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Evaluation of silicon and gypsum amendments on growth and yield of rice in an alkali soil

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Abstract
A pot culture experiment was conducted in order to check the effect of silicon (Si) and gypsum on growth and yield of rice in an alkali soil. The Si sources used were rice hull ash (RHA), diatomite (DE) and calcium silicate. These Si sources were applied in two graded levels *viz*., Si @ 125 and 250 kg ha^{-1}. Gypsum was applied based on the gypsum requirement of the soil. Combined application of Si and gypsum proved to be effective in improving the growth and yield attributes of rice than the sole application of Si. Regardless of the dosage, the combination of Si as DE and RHA performed well with gypsum than $CaSiO_3$ with gypsum which might be due to the differential reactivity of these silica materials with gypsum and with soil. Rice yield was significantly higher with the application of DE @ 250 kg Si ha^{-1} + gypsum @ 100% GR. Both concentration and uptake of Si also differed with regards to combinations of different Si sources with gypsum. Grain Si content uptake was significantly higher with the combined application of DE @ 250 kg Si ha^{-1} with gypsum @ 100% GR. On the contrary, significantly higher straw Si content and uptake was observed with the combination of RHA @ 250 kg Si ha^{-1} + gypsum @ 100% GR.

Keywords: Alkali soil, RHA, DE, $CaSiO_3$, gypsum requirement

Introduction
Rice is an important cereal crop consumed by major population of the world and is grown globally. Rice is considered as a typical silicon (Si) accumulator plant. Silicon is regarded as a beneficial element which influences the growth, development and yield of many plants particularly those belonging to *Gramineae* family *viz*., rice. Its availability on earth's crust is next to oxygen (Ehrlich 1981) [4]. Requirement of Si by rice plant is very high. It is appraised that to produce a total grain yield of 5.0 t ha^{-1}, rice crop removes 230-470 kg Si ha^{-1} from the soil (Rodrigues and Datnoff 2005) [11], hence Si may be a yield-limiting element for rice production (Datnoff *et al*. 1997) [2] particularly in soils with deficient or low in available Si. Therefore, it is necessary to provide exogenous Si supplementation for an economic and sustainable rice production system (Bocharnikova *et al*. 2010) [1].
Growth of plants in sodic soils is a major concern as it presents poor physico chemical properties of soil. Amelioration of sodic soil is done in order to improve the physical and chemical properties. The most commonly used ameliorant in reclamation of sodic soil is gypsum which is cheap and easily available source of Ca. The lacuna behind use of gypsum in sodic soil is that its reclamation efficiency depends on the application method, fineness of the gypsum and efficiency of drainage structure provided. Hence alternative methods of reclamation including exogenous application of nutrients such as Si can be preferred (Raza *et al*., 2006) [10]. The major role played by Si is biotic and abiotic stress tolerance. Among the abiotic stress, salt stress is the dominant one. There are plethora of scientific literatures pertaining to mechanisms of Si induced salt tolerance in plants. With this concept the current study was designed with an objective to analyse the effect of combined application of Si and gypsum on growth and yield of rice.

Material and Methods
A pot culture experiment was carried out in the greenhouse of Department of Soil Science and Agricultural Chemistry, University of Agricultural Sciences, Bengaluru, Karnataka, India. Sodic soil was collected from Zonal Agricultural Research Station, V C Farm, Mandya, Karnataka. The collected bulk soil sample was air dried and used for the study. The soils were analysed for initial properties by following standard procedures and the data are presented in table 1.

Silicon sources

The experiment was carried out with three sources of Si such as rice hull ash (RHA), diatomite (DE) and calcium silicate ($CaSiO_3$). Total Si content of RHA, DE and calcium silicate, were 34.84, 30 and 12 per cent, respectively. RHA is obtained from rice mills whereas $CaSiO_3$ is an industrial slag by product. DE is a sedimentary rock resulting from the deposition of Si rich unicellular diatoms (Sandhya and Prakash, 2018) [13]. All these sources were finely powdered and used for pot experiment. The chemical composition of silica sources used is depicted in table 2.

