LR-4981
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RESEARCH ARTICLE Legume Research- An International Journal, Volume Issue : ()

Effect of Different Rate and Time of Application of Slag based Gypsum on Nutrient Use Efficiency, Quality and Yield of Groundnut

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ABSTRACT

Background: Slag based gypsum (SBG) is a value-added product of iron and steel industry. Application of gypsum as source of calcium and sulphur for groundnut cultivation is common practice and mainly applied during peg initiation stage of groundnut. However, its effect is mainly influenced by the type of soil and dissolution of gypsum, which facilitates the yield and quality of groundnut. Hence, field experiments were conducted to know the effect of application of different rates of SBG as basal and split application on soil properties, yield, quality, nutrient use and uptake efficiency of groundnut in acidic soil.

Methods: This study contains of seven treatments which includes recommended dose of fertilizer (RDF) with three levels of SBG (375, 500 and 625 kg ha^{-1}) was applied as basal and split and 500 kg natural gypsum (NG) ha^{-1} was applied as basal dose according to package of practice (POP) of University of Agricultural Sciences, Bangalore by using randomly complete block design (RCBD) at Agricultural Research Station, Balajigapade during *kharif* 2018 and 2019.

Result: The pooled data of two field experiments on groundnut revealed that application of RDF + 625 kg SBG ha^{-1} as 50% at sowing + 50% at peg initiation stage recorded higher pod (28.01 q ha^{-1}), haulm (54.46 q ha^{-1}), kernel (20.59 q ha^{-1}), protein (89.70 q ha^{-1}) and oil (7.06 q ha^{-1}) yield when compared to other treatments. There was an increase in pod, haulm and oil yield of groundnut by 11.62, 20.59 and 17.99%, respectively with the split application of 625 kg SBG ha^{-1} (50% at sowing + 50% at 30 DAS) over NG applied treatments. Split application of SBG significantly increased the availability of nutrients in post harvest soils than basal application. Significantly higher S and Ca nutrient use efficiency (33.98 and 28.93 kg produce/kg S and Ca utilized, respectively) and uptake efficiency (0.39 and 1.29 kg kg^{-1}, respectively) was recorded with the split application of SBG @ 375 kg ha^{-1}.

Key words: Natural gypsum, Nutrient use efficiency, Slag based gypsum, Uptake efficiency.

INTRODUCTION

Oilseed crops are the second most important determinant of agricultural economy, next only to cereals within the segment of field crops. Groundnut (*Arachis hypogaea* L.) is one of the most important oil seed crops of India occupies the first place both in regard to the area (7.5 m. ha) and production (6.00 m. ha) in the world (Misra 2017).

Groundnut is adapted to a wide range of soil types and environments. However, its better growth and development is observed under marginally acidic and neutral soil pH. (Chen *et al.* 2016). Secondary nutrients such as calcium and sulphur also play an important role in enhancing production and productivity of groundnut (Kamble *et al.* 2018). Calcium nutrition is also considered a yield limiting factor for groundnut production especially in acid soil due to its low accessibility. Enough calcium content in the soil around the pods leads to increased growth and yield. Calcium in groundnut bush is immobile and its content in any parts of the plant depends on calcium presence when that part is forming and growing. Because calcium is absorbed through roots of groundnut and then transmitted to the aerial parts of the plant but is not transmitted from aerial parts of the plant, so the calcium of the soil must be adequate around the growing. Deficit of calcium and lower soil pH leads to the weak germination, immature pods and higher aflatoxin content in kernel (Patro and Ray, 2016).

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How to cite this article: Dhumgond, P., Shruthi Laxmanarayanan, M., Jahir Basha, C.R. and Prakash, N.B. (2022). Effect of Different Rate and Time of Application of Slag based Gypsum on Nutrient Use Efficiency, Quality and Yield of Groundnut. Legume Research. doi: 10.18805/LR-4981.

Submitted: 06-06-2022 **Accepted:** 17-11-2022 **Online:** 27-01-2023

Sulphur is also an essential plant nutrient and plays a vital role in the synthesis of amino acids, proteins, chlorophyll and flavour imparting compounds (Tiwari and Gupta 2006). Plants absorb S mainly in the form of inorganic sulfate (SO_4^{-2}) ions through the roots, thus sulfate must be present in soils in sufficient amount in order to meet crop S requirements. Inadequate availability of calcium and sulphur to crop plants not only declines their growth and yield but can also deteriorate nutritional quality of groundnut (Biswas *et al.* 2003). Hence, presence of enough calcium and sulphur is essential in both vegetative and reproductive stages, especially in absorbable form.

