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Effect of slag based gypsum on chemical properties and macro nutrient availability in sodic soil

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Abstract
Slag based gypsum (SBG) is a synthetic gypsum which is alkaline in nature, its high calcium and magnesium content serve as soil conditioner by improving the soil physical and chemical properties particularly in deep black and alkaline soil. In this study, we evaluated the effect of SBG on soil chemical properties and macro nutrients over gypsum. Field experiments were conducted by taking French bean (*phaseolus vulgaris* L.) as test crop and experiment contains 10 treatments which include four levels of SBG and natural gypsum (150, 300, 450 and 600 kg ha^{-1}) applied as basal. Application of SBG @ 600 kg ha^{-1} recorded significantly decreased (7.56 and 8.02 respectively) soil pH and exchangeable sodium percentage and significantly higher electrical conductivity (0.49 dS/m) resulting in improving soil chemical property compared to control and RDF alone. Availability of macronutrients increased with the increasing rate of SBG and gypsum application except nitrogen and phosphorous.

Keywords: Slag based gypsum, gypsum, soil conditioner, French bean

Introduction
Gypsum is a hydrated calcium sulphate ($CaSO_4 \cdot 2H_2O$) which commonly used as an amendment for alkaline soil (Ahmad *et al.*, 2010) [2]. Mainly, it is a source of calcium and sulphur on legumes. Increase in population resulting in food demand that lead to increased stress on natural mineral resources which are important raw material for fertilizer production. Therefore, in the future, the utilization of various industrial waste–based values added nutrient supplements would be helpful to decrease the rate of exhaustion of natural mineral resources. Total reserve mineral gypsum in India has been estimated around 1330 MT (Indian Minerals Yearbook 2018) [6].

Slag is a by-product of steel industries during iron and crude steel production. It is evaluated that the steel industry produces about 150-200 kg of steel slag per tonne of steel produced during the Linz–Donawitz (LD) process. Presently, India is the fourth-largest manufacturer of steel and India's steel demand is likely to grow by over 7 percent in 2019-20, driven by sectors like construction, capital goods and railways. In India, total production of steel slag is around 12 MT per annum (Indian Mineral Yearbook, 2018) [6] while utilization is only of 30 percent. Open dumping and landfills are some common management practices that are adopted for disposal resulting in environmental pollution in the form of dusts and leachate (Sarkar and Mazumder, 2015; Khan and Shinde, 2013) [14, 9].

Slag based gypsum contains quite good amount of essential plant nutrients, particularly Ca, Mg, S, and it also contains other micronutrients like Fe, Mn and beneficial element like Si. Its high calcium and Mg content could also serve as soil conditioner by improving the soil physical and chemical condition particularly in deep black and alkaline soil. With this background the present work endeavors to evaluate the effect of SBG application on properties of soil by growing French bean as test crop in sodic soil.

Material and Methods
Study area and soil properties
The experiment was laid out in the Main Horticultural Research and Extension Centre (MHREC), UHS, Bagalkot, during 2019. The land topography of the experimental site was almost uniform with an adequate surface drainage. Climate is warm and dry throughout the year with an average annual rainfall of 561 mm. The average maximum temperature is 31.0 °C and minimum temperature is 19.6 °C.

Before sowing, surface soil samples (0–20 cm depth) were collected using screw auger from various spots to form one composite soil sample for initial soil fertility evaluation and analyzed based on the standard laboratory procedures. Experimental soils were sodic (8.45) in reaction with an electrical conductivity and ESP of 0.23 dS/m and 15.40% respectively, low in available nitrogen and phosphorus and high potassium 15.40% respectively, low in available nitrogen and phosphorus and high potassium (Table 1).

Sources of gypsum and its composition

Two types of gypsum sources used in the experiment were SBG and natural gypsum. Slag based gypsum is another product produced from steel industry by-product by treating basic slag with 20 percent lime solution and concentrated sulphuric acid. SBG contains around 22.65% of Ca, 16.91% of SO_4-S, and 3.41% of Si as SiO_2. However, natural gypsum is a hydrated calcium sulphate ($CaSO_4 \cdot 2H_2O$) which commonly used as an amendment for alkaline soil (Ahmad *et al.*, 2010) [2]. Mainly, it is a source of calcium and sulphur and it contains 23.12% of Ca, 17.95% of SO_4-S, and 1.37 of Si as SiO_2 (Table 2).