Table 1: Initial properties of the soil

Parameter	Value
Particle size distribution (%)	
Sand	53.6
Silt	17.8
Clay	28.6
Soil textural class	Sandy clay loam
pH (1:2.5 soil water)	8.63
EC (dSm^{-1}) (1:2.5 soil water)	1.02
Exchangeable cations (Cmol (p^+) kg^{-1}) Ca	10.84
Mg	3.25
Na	6.48
Gypsum Requirement; GR (t ha^{-1})	19.2
CEC (Cmol (p^+) kg^{-1}) ESP	28.65 22.62

Table 2: Chemical composition of silica sources

Parameter	$CaSiO_3$	DE	RHA
pH	12.45	9.21	8.33
EC (dSm^{-1})	n. d	0.72	1.62
Cation exchange capacity (cmol(p^+)kg^{-1})	n.d	52	36.52
Si (%)	12	30	34.84
N (%)	n. d	0.03	0.79
P (%)	n. d	0.02	0.26
K (%)	0.076	0.4	0.99
Ca (%)	5.83	2.70	0.38
Mg (%)	0.82	3.25	0.32

*n.d not determined Source: Sandhya and Prakash, 2018 [13].

Experimental details

The study was undertaken by filling 5 kg of sodic soil per pot and thoroughly mixed gypsum based on gypsum requirement of the soil as per treatment details. Prior to filling the pots with soil, each pot was layered with gravel to facilitate smooth flow of water. After the incubation period of one week, the leaching process was carried out with uniform amount of water (2.5 L/ pot) which was fixed based on the maximum water holding capacity of the soil. The leaching process was continued thrice at five days interval and the leachate coming out of the holes provided in the bottom of the pots were collected each time in the plates kept below. After completion of leaching, soil was treated with three silicon sources *viz*., RHA, DE and $CaSiO_3$ at two levels i.e., 125 (0.0625g Si kg^{-1} soil) and 250 (0.250 g Si kg^{-1} soil) kg Si ha^{-1}; decided based on the results of previous experiment. After the incubation period of one week, the pots were transplanted with salt tolerant rice variety of IR30864. At the time of transplanting recommended dose of fertilizers 100: 50: 50 kg ha^{-1} of N, P_2O_5 and K_2O as urea, DAP and MOP were applied as per the package of practices. Biometric observations like plant height, number of tillers and yield attributes like number of productive tillers and test weight were recorded. Grain and straw yield were also noted down after harvest of the crop. Concentration of Si in the grain and straw samples were analysed by as per standard procedures and the uptake was calculated. The data was subjected to statistical analysis using the factorial completely randomised design.

Results and Discussion

Biometric observations

The plant growth parameters such as plant height, number of tillers, number of panicles and test weight was statistically influenced by combined application of Si sources and gypsum are presented in table 3. However, with increase in Si levels and with gypsum application there was numerical increment in all the biometric observations. Among the different sources used Si applied as DE accounted for numerical increment in the biometric observations.

Grain and straw yield

Grain and straw yield of rice was significantly affected by silicon and gypsum application (Fig. 1 and 2 respectively). Significantly higher grain yield of 28.53 g pot^{-1} was obtained with the combined application of Si as DE@ 250 kg ha^{-1} and gypsum @ 100% GR and was statistically on par with that of DE @ 125 kg ha^{-1} and gypsum @ 100% GR and DE @250 kg ha^{-1} and gypsum @ 50% GR which recorded grain yield of 26.72 and 26.68 g pot^{-1}.Simialrly statistically significant straw yield of 39.39 g pot^{-1} was observed with the application of DE@ 250 kg ha^{-1} and gypsum @ 100% GR which was statistically on par with RHA @ 250 kg Si ha^{-1} with gypsum @ GR (38.43 g pot^{-1}), DE@ 250 kg ha^{-1} and gypsum @ 50% GR (36.66 g pot^{-1}) and DE@ 125 kg ha^{-1} and gypsum @ 100% GR (38.55 g pot^{-1}).

