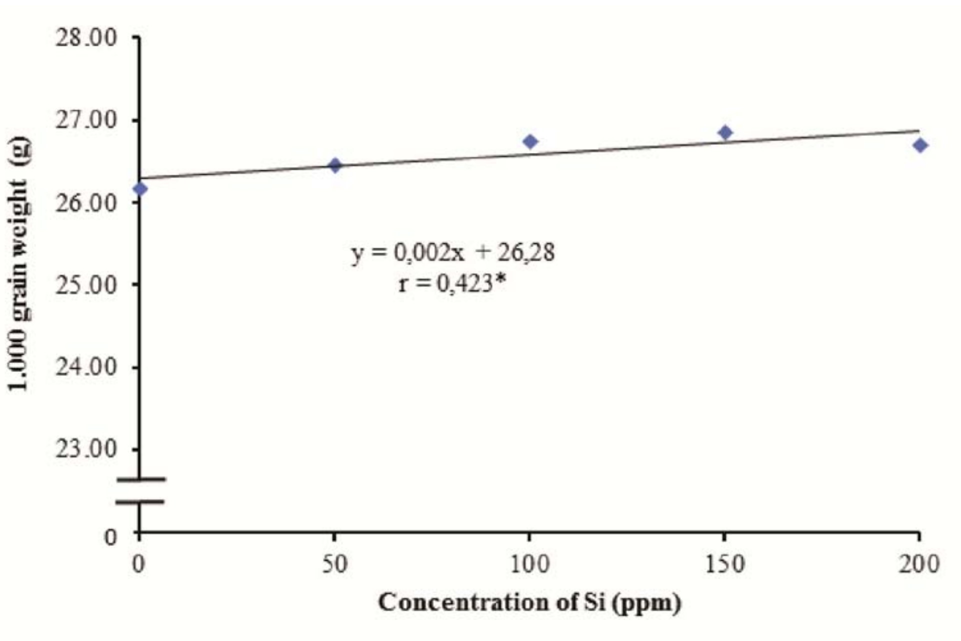

Figure 5. Response of the increasing concentration of Si on 1000-grain weight

*GRAIN YIELD HA⁻¹***.** The results showed that the addition of 5 ppm Mn with increased concentration of Si to 200 ppm affected grain yield significantly. The application of 50 ppm Si with addition of 5 ppm Mn showed the best response, 30.14 % better than without Mn followed by 150, 200, and 100 ppm Si with addition of 5 ppm Mn which were 18.85, 13.88, and 10.06 % better, respectively (Figure 6).

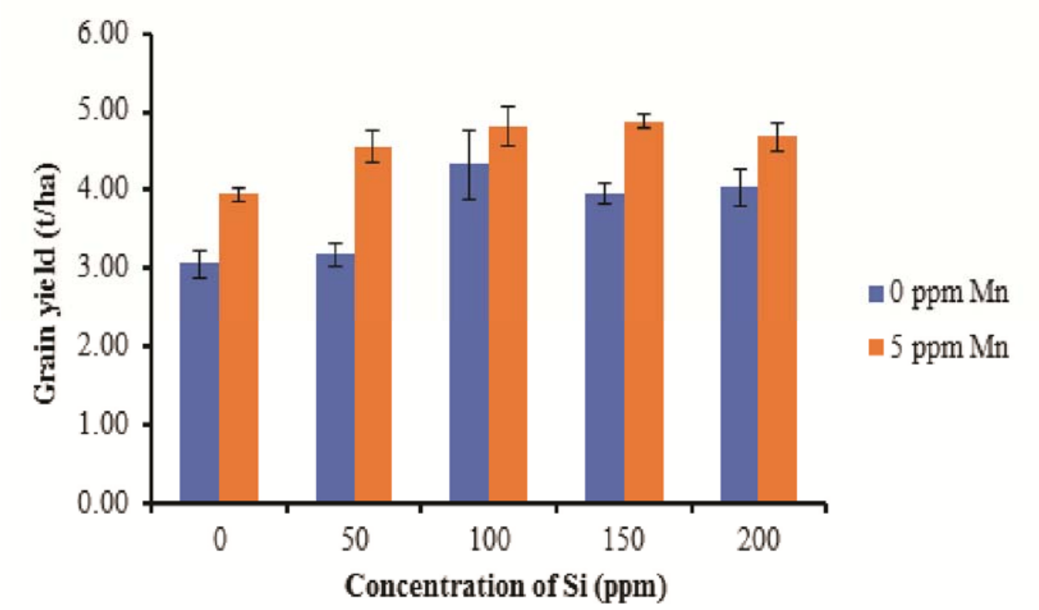

Figure 6. Response of the increasing concentration of Si with and without Mn on grain yield ha^{-1}