Slag based gypsum (SBG) is first kind of gypsum produced from steel industry slag by acid treatment (Ashrith *et al.* 2015), which is also a rich source of calcium, magnesium, sulphur, in addition to silicon and other micronutrients (Prakash *et al.* 2020). Under such scenario, use of SBG produced from the iron and steel industry could be an alternative and cheap source of sulphur for agricultural production.

Application of gypsum as source of calcium and sulphur for groundnut cultivation is common practice in India. The sources of survey and interactions with farmers reveals that, farmers practice one-time gypsum application during the time of earthing up of soil or peg initiation time. So, this practice of farmers could affect the quality and yield of groundnut due to lesser and balanced availability calcium and sulphur. Keeping in view the facts described above, a comprehensive study was planned to optimize gypsum application time and rate in groundnut cultivation in semi-arid regions of Karnataka.

MATERIALS AND METHODS

Experimental location and initial soil properties

Field experiments were conducted at Agricultural Research Station (ARS), Balajigapade of two different places representing Eastern Dry Zone of Karnataka, South India, during rainy seasons of 2018-19 (N 13°26′73.5″, E 77°46′ 59.2″) and 2019-20 (N 13°26′73.5″, E 77°46′59.2″), respectively. Soils under investigation were classified as Kandic paleustalfs. Before designing of field experiments, surface soil samples (0-15 cm depth) were collected using screw auger. The selected physicochemical properties of two experiments are presented in Table 1.

Sources of gypsum and its composition

Gypsum namely, SBG and NG were used as gypsum sources in the experiment. The SBG was provided by Tata Steel Ltd., Jamshedpur, India. The NG is a commercially available gypsum and commonly used by the local farmers. The composition of SBG and NG is presented in Table 2.

Field experiment

The groundnut field experiment was conducted in randomized complete block design (RCBD) with a plot size of 5 m × 4 m with three replications and seven treatments consisting of three levels (375, 500 and 625 kg ha^{-1}) of SBG as basal and basal + split application together with recommended dose of fertilizer (RDF) and only one level of NG (500 kg NG ha^{-1}). Application of RDF is common to all the treatments. The basal application of 500 kg NG ha^{-1} was considered as control to compare with SBG and which has been adopted in the package of practice for groundnut recommended by University of Agricultural Sciences, Bangalore, India. Basal application treatments received 100% of SBG and NG at 30 days after sowing (peg initiation stage). While split application treatments received 50% of SBG at sowing and 50% of SBG at peg initiation stage.

The groundnut variety Kadiri-6 was used as a test crop. Recommended dose of fertilizer (25:75:37.50 N:P_2O_5:K_2O, respectively) was applied through urea, diammonium phosphate and muriate of potash as basal fertilizer. Gypsum sources such as SBG and NG were broadcasted manually to treatment plots and then mixed thoroughly with soil. while for split application, SBG was band placed near the established

Table 1: Initial soil properties of experimental site.

Location	Balijigapade	Balijigapade
Season	*Kharif-2018*	*Kharif-2019*
Parameters		
pH (1:2.5 soil: water)	5.77	4.80
EC (m Sm^{-1}) (1:2.5 soil: water)	0.06	8.94
Particle Size distribution (%)		
Sand	28.71	27.40
Silt	9.27	15.30
Clay	62.02	56.20
Textural class	Sandy clay loam	Sandy clay loam
Available N (kg ha^{-1})	162.4	127.12
Available P_2O_5 (kg ha^{-1})	11.69	151.36
Available K_2O (kg ha^{-1})	195.44	120.66
Exchangeable Ca (c mol (p$^+$) kg^{-1} soil)	3.10	1.56
Exchangeable Mg (c mol (p$^+$) kg^{-1} soil)	2.20	0.70
Available S (mg kg^{-1})	8.90	17.28
DTPA extractable Fe (mg kg^{-1})	3.08	16.18
DTPA extractable Mn (mg kg^{-1})	0.36	34.25
DTPA extractable Cu (mg kg^{-1})	3.07	1.42
DTPA extractable Zn (mg kg^{-1})	0.042	0.72
AA Si (mg kg^{-1})	41.50	15.96
$CaCl_2$ Si (mg kg^{-1})	43.16	10.06

plants. Groundnut plants were harvested at maturity stage of crop and Pod, kernel and haulm yield were recorded.

Quality parameters of groundnut

The protein content in the kernels was analyzed by estimating nitrogen (N) content in kernel by micro Kjeldahl method (Piper, 1966) which was multiplied by a factor 6.25 to get the protein content of the kernel and expressed in percentage. Protein yield was worked out on the basis of kernel protein content and kernel yield of groundnut and expressed in kilograms per hectare.