The different sources performed differently which might be due to their difference in reactivity in alkali soil and with gypsum. The performance was in the order of DE, RHA and $CaSiO_3$. The lesser reactivity of $CaSiO_3$ might be due to their lesser dissolution in alkaline condition. Similar results were opined by Sandhya and Prakash, (2019) [14]. $CaSiO_3$ was effective in acidic and neutral soil (Haynes, 2014) [5] and DE in alkaline and neutral soil (Prakash *et al*., 2016) [8]. Also, $CaSiO_3$ and gypsum may not be compatible as there can be suppression of dissolution arising from common ion effect. Silicon fertilization enhanced rice grain yield under flooded condition (Takahashi *et al*., 1980; Singh *et al*., 2006 and Sandhya and Prakash, 2019) [17, 16, 14]. Singh *et al*. (2005) [15] documented marked increase in grain yield with Si application level up to 150 kg Si ha^{-1}. The increase in grain yield with silicon nutrition can be ascribed to increase in number of panicles per plant, spikelet number per panicle, test weight and harvest index (Rani *et al*., 1997) [9]. Pati *et al*. (2016) [7] highlighted 11.4 per cent yield increase with Si @ 600 kg ha^{-1} as DE over control. The increase in grain yield with Si addition might be attributed to enhancement in the growth and yield attributes of rice together with stimulating effect of Si in mitigating the biotic and abiotic stress. Combination of potassium silicate and gypsum enhanced the grain yield to a greater extent than their individual application (Zahra and Sarwar, 2015) [18]. Among the three sources of Si, DE and RHA was more compatible with gypsum which might be ascribed to the organic nature of the material and its high dissolution under alkaline condition.

Table 3: Effect of Si sources and gypsum on growth and yield attributes of rice in alkali soil

Treatments	Plant height (cm)	No. of tillers	No. of panicles	Test weight (g)
RHA@125 kg Si ha-1+ gypsum@ 0%GR	63.08	15.09	14.11	24.13
RHA@125 kg Si ha-1+ gypsum@ 50%GR	63.42	15.93	15.50	25.32
RHA@125 kg Si ha-1+ gypsum@ 100%GR	66.01	15.24	15.29	27.04
RHA@250 kg Si ha-1+ gypsum@ 0%GR	67.67	16.35	14.38	24.28
RHA@250 kg Si ha-1+ gypsum@ 50%GR	69.62	16.20	15.79	25.28
RHA@250 kg Si ha-1+ gypsum@ 100%GR	68.91	16.75	16.58	28.24
DE@125 kg Si ha-1+ gypsum@ 0%GR	68.33	14.51	14.44	25.95
DE@125 kg Si ha-1+ gypsum@ 50%GR	70.34	18.35	15.52	27.02
DE@125 kg Si ha-1+ gypsum@ 100%GR	71.49	18.63	17.65	28.86
DE@250 kg Si ha-1+ gypsum@ 0%GR	71.37	15.68	16.84	26.57
DE@250 kg Si ha-1+ gypsum@ 50%GR	72.65	19.89	18.98	27.15
DE@250 kg Si ha-1+ gypsum@ 100%GR	74.38	19.15	19.29	28.51
CS @125 kg Si ha-1+ gypsum@ 0%GR	62.50	15.44	14.08	23.78
CS @125 kg Si ha-1+ gypsum@ 50%GR	67.95	18.23	14.69	24.04
CS @125 kg Si ha-1+ gypsum@ 100%GR	68.45	15.57	15.58	24.94
CS @250 kg Si ha-1+ gypsum@ 0%GR	66.81	15.57	15.32	24.04
CS@250 kg Si ha-1+ gypsum@ 50%GR	66.94	15.59	15.59	24.52
CS @250 kg Si ha-1+ gypsum@ 100%GR	67.24	15.52	15.58	25.04
SEM+	0.90	1.34	0.53	0.60
CD @ 5%	NS	NS	1.53	1.71