IV. DISCUSSIONS

RESPONSES ON PLANT GROWTH

The results showed that the application of 5 ppm Mn significantly affected rice growth as shown by dry weight and number of productive tillers. Rice fertilized with Mn had more productive tillers than without Mn. This was presumably caused by Mn increased the density of chlorophyll in the leaves of rice. Manganese played an important role in the production of chlorophyll and its presence was very important in photosynthesis [10]. The role of Mn was in chlorophyll biosynthesis via the activation of specific enzymes containing aromatic amino acid tyrosine and the formation of secondary product such as lignins and flavonoids [7]. The rate of photosynthesis activity increased as the result of increasing greenness of leaves that could produce more photosyntate to synthesize starchs, lipids, and proteins. These products were used in plant cell division processes to increase cell numbers throughout plant tissues thus the number of productive tillers and dry weight increased.

The results showed that increasing Si concentration to 200 ppm could increase the growth of rice as measured with variables plant height, dry weight and number of productive tillers. The highest concentration of 200 ppm Si increased plant height by 102.29 cm. The function of Si was to strengthen stem and the wall of epidermal tissue and the plant would grow well in an erect fashion. The upright plants could reduce tiller angle which indirectly would affect the height of rice plants [8]

In addition, in response to the increasing concentration to 200 ppm Si the growth of rice increased linearly shown by the variables dry weight and number of productive tillers. The research done by [12] showed that the application of 100 and 200 kg Si ha^{-1} increased the dry weight of rice. The result was also expressed by [6], the addition of 2 mmol l^{-1} Si contributed to the increase of the dry weight of the rice plant. Rice plants absorbed Si in the form of SiO_2 approximately 10–15 % [9]. Si absorbed by plants would accumulate in the leaves and stems which would increase plant dry weight.

RESPONSES ON PLANT YIELD

In general, the increase in the concentration of Si to 200 ppm accompanied by the addition of 5 ppm Mn was able to increase rice production as shown by the variables filled-grain weight and grain yield. According to the research by [17], an increase up to 200 ppm Si accompanied by the addition of 5 ppm Mn improved the efficiency of photosynthesis that rice production increased. Both elements played a role in increasing photosynthate that applying Si with Mn resulted in a better growth and production of rice than without Mn.

Increasing photosynthate through the application of Mn and Si on rice would increase the number of filled-grain and filled-grain weight produced that grain yield would increase, subsequently. [4] reported that the pea plants grown in 25 ppm of Mn concentration had a higher content of chlorophyll as compared to that of Mn below and above 25 ppm. On the other hand, [9] reported that Mn deficiency-induced alterations in O_2 evolution were correlated with changes in the ultrastructure of thylakoid membranes and loss of PS-II functional units in the stacked areas of thylakoid membranes. Resupplying Mn restored the number of the PS-II protein pigment units in the thylakoid membranes [25].

The addition of Si would change the distribution of Mn into a more homogeneous fashion. The application of Si could increase the concentration of Mn in the roots and reduce that in the leaves [6]. Applied Si made Mn was less detectable in symplast (<10 %) and more to be bound to the cell wall (>90 % or more) through the absorption system at the plant apoplast [13]. Moreover, [9] described that the nature of the Mn *immobile* in the plant tissue could cause poisoning when the accumulation was excessive, but the presence of Si enabled to distribute Mn more evenly throughout the plant. The Si role in influencing the metabolism of growth was not yet known, but its role in physiological processes could not be ignored because it could indirectly increase the productivity of rice plants [15].

The positive response of rice plants to the application of Mn which was influenced by the presence of Si occurs during the generative phase of the plants as demonstrated through production variables filled-grain weight and grain yield. Manganese had an important role in the biosynthesis of chlorophyll needed by plants in the photosynthesis process. The presence of Si also made the leaves became more erect and stem stronger so the characteristics of the plant were better (Figure 7).

Good characteristics of a crop would affect the ability of leaves to intercept light better thus lessened the presence of shaded leaves. The more leaves could absorb light well, the more light utilized by chlorophylls for photosynthesis. On the other hand, the presence of Mn was to maintain the condition of greenness on the leaves to delay senescence [16]. This what caused the increased performance of photosynthesis that the resulted grain yield also increased.

