



## **Influence of Silicon on Reduction of Methane Emissions for Sustainable Rice Production**

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### **Authors' contributions**

*This work was carried out in collaboration among all authors. Author KR carried out the research work under the supervision of author GBR. Data collection and statistical analysis were carried out by author KR and wrote the first draft of the manuscript. Author BHK helped in drafting of the paper. All authors read and approved the final manuscript.*

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### **ABSTRACT**

The increasing human population requires greater rice production and methane is the second most potent greenhouse gas emitted from rice soils under anaerobic conditions. To address this, an experiment was carried out in two phases. In the first phase of the experiment, Si content accessed in the rice index leaves and recorded the mean values of 2.50, 2.48, 2.51 and 2.43% at Jagtial, Warangal, Rajendranagar and Rudrur varietal display plots in Telangana. For the second phase of field experiment, one with high Si (JGL-3855) and another with low Si (RNR-2354) content genotypes were selected with each four levels of N (0, 80, 120 & 160 kg ha<sup>-1</sup>) and Si (0, 200, 400 & 600 kg ha<sup>-1</sup>) in strip plot design. Conjunctive application of N and Si to both genotypes, JGL-3855 recorded significantly higher grain and straw yield compared to RNR-2354, among the different combinations of Si and N, application 160 kg N + 600 kg Si ha<sup>-1</sup> recorded significantly higher grain and straw yields (7180 and 9693 kg ha<sup>-1</sup>). The treatments which received a higher

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dose of Si@600 kg ha<sup>-1</sup> in combination with N@ 80, 120 and 160 registered the lower emission of methane@ 25.7, 24.6 and 24.3 mg m<sup>-2</sup> hr<sup>-1</sup> and there was a significant scaling down of pest and disease incidence was noticed in treatments wherever increased Si doses (0, 200, 400 and 600 kg ha<sup>-1</sup>) were included.

**Keywords:** Silicon; nitrogen; CH<sub>4</sub> emission; rice; pest and diseases.

## 1. INTRODUCTION

In agricultural soils, fluxes of greenhouse gases are affected by soil factors such as temperature, water, and inorganic N fractions (NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup>). As a result, unique nature of flooded rice systems has been identified as a major source of CH<sub>4</sub> which accounts for approximately 15% annual global emissions [1]. Predictions based on population growth rate in countries where the rice is the staple food projects rice production increase by 60% in the next few decades to meet the expected food demand for the growing population [2] and further it may increase the CH<sub>4</sub> emissions to accelerate global warming effects. Production of CH<sub>4</sub> and oxidation in flooded rice soils are regulated by various microorganisms, which are controlled by physical, chemical and biological factors present in the soil. Among the various factors, the content of soil oxidants (electron acceptors) and reductants (electron donors) play a vital role in controlling CH<sub>4</sub> emissions from wetland rice agriculture [3].

Although CH<sub>4</sub> emission was suppressed by application of iron oxides in paddy soils [4-6] and silicate fertilizers contain a high amount of active iron oxides, resulting in enhancing the activity of iron-reducing bacteria, and correspondingly depressing the activity of methanogenesis, as competing for electron donor [7]. In addition, application of silicate fertilizers promoted rice root growth, thus leading to an increase in root oxygen exudation, enhancement of methanotrophic activity, depression of methanogenic activity and reduction in CH<sub>4</sub> emission [8]. Moreover, Silicon (Si) is the only element known that does not damage plants upon its excess accumulation and reduces the concentration of toxic elements like Al, Mn and other heavy metals and necessary for healthy rice growth [9] to increase yield potential [10] and developing resistance to pest and pathogens [11]. Therefore, this experiment was undertaken to investigate the feasibility of a combined application of N and silicate fertilizer on rice yield, pest and disease load and methane emission.