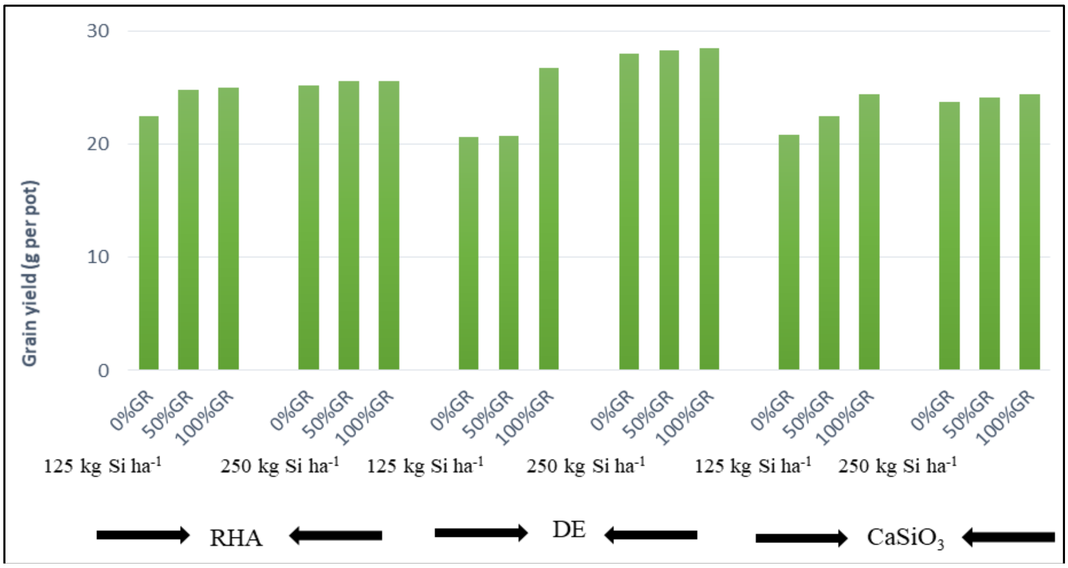

Fig 1: Effect of Si sources and gypsum on grain yield of rice under pot culture

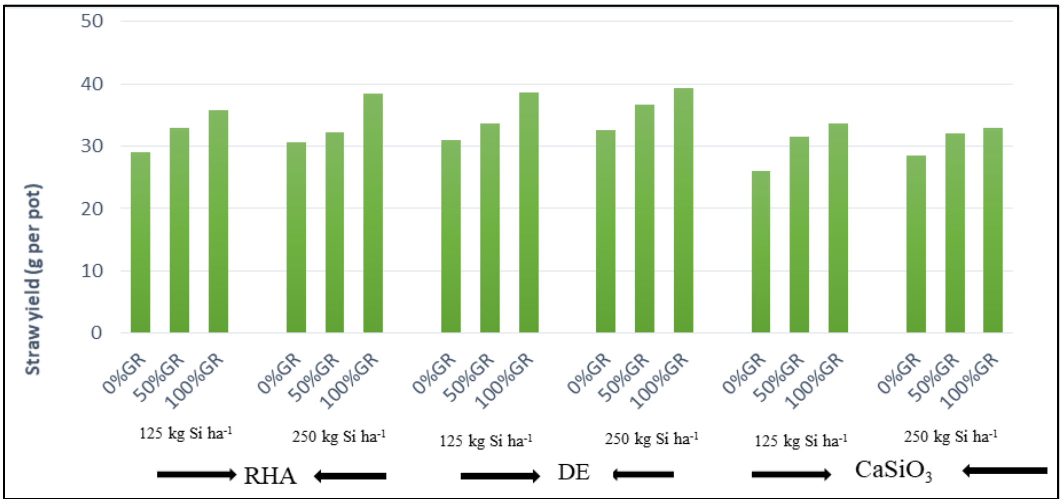

Fig 2: Effect of Si sources and gypsum on straw yield of rice under pot culture

Silicon content and uptake by rice grain and straw

Concentration of Si in rice grain and straw varied statistically across the different silicon sources and its levels and with gypsum (Fig. 3 and 4, respectively). Application of DE @ 250 kg Si ha^{-1} + 100% gypsum based on GR resulted in higher grain Si content (4.54%). Sole application of $CaSiO_3$ @ 250 kg Si ha^{-1} accounted for lower grain Si content (4.14%). On the contrary to grain Si content, among the various combinations of Si with gypsum, RHA @ 250 kg Si ha^{-1} + 100% gypsum based on GR resulted in significantly higher straw Si content (7.61%). Interpretation of data from figure 4 implied that sole application of $CaSiO_3$ @ 125 kg Si ha^{-1} accounted for significantly lower straw Si content (6.49%).

Overall, combined application of Si with gypsum exhibited higher concentration and uptake of Si than their single application. The variation in Si content and uptake with different Si sources can be ascribed to difference in reactivity and bioavailability in soil. Deren *et al*. (1994) [3] observed an increase in Si content and uptake by rate of Si fertilization. Sahu (1990) [12] reported enhanced Si content and uptake with rice hull application. Silicon content and uptake increased with Si addition. Sandhya and Prakash (2019) [14] opined that application of rice husk biochar increased the Si content and uptake in alkaline soil.

