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Effect of Slag Based Gypsum on Nutrient Uptake and Yield of Rice (*Oryza sativa* L.) in an Alkaline Soil

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A pot culture study was undertaken to study the effect of slag based gypsum as a source of nutrient to the rice crop in an alkaline soil. The treatments included recommended dose of fertilizer (RDF) as control, 450, 600, 750 and 900 kg ha^{-1} of slag based gypsum (SBG) along with RDF. The treatments were replicated thrice and complete randomized design (CRD) was followed for statistical analysis. The results revealed that application of 750 kg SBG ha^{-1} recorded significantly higher rice grain (8.85 g pot^{-1}) and straw (9.00 g pot^{-1}) yield when compared with other treatments. Further, application of 750 kg SBG ha^{-1} recorded higher nitrogen (N) (137.68 mg pot^{-1}), phosphorus (P) (48.37 mg pot^{-1}) and potassium (K) (45.38 mg pot^{-1}) uptake by rice grain and also a significantly higher exchangeable calcium (Ca) (12.19 c mol (p^{+}) kg^{-1}) and magnesium (Mg) (12.93 c mol (p^{+}) kg^{-1}) in post-harvest soil. Whereas, application of 900 kg SBG ha^{-1} recorded higher N (75.64 mg pot^{-1}), P (17.95 mg pot^{-1}) and K (49.78 mg pot^{-1}) uptake by rice straw and also higher pH (8.95), electrical conductivity (EC) (1.28 dS m^{-1}), available N (160.53 kg ha^{-1}) and available sulphur (S) (182.50 kg ha^{-1}) in post-harvest soil. Moreover, application of 900 kg SBG ha^{-1} was also reported to give higher micronutrient uptake and availability in post-harvest soil of our studies.

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1. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important cereal crops grown in wide range of climatic zones to nourish the mankind [1]. More than two third of the population in India consumes rice as their staple diet. Rice is a means of livelihood for millions of rural household and plays a vital role in our national food security. United States Department of Agriculture (USDA) estimates that the world rice production in 2020-21 will be 501.96 million metric tonnes (MMt). India grows rice in 43 million hectares (Mha) with production of 112 million tons (Mt) of milled rice and average productivity of 2.6 t ha $^{-1}$ [2,3].

Rice yields are affected mostly as a result of imbalance in fertiliser use, soil deterioration, cropping systems used, and a scarcity of rice genotypes appropriate for low moisture environments [4]. For regular rice cultivation, over 30 percent of the 40 Mha used for rice production recorded high salt concentration [5]. When compared to normal soil, rice production losses from salt-affected soils ranged from 36 to 69 percent, with an overall average loss of 48 percent [6]. Sodic soils diminish calcium (Ca) availability while also impeding Ca transport and mobility to plant growth parts, lowering the quality of both vegetative and reproductive parts [7].

Gypsum is a rich source of calcium (Ca) and sulphur (S) and is widely used for agronomic and environmental purposes [8]. In sodic soils, using gypsum as a source of Ca^{2+} ions replaces sodium (Na^+) in the exchangeable complex. It also combines with sodium carbonate to generate sodium sulphate, a highly soluble neutral salt that does not contribute to high pH levels [9]. The majority of gypsum used in agriculture is obtained and applied from naturally mined sources. This can result in depletion of natural resources. However, synthetic gypsum made from industrial waste, such as LD slag (Linz-Donawitz slag), can be useful in this case for effective natural gypsum conservation.

Steel slag formed as a byproduct of the Linz-Donawitz (LD) process in the steel industry is known as LD slag. It contains Ca-bearing silicates and a minor amount of free lime, as well as metallic iron [10]. Slag based gypsum (SBG) is a gypsum made by Tata Steel Limited's chemical laboratory using –60 mesh LD slag fines. In addition to Ca and S, SBG is a good source of both required plant nutrients (Fe, Mn, Zn, P) and beneficial elements like Si [11]. The use of SBG as a fertiliser source in agriculture will allow the steel industry's LD slag to be reused, boosting the pollution control business. However, its usage in agriculture on small and large scale is very much limited. Hence, the present study was conducted to study the effect of SBG as a source of nutrients to the rice crop in an alkaline soil.