## 2. MATERIALS AND METHODS

The experiment was carried out in two stages, initial survey work carried out to assess the concentration of silicon in index leaves of rice plants from varietal display plots at Agricultural Research Institute (ARI) Rajendranagar, Regional Agricultural Research Station (RARS) Jagtial, Regional Agricultural Research Station (RARS), Warangal and Regional Sugarcane and Rice Research Station (RS & RRS) Rudrur of Telangana. From the selected plots, the index leaf samples *i.e.*, 3<sup>rd</sup> or 4<sup>th</sup> leaves from the top of the plant were collected at tillering stage and were dried in an oven at 65°C for two days and powdered. From this, 0.5 g of sample digested in a mixture of 50 ml each of 10 ml of HF (46%) + 40 ml of double-distilled water and allowed for cold digestion overnight. Out of which 0.1 ml aliquot collected and added 2 ml of 0.1M B, 2 ml of Mo working solution, and allowed to stand for 1-3 minutes. Then, 4ml of 0.1M citric acid added, made the final volume up to 10 ml with double distilled water and absorbance was measured at 400 nm with UV-visible Spectrometer [2,12]. To assess the available silicon status of different rice-growing soils, representative soil samples were collected simultaneously and were extracted with 0.5 M acetic acid. From it, 0.25 ml filtrate was collected and added 10.5 ml of distilled water, 0.25 ml of 1:1 hydrochloric acid, 0.5ml of 10% ammonium molybdate solution (pH 7-8), finally solution was allowed to stand for 5 minutes. After 5 minutes, 0.5 ml of 20% tartaric acid and 0.5 ml reducing agent (ANSA) was added, and absorbance was measured at 630nm using a UV visible Spectrophotometer [13]. At the end of the first phase survey experiment, grain yield of various display plots were recorded and were correlated with silica content in rice index leaves.

Out of all 133 varieties assessed during the first phase of survey experiment, only two varieties were selected for the second phase of field experiment which was having high Si content (3.20%) *i.e.*, JGL-3855 and another with low Si (2.15%) *i.e.*, RNR-2354 with four levels of Nitrogen (0, 80, 120 and 160 kg ha<sup>-1</sup>) and four levels of Silicon (0, 200, 400 and 600 kg ha<sup>-1</sup>)

consisting of sixteen treatments, replicated thrice in strip-plot design at RARS, Jagtial, Karimnagar, Telangana. The experimental soil was sandy clay loam in texture, slightly alkaline (pH7.61) in reaction, non-saline ( $0.27 \text{ dSm}^{-1}$ ), low in organic carbon (0.48 percent), available N ( $194.61 \text{ kg ha}^{-1}$ ) and available Si ( $82.17 \text{ kg SiO}_2 \text{ ha}^{-1}$ ), high in available  $\text{P}_2\text{O}_5$  ( $29.53 \text{ kg ha}^{-1}$ ) and medium in  $\text{K}_2\text{O}$  ( $170.28 \text{ kg ha}^{-1}$ ). Later, the field was laid out into 96 plots as per the design by providing bunds for individual plots and applied recommended doses of phosphorus and potassium ( $60$  and  $40 \text{ kg ha}^{-1}$ ) uniformly to all treatments in the form of single super phosphate (SSP) and muriate of potash (MOP) as basal. Nitrogen was applied in the form of urea in 3 equal splits (1/3 basal, 1/3 at active tillering stage and 1/3 at the panicle initiation stage). Silicon was applied as basal in the form of sodium silicate, which composed of 99.71, 0.02, 0.03, 0.1, 0.09, 0.01 and 0.02% of  $\text{SiO}_2$ ,  $\text{Na}_2\text{O}$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{TiO}_2$ ,  $\text{CaO}$  and  $\text{ZrO}_2$ .

The  $\text{CH}_4$  fluxes were measured by a static closed chamber method during the rice-growing period [14]. Each experimental plot had removable chambers for gas collection, which measured  $50 \text{ cm} \times 50 \text{ cm} \times 100 \text{ cm}$ , and samples were collected at 5-minute intervals (5, 10, 15 and 20 minutes) between 8:00 to 11:00 in the morning on each sampling day at a one-week interval from tillering to maturity stage. On each sampling day, the sequence of gas measurements in the treatments was randomized to avoid bias due to rising temperatures during the morning hours. Gas samples were collected through sampling ports that were fitted at the top of the chamber by using syringes and were directly analyzed with a gas chromatograph (GC), which was equipped with a flame ionization detector (FID) for  $\text{CH}_4$  analysis. A closed-chamber equation [15] was used to estimate  $\text{CH}_4$  fluxes from each treatment.