Significantly higher Si uptake by rice grain (1295.06 mg pot^{-1}) was observed with DE @ 250 kg Si ha^{-1} + 100% gypsum based on GR. Whereas, lowest Si uptake (864.72 mg pot^{-1}) was recorded with the application of $CaSiO_3$ @ 125 kg Si ha^{-1} without gypsum (Fig. 5). Similar to concentration of Si in rice straw, higher Si uptake (2.93 g pot^{-1}) in straw was observed with RHA @ 250 kg Si ha^{-1} + 100% gypsum based on GR and was statistically different from the rest of the combinations (Fig. 6). Lowest Si uptake was retained by sole application of $CaSiO_3$ @ 125 kg Si ha^{-1}(1.69 g pot^{-1}).

The higher uptake of Si by rice grain and straw with combinations of DE and RHA with gypsum might be ascribed to higher biomass yield and higher concentration of Si in rice grain and straw. The increased silicon content and uptake by rice plants might be related to the enhanced availability of Si in soil coupled with better root development which tends the plant to absorb greater amount of Si from soil. The increase in Si content and uptake by rice upon silicon supplementation was reported by Liang *et al*. (1994), Singh *et al*. (2005) [15], Singh *et al*. (2006) [16], Pati *et al*. (2016) [7] and Sandhya and Prakash (2019) [14]. Although Si is the second most abundant element in the earth crust, Si present in soil solution (plant available Si) in low concentration and hence its uptake primarily depends on the Si supplying capacity of soil. Nayar *et al*. (1977) [6] expressed that both per cent Si and its uptake were linked with duration and straw yield. The Si content in straw is of lesser magnitude during initial stages and then increases towards the later stage of crop development. This increase in silicon content with duration might be connected to increased period of absorption.