2. MATERIALS AND METHODS

2.1 Soil Characteristics

Bulk soil was collected from Chamarajanagara district of Karnataka (Southern dry zone). The bulk soil was then air dried, crushed, powdered, and sieved through a 2.0 mm sieve to be used in pot culture. Soil pH and electrical conductivity (EC) were calculated in a suspension of 1:2.5 soil: water ratio [12]. The International Pipette technique was used to identify the textural class of the soil [12]. The alkaline potassium permanganate technique was used to determine plant available nitrogen [13]. Olsen's approach was used to calculate the amount of available phosphorus pentoxide (P_2O_5) [14]. Using neutral normal ammonium acetate, available potassium (K_2O), exchangeable Ca, and Mg were extracted. Available K_2O was assessed using flame photometry [15], exchangeable Ca and Mg were determined using the complexometric titration method [16] and available S was determined using the turbidimetric method [17]. Diethylenetriamine pentaacetate (DTPA) extractable micronutrients (Fe, Mn, Cu, and Zn) were determined according to Lindsay and Norvell [17] by using atomic absorption spectrophotometer (PinAAcle 900F Flame High Sen US IVD). The initial properties of the experimental soil are given in Table 1.

2.2 Plant Analysis

The rice crop was harvested after maturity stage and dried in an open air. The air dried plant samples were then threshed to separate the grain from straw. The straw and grain samples were washed with distilled water and dried in oven at 70°C to obtain a constant weight. The dried grain and straw samples were weighed for the yield calculation. The samples were then cut into smaller pieces and powdered. Powdered plant sample (0.1 g) was pre-digested with 7 mL HNO_3 (70%) and 3 mL H_2O_2 (30%) in PTFE

(Poly Tetra Fluoro Ethylene) vessels and later digested using a microwave digester (Milestone-START D) at 150°C [18]. Following standard procedures, the digested samples were utilised to determine the nutritional content.

2.3 Pot Culture Experiment

A pot culture experiment was conducted with rice as test crop in an alkaline soil at Department of Soil Science and Agricultural Chemistry, UAS, Bengaluru, Karnataka during *Kharif* 2019. The experiment was laid out in complete randomized design (CRD) with five treatments and three replications. The treatments included recommended dose of fertilizer (RDF) (100: 50: 50 as N: P_2O_5: K_2O kg ha^{-1}) as control and four graded dose of SBG (450, 600, 750 and 900 kg SBG ha^{-1}) along with RDF were used. The SBG as per the treatment details were weighed for 15 kg soil (three replications) then mixed thoroughly with the soil and filled in each pots with 5 kg of these mixture. Twenty one days old two rice seedlings of variety Gangavathi Sona was transplanted to each pot and submerged condition was maintained. RDF was applied in solution form after two days of transplanting. Nitrogen (N) as urea was applied in three split doses viz. basal, tillering and panicle initiation stage. Phosphorus (P) and potassium (K) were applied as basal dose in the form of diammonium phosphate (P_2O_5) and muriate of potash (K_2O), respectively.

2.4 Source of Gypsum and its Composition

The gypsum used in our study was SBG which was produced from the TATA steel Ltd. Jamshedpur, Jharkhand. It contains around 22.65% of Ca, 16.91% of SO_4-S and 3.41% of Si as SiO_2 [19]. The particle size of SBG varies from 1.8 to 500 μm; the volume under 1.8 μm is 5.41% and that under 500 μm is 99.99% [20].

2.5 Statistical Analysis

The statistical analysis of the data was carried out by using standard statistical method of analysis of variance [21] and treatment means were compared using the Duncan's multiple range test (DMRT) at $P \leq 0.05$ probability level.

3. RESULTS AND DISCUSSION

In general, there was a linear increase in grain and straw yield of rice with the application of graded levels of SBG along with RDF (Fig. 1). Grain yield ranged from 5.58 to 8.85 g pot^{-1} and was recorded highest with the application of 750 kg SBG ha^{-1}. However, application of both 750 and 900 kg SBG ha^{-1} recorded significantly higher (9.00 g pot^{-1}) straw yield. A better correlation was recorded between straw yield and SBG application (0.85) over grain yield and SBG application (0.83).