The observations on various pest viz., yellow stem-borer (*Scirpophaga incertulas*), gall midge (*Orseolia oryzae*), brown plant-hopper (*Nilaparvata lugens*) and green leaf-hopper (*Nephotettix virescens*) were recorded during tillering, vegetative and reproductive phases by following standard procedures [16]. The disease incidence was assessed by recording the severity of sheath blight (*Rhizoctonia solani*) and brown spot (*Helminthosporium oryzae*) during boot leaf, tillering and at harvesting stage, whereas sheath rot (*Sarocladium oryzae*) and grain discoloration (complex disease caused by fungi and bacteria) were recorded at harvest of the rice crop in accordance with standard

evaluation system by adopting 0-9 scale [17] and calculated percent disease intensity [18]. The analysis of variance for grain and straw yield, pest, and diseases and methane flux were worked out by feeding the replicated data into the INDOSTAT software.

### 3. RESULTS AND DISCUSSION

#### 3.1 Si Content in Index Leaf Samples and Grain Yields of Promising Varieties

Among the various locations of the present study (Table 1), the Si content in the index leaves of promising varieties at tillering ranged from 1.50 to 3.20, 1.60 to 3.15, 1.49 to 3.20 and 1.55 to 3.06% with mean values of 2.50, 2.48, 2.51 and 2.43% at RARS (Jagtial), RARS (Warangal), ARI (Rajendranagar) and RS & RRS (Rudrur) research centers, respectively [19]. The variation in Si concentration in plant species was largely due to the efficiency of plant roots for Si acquisition [20] because the proteinaceous transporter gene mediates Si uptake in rice roots [21]. Besides this, higher density xylem loading transporter genes SIT1 and SIT2 were also responsible for higher Si accumulation [22] in plant roots.

The yield of selected promising rice varieties at different rice-growing areas of Telangana region is presented in Table 1, and it showed an overall yield from four locations ranged from 2886 to 7198  $\text{kg ha}^{-1}$  at RARS, Jagtial, from 2693 to 6831  $\text{kg ha}^{-1}$  at RARS, Warangal, from 2653 to 6860  $\text{kg ha}^{-1}$  at ARI, Rajendranagar and from 4399 to 5950  $\text{kg ha}^{-1}$  at RS & RRS, Rudrur depending on the potentiality of varieties. The overall rice grain yield from four locations ranged from 3157  $\text{kg ha}^{-1}$  to 6709  $\text{kg ha}^{-1}$  with a mean of 4933  $\text{kg ha}^{-1}$ . These variations in yields might have been due to the genotypic variations and also due to variations in climatic and soil conditions of different locations [23].

#### 3.2 Correlation of Rice Grain Yield with Si Content

Correlation coefficients between Si concentration (%) in index leaves and yields ( $\text{kg ha}^{-1}$ ) of different genotypes showed a positive and significant correlation ( $r = 0.55^{**}$ ) presented in Table 2. This may be due to the soils in which the genotypes were grown at different locations are clay to sandy clay loam in texture, contained enough quantities of available Si, and hence had a good Si supplying power to rice crop [24].

**Table 1. Mean values of Si content in index leaves and yield at different locations of state**

Location	No. of varieties	Yield (kg ha <sup>-1</sup> )		Silica (%)	
		Range	Mean	Range	Mean
RARS (Jagtial)	41	2886-7198	5845	1.50-3.20	2.50
RARS (Warangal)	33	2693-6831	5871	1.60-3.15	2.47
ARI (Rajendranagar)	47	2653-6860	5646	1.49-3.20	2.51
RS&RRS (Rudrur)	12	4399-5950	5069	1.55-3.06	2.43
Mean	133	3157-6709	4933	1.49-3.20	2.34

Source Rajamani et al. [19]

**Table 2. Correlation coefficients between Si concentration in index leaves of different genotypes and their grain yields**

Parameters	Yield (kg ha <sup>-1</sup> )	Si (%)
Yield (kg ha <sup>-1</sup> )	1.00	0.55**
Si (%)		1.00

\* Significant at  $P = 0.05$  \*\*Significant at  $P = 0.01$

### 3.3 Influence of Different Levels of N and Si on Grain and Straw Yields

It is observed that both the varieties as well as nutrient levels showed a significant influence on rice grain and straw yields (Fig. 1). Among the varieties, JGL-3855 showed significantly higher grain (6779 kg ha<sup>-1</sup>) and straw yields (8949 kg ha<sup>-1</sup>) compared to RNR-2354, which register 6460 and 8530 kg of grain and straw yield ha<sup>-1</sup>. It could be due to the high efficiency of JGL-3855 in remobilizing nutrients or with the genotypic characteristic to put forth more yield attributes like number of productive tillers, number of grains per panicle and test weight [25]. According to [26], rice is a silicon accumulator and fertilization of silicon improves the yield and quality of rice by improving plant growth [27] and also impart the resistance/tolerance to biotic and abiotic stress [28].