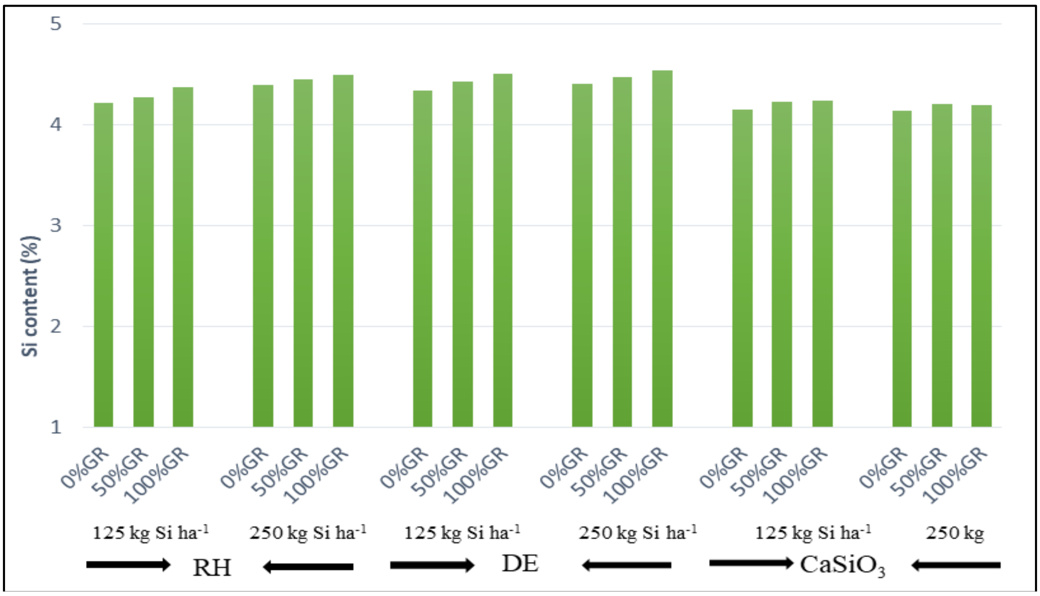

Fig 3: Effect of Si sources and gypsum on silicon content in rice grain under pot culture

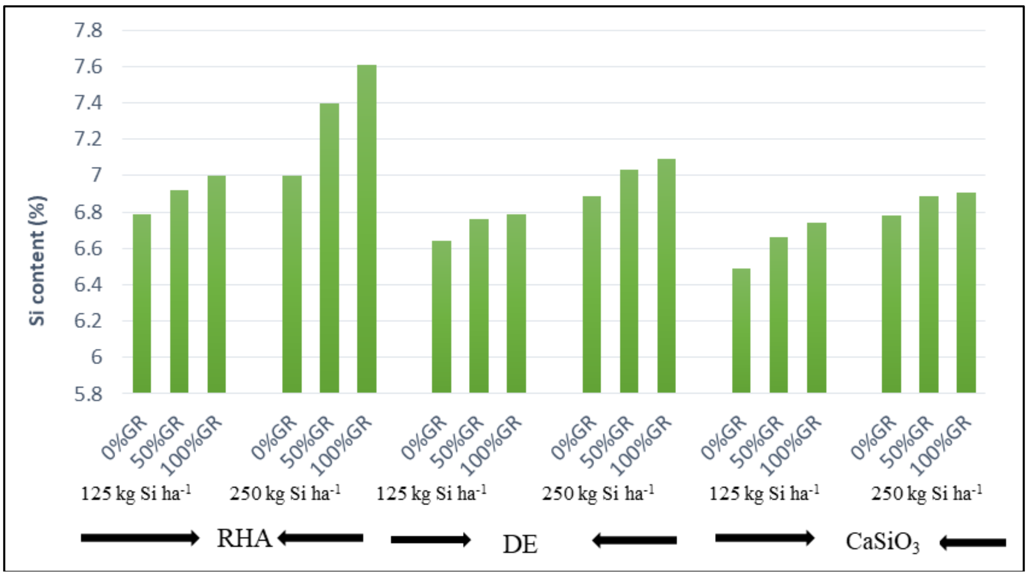

Fig 4: Effect of Si sources and gypsum on silicon content in rice straw under pot culture