Table 1. Initial properties of the experimental soil

Parameter	
pH (1:2.5; soil: water)	9.04
EC (dS m^{-1})	0.34
Particle size distribution (%)	
Sand	42.60
Silt	5.69
Clay	51.70
Textural Class	Clay
Soil taxonomy	*Vertic Haplustepts*
Avail. Nitrogen (kg ha^{-1})	173.6
Avail. P_2O_5 (kg ha^{-1})	47.87
Avail. K_2O (kg ha^{-1})	542.98
Exch. Ca (c mol (p^{+}) kg^{-1} soil)	11.95
Exch. Mg (c mol (p^{+}) kg^{-1} soil)	12.85
Avail. S (ppm)	61.56
Fe (mg kg^{-1})	39.25
Mn (mg kg^{-1})	21.38
Cu (mg kg^{-1})	4.27
Zn (mg kg^{-1})	2.76
Acetic Acid Silicon (mg kg^{-1})	76.25
$CaCl_2$ Silicon (mg kg^{-1})	53.05

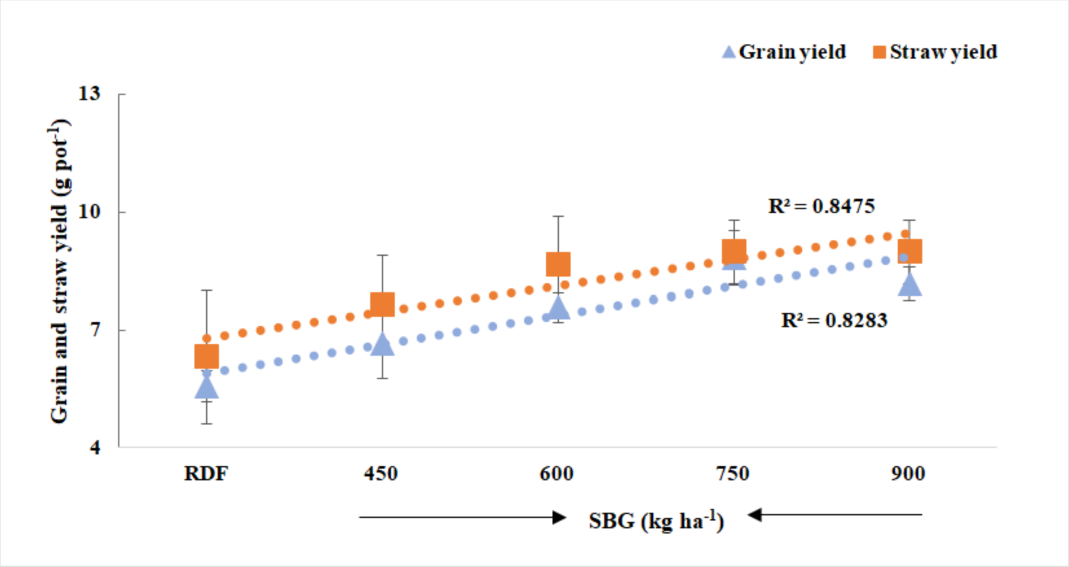

Fig. 1. Effect of slag based gypsum application on rice grain and straw yield

Application of various levels of SBG significantly increased the major nutrients uptake by both rice grain and straw (Fig. 2). Highest N (137.68 mg pot^{-1}), P (48.37 mg pot^{-1}) and K (45.38 mg pot^{-1}) uptake by rice grain was recorded with the application of 750 kg SBG ha^{-1}. Whereas, Application of 900 kg SBG ha^{-1} recorded significantly higher N (75.64 mg pot^{-1}), P (17.95 mg pot^{-1}) and K (49.78 mg pot^{-1}) uptake by rice straw. Similarly, secondary nutrients were significantly influenced with the application of graded levels of SBG and recorded highest grain uptake of Ca (80.58 mg pot^{-1}), Mg (59.45 mg pot^{-1} and S (7.99 mg pot^{-1}) with the application of 750 kg SBG ha^{-1} (Fig. 2). However, the treatments receiving 900 kg SBG ha^{-1} recorded highest Ca (52.59 mg pot^{-1}), Mg (52.45 mg pot^{-1}) and S (23.55 mg pot^{-1}) uptake by rice straw. Further, application of 900 kg SBG ha^{-1} recorded higher micronutrient uptake by both rice grain and straw (Fig. 3).