The oil content of groundnut kernel was analyzed using nuclear magnetic resonance (NMR) spectrometry. The standard volume of groundnut seeds and reference oil was weighed and the NMR reading was collected. NMR oil equivalent in the groundnut kernel sample was determined by using the following formula:

$$\text{Oil yield (kg ha}^{-1}) = \frac{\text{Oil content in kernel (\%)}}{100} \times \text{Kernel yield (kg ha}^{-1})$$

Plant and soil analysis

Ten groundnut plants randomly harvested at maturity stage of crop were thoroughly washed with deionized water. Pod, kernel and haulm were separated and oven dried at 70°C to obtain constant weight, powdered and stored for analysis. Powdered plant samples were digested using a microwave digester (Campbell and Plank 1998). The digested samples were analyzed for various nutrient content by adopting standard procedures.

Collected composite soil samples from each treatment after harvest of groundnut were air-dried, powdered and passed through a 2 mm sieve and analyzed for various chemical properties. Soil pH and EC were measured in a suspension with a 1:2.5 soil: water ratio (Jackson 1973). Available P_2O_5 was estimated by using Bray's 1 method (Bray and Kurtz 1945). Exchangeable Ca^{2+} and Mg^{2+} were estimated by complexometric titration (Baruah and Barthakur 1997). Available S content was estimated by turbidiometric method (Williams and Steinberg 1959). DTPA extractable micronutrients such as Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+} were analyzed (Lindsay and Norvell 1978) by using atomic absorption spectrophotometer (PinAAcle 900F Flame High Sen US IVD).

Nutrient use and uptake efficiency

The nutrient use and uptake efficiency was calculated by using the formula given by Amritbir *et al.* (2020).

$$\text{Nutrient uptake efiiciency (kg kg}^{-1}) = \frac{\text{kernel yield}}{\text{Fertilizer added + Soil nutrient}}$$

$$\text{Nutrient uptake efiiciency (kg kg}^{-1}) = \frac{\text{Total uptake of nutrient}}{\text{Fertilizer added + Soil nutrient}}$$

Statistical analysis

The experiment results were statistically analysed according to (Panse and Sukhatme 1985). The yield, post-harvest soil nutrients, nutrient use and uptake efficiency of groundnut were analysed using SPSS Statistics 25.0 (SPSS, Inc., Chicago, IL, USA). Least significant difference (LSD) test was used for mean separation when the ANOVA was significant (P<0.05).

RESULTS AND DISCUSSION

Basal and split application of slag based gypsum on pod, kernel and haulm yield of groundnut

Pooled mean of groundnut yield was presented in the Table 3. Pod yield of groundnut significantly varied by basal and split application of SBG. The pod yield of groundnut increased by 7.97 and 11.67 per cent in 625 kg ha^{-1} of SBG applied as basal and split respectively over 500 kg ha^{-1} of NG applied control plots. Application of SBG @ 500 and 625 kg ha^{-1} in two splits boost the kernel and haulm yield to the tune of (5.73, 7.10 and 14.03, 19.32 per cent, respectively) over NG applied @ 500 kg ha^{-1} as basal dose, which served as control.

Significantly higher yield with split application of 625 kg SBG ha^{-1} attributed to the applied calcium and sulphur resulted in increased synthesis sulphur containing amino acids, proteins and cell wall development (Kumar *et al.*, 2011). Besides Ca and S, SBG also supplies P, Si, Fe and Zn in higher proportion compared to NG and it can be attributed to higher yield in SBG receiving treatments than control (Prakash *et al.* 2021). Sumner (1993) also found that gypsum applied to acidic soils resulted substantial increases in yield of different crops.

The basic concept of application of SBG as basal + split was mainly to coincide with peak period of Ca and S requirements of groundnut. The availability of nutrients from applied gypsum mainly depends on the type of soil and dissolution of gypsum. Further, pods are the key organ for Ca uptake and play a major role in kernel development (Patro and Ray, 2016). However, pods are poor absorbers of Ca

Table 2: Composition of slag based gypsum (SBG) and natural gypsum (NG).

Parameters	SBG	NG
pH(1:2.5)	8.15 ± 0.18	4.92±0.03
Ca^{2+} (%)	22.65±1.28	23.12±1.07
Mg (%)	0.851±0.13	0.082±0.007
SO_4^{2-} (%)	16.91±0.24	17.95±0.31
P_2O_5 (%)	0.32±0.02	Nil
SiO_2 (%)	3.41±0.64	1.37±0.59
Iron (%)	5.45±0.49	0.03±0.004
Mn (%)	0.086±0.001	0.002±6.44×10^{-5}
Zn (%)	0.37±0.02	0.004±0.001

(± value indicates the standard deviation. Each value represents the mean value of three replications).