Table 1: Initial soil properties of experimental field

Soil properties	Value
pH	8.45
Electrical conductivity (dS/m)	0.23
Exchangeable sodium percentage (%)	15.40
Available N (kg ha^{-1})	212.60
Available P (kg ha^{-1})	4.90
Available K (kg ha^{-1})	456.50
Exchangeable Ca (me/100 g)	17.10
Exchangeable Mg (me/100 g)	2.80
Iron (ppm)	1.25
Copper (ppm)	0.58
Manganese (ppm)	3.90

Table 2: Chemical composition of Slag based gypsum and natural gypsum

Parameters	Slag based gypsum	Gypsum
pH (1:2.5 gypsum: water ratio)	8.15	6.92
Ca (in % by mass)	22.65	23.12
SO_4^2 (%)	16.91	17.95
SiO_2 (%)	3.41	1.37
Mg (%)	0.85	0.08
P_2O_5 (%)	0.32	Nil
Fe (%)	5.45	0.03
Mn (%)	0.09	0.02
Zn (%)	0.37	0.004

Field experiment

French bean variety, Arka Arjun maturing at 60 days was grown during *rabi* 2019–20 at UHS, Bagalkot. The experiment was laid out in randomized block design with plot size of 2.5 m × 2.5 m with three replication and ten treatments consisting of four levels (150, 300, 450 and 600 kg ha^{-1}) of SBG and gypsum together with recommended dose of fertilizer (RDF) and one control (RDF alone). Fifty percent of the recommended dose of N and entire dose of P and K was applied as basal dose and remaining nitrogen as top dress at 30 DAS. Treatment wise basic slag will be mixed with FYM (@ 25 t/ha) or vermicompost and applied in planting line and mixed with top 20 cm soil. All recommended cultural practices for French bean production were adopted for the management of the experiment. Soil samples were collected at 30 and 60 DAS and analyzed plant-available nutrients.

Soil analysis

Collected composite soils samples from each treatment were air-dried, powdered and passed through a 2 mm sieve and analyzed for various chemical properties. The pH (1:2.5) and EC of soil were determined by pH meter and conductivity meter, respectively (Jackson 1973) [7]. The soil samples were analyzed for available nitrogen (N) by the alkaline permanganate method (Subbiah and Asija 1956) [18]. Available phosphorus (P) was estimated by using Olsen extractant for sodic soil (Jackson 1973) [7]. Available potassium (K) by 1 N neutral NH_4OAc extraction on flame photometer (Jackson 1973) [7], exchangeable Ca^{2+} and Mg^{2+} by complexometric titration method (Jackson 1973) [7] and DTPA extractable micronutrients (Fe^{2+}, Mn^{2+} and Cu^{2+}) (Lindsay and Norvell 1978) [10].

Results and Discussion

Effect of SBG and gypsum on soil chemical property

Soil pH

The result of present study exhibited significant effect on soil pH at 30 and 60 DAS by the application of SBG and gypsum (Table 1). The application of different levels of SBG and gypsum significantly decreased the soil pH. Application of SBG at the rate of RDF + 600 kg/ha decreased the soil pH (7.56) compared to control (8.51), and it was on par with gypsum at the rate 600 kg/ha (7.69). The decrease in soil pH may be due to replacement of exchangeable Na^+ by Ca^{2+} and formation of neutral salts with SO^-_4 as indicated by raise in the exchangeable Ca^{2+} from initial 16.09 to 29.71-31.22 c mol (p^+) kg^{-1} soil with the application of RDF+600 kg of gypsum and SBG. The effect of SBG on soil pH decrease was comparable with gypsum because of the calcium (22.65%) content was comparable with gypsum (23.12%). Similar view was expressed by Abdel-Fattah, (2012) [1] and Sundhari *et al.*, (2018) [19].

Electrical conductivity

Application of different levels of SBG and gypsum significantly increased the electrical conductivity (EC) of soil. Application of RDF+600 kg SBG/ha (T_6) recorded significantly higher EC and it was on par with RDF+600 kg gypsum/ha (T_{10}). The higher EC values in the SBG and gypsum applied treatments compared to control may be due to elevated level of sorbed SO_4 and Ca which increased the electrolyte in the soil solution (Toma *et al.*, 1999) [20].

Exchangeable sodium percentage

There was a significant decrease in exchangeable sodium percentage of soil with increased level of SBG and gypsum (Table 1). Lower ESP was recorded in T_{10} (RDF+600kg gypsum/ha) (7.62%) compared to control (14.60%) and it was on par with T_6 (RDF+600 kg SBG/ha) (8.02%). Decrease in ESP in gypsum and SBG applied compared to control might be due to leaching of exchangeable sodium by replacement of calcium ions as indicated by increase in the exchangeable Ca^{2+} from initial 16.09 to 29.71-31.22 c mol (p^+) kg^{-1} soil with the application of RDF+600 kg of gypsum and SBG. (Qadir *et al.*, 2001) [13].