There was a significant increase in soil pH and EC with the application of various levels of SBG (Table 2). Significantly higher soil pH (8.95) and EC (1.28 dS m^{-1}) was recorded with the application of 900 kg SBG ha^{-1}. There was an increase of 8.29 per cent in soil pH over control. Similarly, application of 900 kg SBG ha^{-1} recorded significantly higher available N (160.53 kg ha^{-1}). Whereas, a significantly higher available P_2O_5 (82.71 kg ha^{-1}) and K_2O (964.32 kg ha^{-1}) was recorded with the treatment which received 750 kg SBG ha^{-1}.

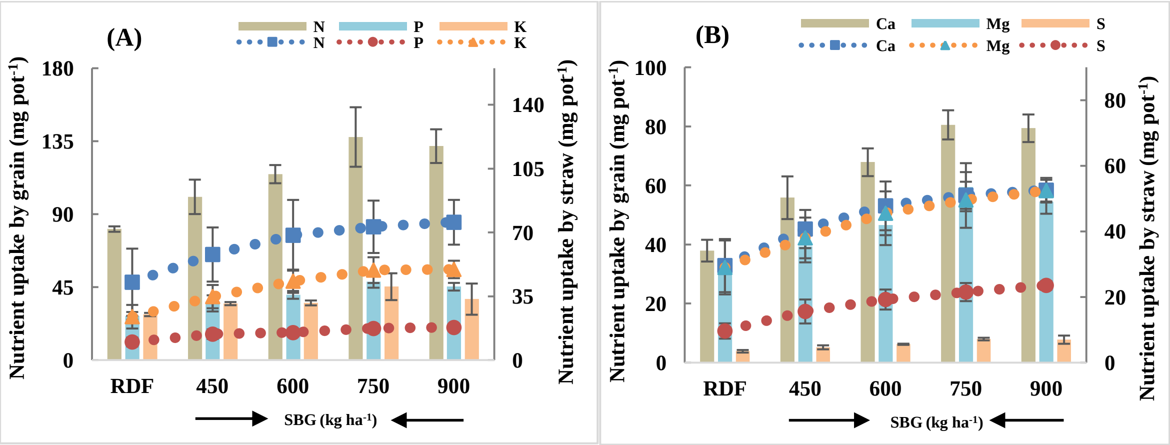

Fig. 2. Effect of slag based gypsum application on uptake of (A) Major nutrient and (B) Secondary nutrient