Among the different combinations of Si and N, application of 160 kg N+600 kg Si ha<sup>-1</sup> recorded significantly higher grain and straw yield (7180 and 9693 kg ha<sup>-1</sup>) over control (5622 and 7197 kg ha<sup>-1</sup>) and was on par with (N<sub>160</sub> + Si<sub>400</sub>), (N<sub>160</sub> + Si<sub>200</sub>), (N<sub>120</sub> + Si<sub>600</sub>), (N<sub>120</sub> + Si<sub>400</sub>) and (N<sub>120</sub> + Si<sub>200</sub>) with their respective grain and straw yields of 7169 and 9607, 7172 and 9601, 7172 and 9611, 7165 and 9597, 7155 and 9594 kg ha<sup>-1</sup>. It could be due to the synergistic effect of Si and N in decreasing percent spikelet sterility, decreasing susceptibility to lodging, decreasing the incidence of infections with root parasites and pathogens, leaf pathogens and preventing toxicity of harmful elements and to increase the N use efficiency by efficient use solar radiation [29].

Even among these treatments, the treatments which did not receive any Si with N@120 and 160 kg ha<sup>-1</sup>, recorded lower grain yields of 6466 and 6467 kg ha<sup>-1</sup> compared to the treatments which received Si@200, 400 & 600 kg ha<sup>-1</sup> along with N. This can be attributed to the application of Si and causes an increase in growth and yield in cereals, because of high phosphate uptake in rice with the application of silica [30]. There was a spectacular increase in mean grain yield from 6022 kg ha<sup>-1</sup> at N<sub>0</sub> level to 6990 kg ha<sup>-1</sup> when 120 kg N ha<sup>-1</sup> was applied. However, at the highest rate of N (160 kg ha<sup>-1</sup>) application, the yield increase was very marginal and the percentage increase was 7.38%, 16.07% and 16.24%, respectively over N<sub>0</sub>. These results show that Si reduces negative effects like drooping of leaves due to excess application of N as erect leaves can easily account for a 10% increase in the photosynthesis of the canopy and consequently a similar increase in yield [31]. The application of Si increased rice yield on Histosols mainly due to the supply of plant-available Si and not due to the supply of other nutrients [32]. Similar to grain yields, the results revealed a significant influence of fertility levels as well as their interactions on rice straw yields. Higher straw yield could also be attributed to increased number of tillers per hill and plant height. The dry matter production increased significantly with each increment in N and Si fertility level due to increased chlorophyll formation which ultimately improved photosynthesis [33] in different rice soils of India.

### 3.4 Effect of N and Si Fertilization on CH<sub>4</sub> Emission

Methane emission was low at initial crop growth stage *i.e.*, within 35 days after transplanting, and it increased with plant growth, thereafter gradually decreased and finally dropped to minimum levels as plant reached the maturity stage (Fig. 2). The data revealed a significant influence of different N and Si levels on CH<sub>4</sub> emission, while the varieties and the interaction