Table 3: Effect of application of SBG and gypsum on chemical properties of the soil

Treatment	pH		EC (dSm^{-1})		ESP (%)	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
T_1-Absolute control	8.41	8.51	0.26	0.27	15.10	14.60
T_2-RDF	8.30	8.25	0.32	0.31	14.30	13.90
T_3-RDF+ Slag based Gypsum @ 150 kg ha^{-1}	8.24	8.14	0.36	0.37	10.80	10.60
T_4-RDF + Slag based Gypsum @ 300 kg ha^{-1}	8.12	8.08	0.42	0.38	9.24	9.10
T_5-RDF+ Slag based Gypsum @ 450 kg ha^{-1}	7.97	7.90	0.49	0.44	8.70	8.36
T_6-RDF + Slag based Gypsum @ 600 kg ha^{-1}	7.68	7.56	0.56	0.49	8.12	8.02
T_7-RDF+ Gypsum @ 150 kg ha^{-1}	8.30	8.26	0.35	0.32	10.65	9.90
T_8-RDF + Gypsum @ 300 kg ha^{-1}	8.24	8.18	0.41	0.37	9.60	9.36
T_9-RDF+ Gypsum @ 450 kg ha^{-1}	8.08	8.00	0.48	0.46	9.32	9.20
T_{10}-RDF + Gypsum @ 600 kg ha^{-1}	7.71	7.69	0.54	0.50	7.90	7.62
S.Em ±	0.09	0.16	0.03	0.03	0.53	0.61
C.D. (p=0.05)	0.27	0.48	0.10	0.09	1.59	1.82
C.V. (%)	1.94	3.50	14.18	14.28	8.89	10.49

Effect of SBG and gypsum on soil macro and micro nutrient

Available nitrogen

There was no significant effect of SBG and gypsum application on soil available N during 30 DAS, but showed significant difference at 60 DAS. Treatment T_7 (RDF+150 kg Gypsum ha^{-1}) recorded significantly higher available nitrogen (268.20 kg ha^{-1}) content compared to all other treatment. Among SBG, treatment T_3 (RDF+150 kg SBG ha^{-1}) recorded significantly higher available N content (238.30 kg ha^{-1}) compared to control (138.00 kg ha^{-1}). Decreased in nitrogen content with increase in rate of SBG and gypsum was observed. This may be due to better plant growth resulting in higher uptake of nitrogen from soil, hence available N declined in higher rate of SBG and gypsum applied treatments. Singh and Taneja (1977) [16] also reported that, rate of N mineralization in soils is usually stimulated by the addition of gypsum at the rate of 2.5 to 5 t/ha. However, addition of higher rates of gypsum (7.5 to 10 t/ha) led to a lower level of N mineralization and declined the available N in higher rate of gypsum application.

Available phosphorus

The available P_2O_5 was significantly influenced by application of SBG and Gypsum in the soil. Application of RDF + SBG @ 600 kg ha^{-1} recorded higher available P_2O_5 (22.24 kg ha^{-1}) compared to other treatments during 30 DAS and it was on par with treatment RDF +Gypsum @ 600 kg ha^{-1} (21.45 kg ha^{-1}). The increase in available P_2O_5 with increased levels of SBG and gypsum might be due to its SO_4^{2-}-S content which consequently interacts with adsorbed phosphate and releases phosphate ions into soil solution phase. The increase in available P_2O_5 with increased levels of SBG might also be due to its P content (0.14%) compared to no phosphorous in gypsum (Prakash *et al.*, 2020) [12]. The increased available P_2O_5 after the addition of gypsum was consistent with the findings of Skwierawska *et al.*, (2008) [17]; Kannan *et al.*, (2017) [8] and Bairagi *et al.*, (2017) [3].

Table 4: Effect of SBG and gypsum on primary nutrients in soil

Treatment	Available N kg/ha		Available P_2O_5 kg/ha		Available K_2O kg/ha	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
T_1-Absolute control	210.05	138.00	4.78	4.16	496.30	476.20
T_2-RDF	256.22	239.68	18.78	5.29	549.00	523.36
T_3-RDF+ Slag based Gypsum @ 150 kg ha^{-1}	248.00	238.30	19.52	9.64	553.40	528.00
T_4-RDF + Slag based Gypsum @ 300 kg ha^{-1}	242.00	236.20	20.22	8.86	558.60	533.90
T_5-RDF+ Slag based Gypsum @ 450 kg ha^{-1}	237.00	222.60	21.25	7.26	586.00	535.00
T_6-RDF + Slag based Gypsum @ 600 kg ha^{-1}	220.00	218.30	22.24	6.60	590.20	538.00
T_7-RDF+ Gypsum @ 150 kg ha^{-1}	260.00	268.20	18.83	10.00	548.00	531.00
T_8-RDF + Gypsum @ 300 kg ha^{-1}	254.00	262.00	19.50	9.18	551.00	536.00
T_9-RDF+ Gypsum @ 450 kg ha^{-1}	246.00	253.20	20.98	8.42	565.00	540.00
T_{10}-RDF + Gypsum @ 600 kg ha^{-1}	238.00	223.00	21.45	7.63	570.23	542.00
S.Em ±	13.98	13.92	1.03	0.63	38.67	26.33
C.D. (p=0.05)	NS	41.69	1.40	1.89	NS	NS
C.V. (%)	10.04	10.49	10.49	14.22	12.03	8.61