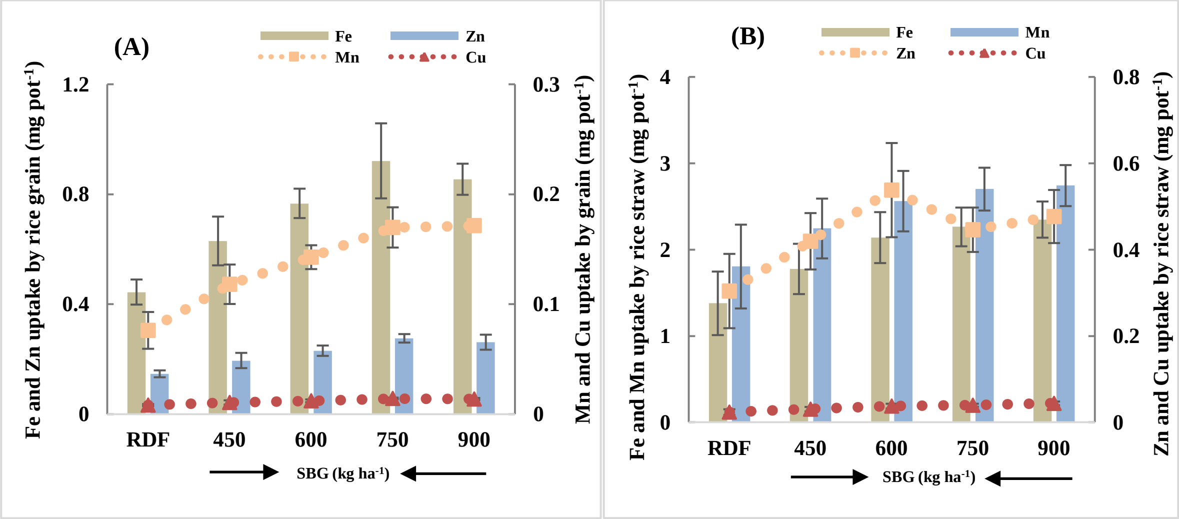

Fig. 3. Effect of SBG application on micronutrient uptake by rice (A) Grain and (B) Straw

Table 2. Effect of SBG application on pH, EC and available major nutrients of post-harvest soil

Treatments	pH	EC (dS m^{-1})	Available N	Available P_2O_5	Available K_2O
			→	Kg ha^{-1}	←
RDF	8.26	0.89	156.80	82.42	959.84
450 kg SBG ha^{-1}	8.71	1.16	153.07	85.66	985.60
600 kg SBG ha^{-1}	8.94	1.21	160.53	79.51	994.56
750 kg SBG ha^{-1}	8.67	1.22	153.07	82.71	964.32
900 kg SBG ha^{-1}	8.95	1.28	160.53	82.16	958.72
S. Em ±	0.09	0.05	9.24	0.94	9.78
CD @ 5 %	0.26	0.15	N.S	2.82	29.29

Table 3. Effect of SBG application on exchangeable Ca and Mg and available S in post-harvest soil

Treatments	Exchangeable Ca	Exchangeable Mg	Available S
	→ (c mol (p$^+$) kg^{-1}) ←		mg kg^{-1}
RDF	11.46	12.85	166.46
450 kg SBG ha^{-1}	11.85	12.88	168.13
600 kg SBG ha^{-1}	12.10	12.91	171.25
750 kg SBG ha^{-1}	12.19	12.93	173.96
900 kg SBG ha^{-1}	12.04	12.91	182.50
S. Em ±	0.12	0.04	4.23
CD @ 5 %	0.36	0.11	12.69

Table 4. Effect of SBG application on DTPA extractable micronutrients of post-harvest Soil

Treatments	Fe	Mn	Zn	Cu
	→		mg kg^{-1}	←
RDF	20.63	13.35	3.57	3.72
450 kg SBG ha^{-1}	22.73	13.78	3.72	3.73
600 kg SBG ha^{-1}	22.98	13.90	3.62	3.67
750 kg SBG ha^{-1}	19.72	13.90	3.62	3.77
900 kg SBG ha^{-1}	21.85	14.37	3.60	4.03
S. Em ±	0.75	0.19	0.08	0.08
CD @ 5 %	2.26	0.56	0.23	0.25

Further, secondary nutrients in post-harvest soil were significantly influenced with the application of SBG (Table 3). Significantly higher exchangeable Ca (12.19 c mol (p^+) kg^{-1}) and Mg (12.93 c mol (p^+) kg^{-1}) was recorded with the application of 750 kg SBG ha^{-1}. However, application of 900 kg SBG ha^{-1} recorded higher available S (182.50 mg kg^{-1}) in soil. In addition, DTPA extractable micronutrients also were substantially increased with the increase in application levels of SBG (Table 4). A significantly higher Fe (21.85 mg kg^{-1}), Mn (14.37 mg kg^{-1}) and Cu (4.03 mg kg^{-1}) was recorded with the application of 900 kg SBG ha^{-1} and Zn (3.62 mg pot^{-1}) with the application of 750 kg SBG ha^{-1}.

The increase in rice yield can be attributed to presence of quite good amount of plant nutrients in SBG [22] which could have improved soil fertility and the root environment in the subsurface resulting in better root growth in deeper layers, favouring water and nutrient uptake by crop and thereby increasing crop yield [23] Similar result was also recorded by Prakash et al. [24] with SBG application in maize crop grown in acidic and neutral soil.