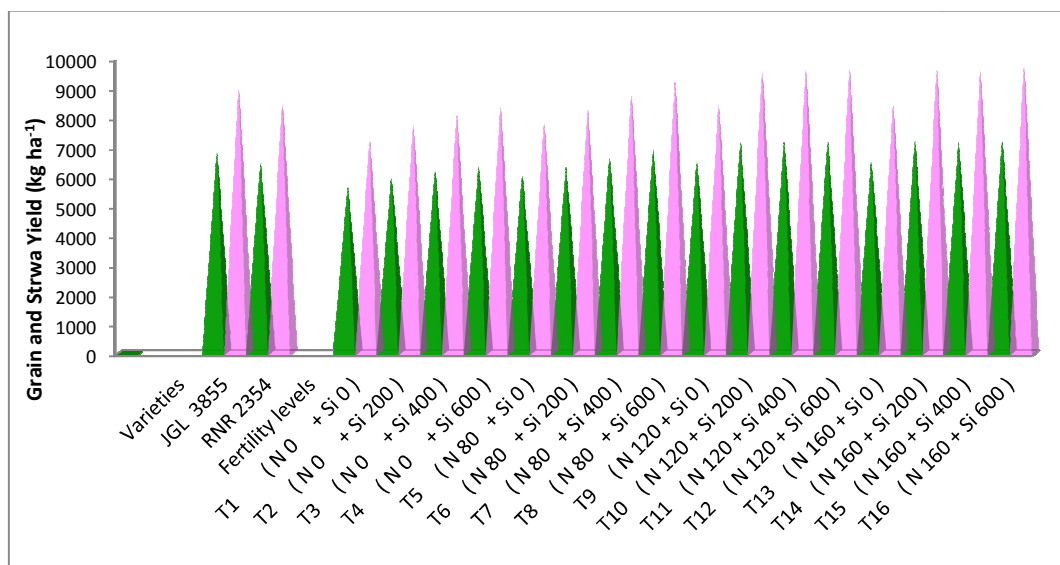
effects between the varieties and different N and Si levels were statistically non-significant. The first CH<sub>4</sub> peak (5.6 mg m<sup>-2</sup> hr<sup>-1</sup>) was observed on the 43<sup>rd</sup> day after rice transplanting, followed by the highest peak (7.4 mg m<sup>-2</sup> hr<sup>-1</sup>) on the 71<sup>st</sup> day after transplanting, and these results in tune with [34]. These changes in the CH<sub>4</sub> emission pattern usually influenced by the development of intense reduced conditions in the rice rhizosphere [35], which increases fermentation of labile organic C and root exudates [36].

Among the fertility levels, the T<sub>1</sub> treatment which did not receive any N or Si levels registered the highest cumulative CH<sub>4</sub> emission (26.6 mg m<sup>-2</sup> hr<sup>-1</sup>), compared to other treatments that received the conjunctive application of both N and Si. With an increase in the level of N@80, 120 and 160 the cumulative methane emission increased as 26.7, 26.9 and 27.1 mg m<sup>-2</sup> hr<sup>-1</sup>. It may be due to the urea application, which enhances ammonium ion concentration in soil and due to structural symmetry between CH<sub>4</sub> and ammonium ion [37], methanotrophs bind with ammonium which results in low CH<sub>4</sub> oxidation and high CH<sub>4</sub> emission from paddy soils [38]. However, when N is integrated with Si the emission was decreased. Among the treatment combinations, the treatments which received a higher dose of Si@600 kg ha<sup>-1</sup> in combination with N@ 80, 120 and 160 registered the lower emission of methane@ 25.7, 24.6 and 24.3 mg m<sup>-2</sup> hr<sup>-1</sup>. Several factors may be responsible for the decrease in CH<sub>4</sub> emission with silicate

fertilization; firstly, ferric oxide might have accepted electrons formed under anaerobic soil conditions with suppression of the methanogens activity [39]. Secondly, adequate Si supply increased oxygen transport from the plant top to the roots by enlarging aerenchyma gas channels [40], and this enhanced root rhizosphere oxidative conditions with accelerated CH<sub>4</sub> oxidation and reduced CH<sub>4</sub> emission [41].

### 3.5 Correlation Coefficients of Si Concentration with Rice Pest and Diseases

It was observed that the occurrence of major pest and diseases of rice crop was negatively correlated with silicon content in both the varieties at harvest (Tables 3 and 4). Correlation values of JGL-3855 and RNR-2354 existed as -0.84 and -0.90 for stem borer and -0.84 and -0.90 for gall midge. Similarly, presence of high silica content is negatively correlated with the incidence of diseases by JGL-3855 was -0.88 for sheath rot, -0.88 for sheath blight, -0.88 for grain discoloration and -0.87 for brown spot and also with RNR-2354 correlation values for same above-mentioned diseases were -0.91, -0.89, -0.91 and -0.90. The promoter or carrier-induced silicon transportation into rice concerning to pest and disease resistance [42]. They reported that simple amino acids, such as histidine, imidazole, glutamic acid, glycine, and glutamine significantly enhanced the levels of Si(OH)<sub>4</sub> in the stem and 14 to 18% into the leaf surface.