Application of gypsum significantly decreases the exchangeable Na^+ and adsorption of phosphorus and thus increases the available P content of soil (Mora *et al.*, 2002) [21]. As 60 DAS, P_2O_5 content suddenly decreased with increased rate of SBG and gypsum, this may be due to better plant growth resulting in higher uptake of phosphorous from soil. Decreased in available P_2O_5 may also due to continued trend of Ca^{2+} release from SBG and gypsum at 60 DAS. Similarly, Chhabra and Thakur (2000) [5] reported that, addition of different amounts of gypsum led to a high concentration of calcium in the soil results in precipitation of insoluble calcium phosphate compounds and decreased the P concentration in the soil.

Available potassium

Application of SBG and gypsum showed no significant effect on available K_2O (Fig 6 and 7). The highest soil available K_2O was observed in RDF+600 kg SBG ha^{-1}(590.20 kg ha^{-1}) and RDF+600 kg gypsum ha^{-1} (570.23 kg ha^{-1}) and lowest was observed in control (496.30 kg ha^{-1}).

Exchangeable calcium and magnesium

There was a significant increase in exchangeable Ca^{2+} and Mg^{2+} in soil as a result of SBG and gypsum application (Table 5). Significantly higher exchangeable $Ca^{2+}$and Mg^{2+} was recorded in treatment with RDF+600 kg SBG ha^{-1} and RDF+600 kg gypsum ha^{-1}. Increasing the rate of SBG and gypsum application from 150 to 600 kg ha^{-1} corresponding significant increase in Ca^{2+} in the soil was observed. Similarly Caires *et al.*, (2011) [4] and Michalovicz *et al.*, (2014) [11] also reported that the increase in exchangeable Ca^{2+} in the soil profile depends on the application rates of gypsum. The greater availability of exchangeable Ca^{2+} and Mg^{2+}due to application of SBG and gypsum may be ascribed to the higher supply of particularly Mg^{2+} which with the increasing level of SBG there is a significantly increase in Mg^{2+} compared to gypsum may be attributed to the higher Mg content (0.85%).

Table 5: Effect of SBG and gypsum on secondary nutrients in soil

Treatment	Exch. Ca (c mol (p^+) kg^{-1} soil)		Exch. Mg (c mol (p^+) kg^{-1} soil)	
	30 DAS	60 DAS	30 DAS	60 DAS
T_1-Absolute control	17.06	16.09	2.76	2.80
T_2-RDF	18.80	18.47	2.94	3.50
T_3-RDF+ Slag based Gypsum @ 150 kg ha^{-1}	22.56	21.16	3.63	3.49
T_4-RDF + Slag based Gypsum @ 300 kg ha^{-1}	25.09	24.38	4.15	4.00
T_5-RDF+ Slag based Gypsum @ 450 kg ha^{-1}	28.32	27.68	4.54	4.28
T_6-RDF + Slag based Gypsum @ 600 kg ha^{-1}	30.09	31.22	5.77	5.52
T_7-RDF+ Gypsum @ 150 kg ha^{-1}	23.16	19.78	2.59	2.43
T_8-RDF + Gypsum @ 300 kg ha^{-1}	25.28	23.08	2.69	2.52
T_9-RDF+ Gypsum @ 450 kg ha^{-1}	28.51	25.28	2.77	2.61
T_{10}-RDF + Gypsum @ 600 kg ha^{-1}	29.52	29.71	2.96	2.88
S.Em ±	1.52	1.74	0.28	0.25
C.D. (p=0.05)	4.57	5.23	0.85	0.76
C.V. (%)	10.65	12.79	14.27	12.98

Conclusion

Results of this study revealed that Slag based gypsum produced from steel industries slag by-product could be used as soil conditioner so it can be a alternative source to natural gypsum. This study also confirms that, Slag based gypsum can be a good source of calcium, magnesium, phosphorous and iron and also proved its beneficial effect on soil chemical properties and nutrient availability over gypsum. Our results suggested that band application of 600 kg SBG ha^{-1} to root zone significantly improved the chemical property and plant available nutrients in soil over control and RDF alone. Further, studies are needed to better understand the long term effect of application of SBG on soil properties and the response of crops.

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