CONCLUSIONS AND SUGGESTIONS

The results of this study concluded that the (1) foliar application of 5 ppm Mn prior to Si application could improve plant growth and yield of rice as shown by all the variables of observation except plant height; (2) foliar application of Si with concentration up to 200 ppm abled to increase growth and yield of rice in a linear fashion as shown by variables plant height, dry weight of plant, number of productive tillers, and 1000 grain weight; (3) application of 50 ppm Si with addition of 5 ppm Mn showed the best response of rice in filled-grains weight and grain yield.

The authors suggested to repeat the research in which Mn and Si was not applied on the same day. It would be possible, therefore, to study the effect of each of these elements in the vegetative and generative phase of rice.

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VI.

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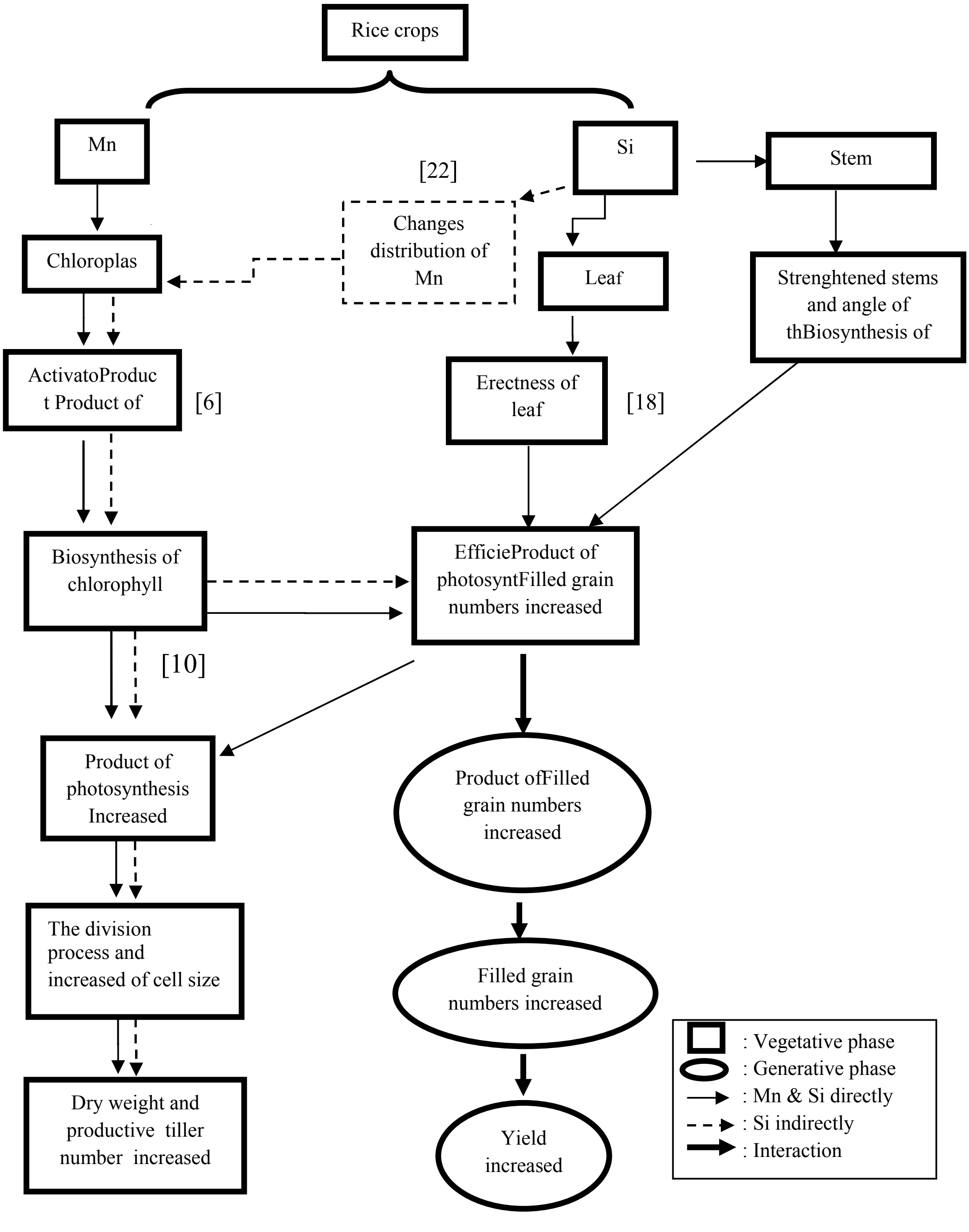

Figure 7. The summary of research results on the mechanism of interaction of Mn and Si on the growth and yield of rice.