**Fig. 1. Influence of different levels of nitrogen and silicon on grain and straw yields of two different rice genotypes**

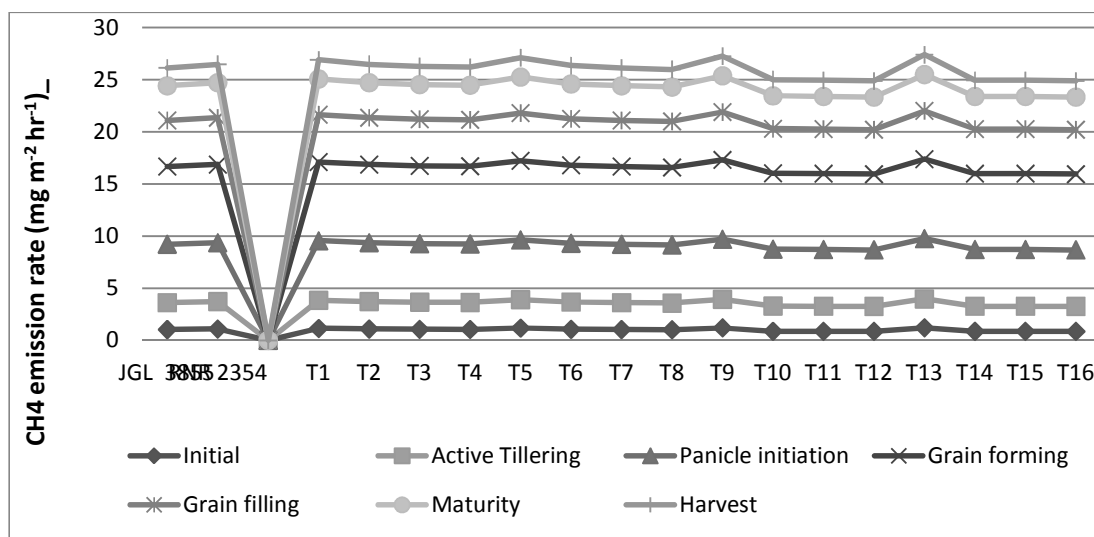


Fig. 2. Methane emission ( $\text{mg m}^{-2} \text{h}^{-1}$ ) from rice cultivars grown under different levels of nitrogen and silicon

Table 3. Correlation coefficients of Si concentration with rice pests in JGL-3855 and RNR-2354

Parameters		Dead Hearts	Galls
<b>JGL-3855</b>			
Si (%)	1.00	-0.84**	-0.84**
Dead Hearts		1.00	0.99
Galls			1.00
<b>RNR-2354</b>			
Si (%)	1.00	-0.90**	-0.90**
Dead Hearts		1.00	0.99
Galls			1.00

Table 4. Correlation coefficients of Si concentration with rice diseases in JGL-3855 and RNR-2354

Parameter	Si (%)	Sheath rot	Sheath blight	Grain discoloration	Brown spot
<b>JGL- 3855</b>					
Si (%)	1.00	-0.88**	-0.88**	-0.88**	-0.87**
Sheath rot		1.00	0.97	0.98	0.97
Sheath blight			1.00	0.97	0.96
Grain discoloration				1.00	0.95
Brown spot					1.00
<b>RNR-2354</b>					
Si (%)	1.00	-0.91**	-0.89**	-0.91**	-0.90**
Sheath rot		1.00	0.97	0.98	0.98
Sheath blight			1.00	0.97	0.97
Grain discoloration				1.00	0.96
Brown spot					1.00

#### 4. CONCLUSION

Flooded paddy is one of the most important anthropogenic sources of atmospheric CH<sub>4</sub>.

Research worldwide indicates that fertilizer management and candidate rice cultivars sustainably affect the flux of CH<sub>4</sub> to protect the economically important ecosystem. Studies

conducted with different levels of N and Si clearly indicated that application of 160 kg N + 600 kg Si ha<sup>-1</sup> recorded significantly higher grain and straw yields (7180 and 9693 kg ha<sup>-1</sup>) and simultaneously a higher dose of Si@600 kg ha<sup>-1</sup> in combination with N@ 80, 120 and 160 registered lower cumulative CH<sub>4</sub> flux@25.7, 24.6 and 24.3 mg m<sup>-2</sup> hr<sup>-1</sup>. Further, there was a significant scaling down of pest and disease incidence was noticed in treatments wherever increased Si doses (0, 200, 400 and 600 kg ha<sup>-1</sup>) were included. Therefore, silicate fertilizers could be a good soil amendment for sustaining rice productivity, pest and disease load, as well as to reduce CH<sub>4</sub> emission from paddy soils. For intense utilization of silicate fertilizers at irrigated rice in tropical soils, further research is needed to gain a better understanding of Si mechanisms in soil-plant interaction towards evaluating the global warming potential (GWP) as well as sustainable production in tropical countries.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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