Application of various levels of SBG significantly increased the nutrients uptake which could be due to SBG being an industrial byproduct gypsum having size varying from 1.8 to 500 μm. Study conducted by Bolan et al. [25] also reported that the industrial gypsum like PG and FGD gypsum were more soluble in comparison to mined gypsum because the mined gypsum contains impurities like $CaCO_3$ coating which hampers its dissolution. The increase in nutrient uptake can also be attributed to the better root growth of the rice crop in a deeper layer with the application of SBG. Chen et al. [26] reported an increase in N content and uptake in grain of corn with application of FGD gypsum as S source. Similarly, Kaniz et al. [27] reported an increase in the P content of the rice with the application of gypsum on a saline soil. Our observation is also corroborated by Jawahar and Vaiyapuri [28] who reported an increase in K uptake by rice with application of gypsum as a source of S in a saline soil.

Further, the uptake of secondary and micronutrients were significantly influenced with the application SBG. The increase in Ca and S uptake can be ascribed to the SBG being a very good source of both nutrients (22.65% Ca and 16.91% S). This result is consistent with the findings of Laxmanarayanan et al. [29] who observed an increase in Ca uptake by groundnut crop with application of SBG. Chen et al. reported an increase in S content in corn grain with the application of FGD gypsum as a source of S in a silt loam soil. Moreover, the soil also recorded higher initial exchangeable Mg (12.65 c mol (p^+) kg^{-1}) which could have attributed to the increase in Mg uptake by both rice grain and straw. There was a significant increase in micronutrient uptake by rice grain and straw with the application of SBG as well. Akbari et al. [30] reported an improvement in all the micronutrients due to gypsum application and attributed to the favourable environment in soil thereby maintaining elements in more available form.

The results also revealed an increase in pH and EC of post-harvest soil. The increase in pH of soil with the application of SBG can be due to the alkaline nature of SBG having pH 8.15 However, Zhao et al. with rice crop in saline alkali soil; Zhao et al. Shahi et al. with rice crop in alkali soil recorded a decrease in soil pH with gypsum applied as a reclamation source. Increase in soil EC with the application of SBG can be ascribed to an enhanced electrolyte concentration of the soil solution through dissolution of SBG and thereby increasing the EC of the soil. This result is supported by the findings of Prakash et al. who recorded an increase in EC of acidic and neutral soil of maize with application of SBG at higher rate.

Application of graded levels of SBG also significantly increased the availability of the nutrients in soil. A significant increase in available N can be due to overall improvement of the soil properties resulting in the faster transformation of nutrients and thereby increasing its availability. Laxmanarayanan et al. recorded an increase in available N in soil with the application of SBG for groundnut crop. Increase in available P_2O_5 with the application of SBG can be ascribed to the formation of $Ca_3(PO_4)_2$ and $FePO_4$ through release of Ca and Fe by dissolution of SBG which reduces P losses. Khan et al. [30] recorded an increase in K content of the soil with the application of gypsum but it was non-significant in both wheat and rice crop in saline soil with pH 8.0.

Secondary and micronutrients were significantly increased with the application of SBG. Increase in exchangeable Ca and Mg content of the soil with the application of SBG can be due to the SBG (22.65% Ca and 0.85 % Mg) having quite good amount of nutrients. Similarly, Zhao et al. reported an increase in Ca^{2+} and SO_4^{2-} concentrations with the application of FGD gypsum in an alkaline soil. The increase in available S can be due to higher S retention in clay colloidal surface of alkaline soil [31]. Increase in DTPA extractable micronutrient with the application of SBG can be ascribed to the presence of Fe (5.45%), Mn (0.086%), and Zn (0.37%) content in SBG which might have directly contributed in increasing their availability on dissolution in soils. Prakash et al. recorded significantly higher DTPA extractable micronutrient in acidic and neutral soil with the application of 750 kg SBG ha^{-1}.

4. CONCLUSION

The results from the present investigation confirms that application of SBG along with RDF increases rice yield, nutrient uptake and availability in soil. SBG being a byproduct gypsum can be an efficient and better alternative over commercial gypsum in terms of reducing pollution and recycling industrial waste product besides maintaining soil productivity and nutrient availability. Further studies are required to assess the long-term effect of SBG in different crops and in different soil.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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