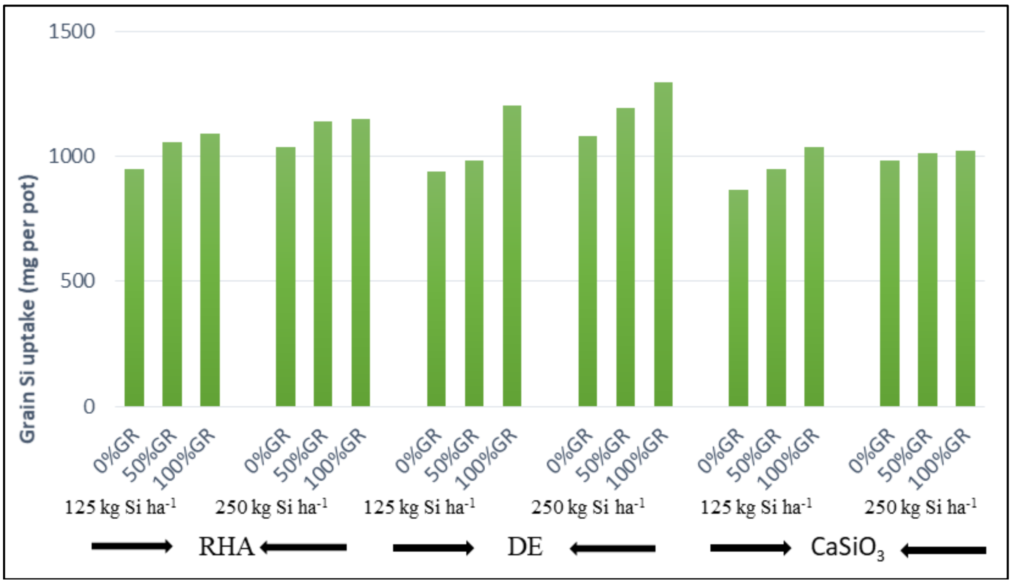

Fig 5: Effect of Si sources and gypsum on silicon uptake by rice grain under pot culture

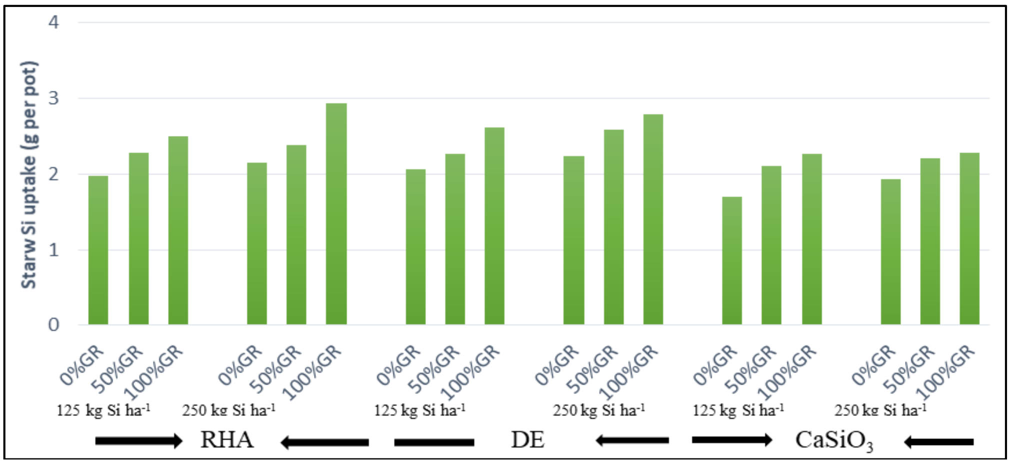

Fig 6: Effect of Si sources and gypsum on silicon uptake by rice straw under pot culture

Conclusion

The analytical observations from the study clearly revealed that combined application of Si and gypsum had significant impact on increasing the rice biomass yield. The yield attributes such as number of panicles and test weight were also significantly enhanced under combined application of Si and gypsum treatments than their sole application. However, the sources used in the present study differed significantly from one another which might be ascribed to their difference in bioavailability in an alkali soil and reactivity with gypsum. Results from the present study revealed that combined application of DE and /RHA with gypsum accounted for significant influence on growth and yield of rice in an alkali soil.

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