Table 3: Effect of graded levels and time of application of SBG on yield of groundnut.

Gypsum sources	Time of application	Rate of application (kg ha^{-1})	Pod yield	% increase/decrease of pod yield over NG application	Kernel yield	% increase/decrease of kernel yield over NG application	Haulm yield	% increase/decrease of haulm yield over NG application
NG	Basal	500	25.09±0.17 c	-	47.76±3.78 b	-	17.26±1.94 bcd	-
SBG		375	22.65±0.14 d	-9.73	45.85±3.91 b	-3.99	15.65±0.94 d	-9.30
	Basal	500	25.37±0.89 bc	1.13	46.41±4.12 b	-2.83	17.43±0.91 bcd	0.99
		625	27.09±1.20 ab	7.97	50.17±4.79 ab	5.05	19.40±0.53 ab	12.41
		375	24.26±1.59 cd	-3.31	46.78±3.20 b	-2.05	16.90±0.62 cd	-2.07
	Split	500	26.06±0.48 bc	3.88	50.5±2.82 ab	5.73	18.49±1.77 abc	7.10
		625	28.01±1.16 a	11.62	54.46±2.63 a	14.03	20.59±0.48 a	19.32
SEm±			0.61		1.53		0.8	
LSD (P <0.05)			1.89		4.72		2.46	

Each value represents the mean value of three replications; values having same letters do not differ significantly at P≤0.05 according to LSD test; Basal application was done at the time of sowing and split application was done at two intervals (50% at sowing and 50% at peg initiation stage).

NG- Natural gypsum, SBG- Slag-based gypsum.

and hence they require significant Ca content in soil. Calcium absorbed by the roots is not channeled to the developing pods because of the subterranean nature of groundnut. Thus, the application of SBG as basal + split (50% at sowing and 50% at peg initiation stage) supplies required amount Ca and S during peak demand period and pod formation stage consequently, enabling higher nutrient uptake and higher pod, kernel and haulm yield (Kannan *et al.* 2017).

Oil and protein yield of groundnut

With regard to quality of groundnut kernels (Fig 1), split application of 625 kg ha^{-1} of SBG significantly recorded higher oil and protein yield (7.06 and 8.96 q ha^{-1}, respectively). However, significantly lower oil and protein yield (4.75 and 6.31 q ha^{-1}, respectively) in the treatment with application of 325 kg SBG ha^{-1} as basal.

The increase in oil and protein yield with SBG application was mainly ascribed to applied sulphur through SBG and higher nutrient uptake. Further, the increase in oil yield might be due to increase in glucoside, which on hydrolysis produce higher amount of oil (Patra *et al.* 2012). The higher protein yield may attribute to the optimum levels of sulphur in the plants are known to enhanced nitrogen uptake which might improves protein synthesis. Higher oil and protein yield of groundnut in split application of SBG ascribed to the higher uptake of Ca and S and timely availability of these nutrients during peak growing period.

Soil pH

A close look of soil pH data revealed that graded levels (375, 500 and 625 kg ha^{-1}) of SBG application had not varied significantly in both the seasons and it was presented in Table 4. In the present study, unit increase of soil pH was very little *i.e* 0.07 and 0.12 in *kharif* 2018 and 2019, respectively was recorded with split application of 625 kg ha^{-1} of SBG.

In general, gypsum is widely known not to correct soil acidity because their solubility products do not produce OH^- nor does it consume H^+ ion (Prakash *et al.* 2021). Small increase of soil pH was also previously reported by other authors of Khandu *et al.* (2022) in rice of acidic soil; Prakash *et al.* (2020) in maize of acidic and neutral soil. NG did not increase the soil pH whereas SBG increased it in both the season might be due to its alkaline nature. However, split application of SBG resulted increase in soil pH may attributed to stabilization of applied gypsum.

Soil EC

EC of post-harvest soils of groundnut varied significantly during *kharif* 2018. In general, split application of SBG at higher rate (625 kg ha^{-1}) noticed higher EC than basal application of SBG in both the seasons. Increased soil EC was attributed to elevated levels of sorbed SO_4^{-2} and Ca^{2+} after the SBG application, which increases slightly more electrolyte concentration in the soil solution by replacing some exchangeable Na^+ from the soil colloid (Prakash *et al.* 2020).

Available P_2O_5

Significantly higher available P_2O_5 content in *kharif* 2018 (19.42 kg ha^{-1}) and 2019 (229.08 kg ha^{-1}) was recorded with the split application of 625 kg ha^{-1} of SBG (Table 5). The use of SBG increased available P_2O_5 content as a result of its containing about 0.32% of this element. Increase in available P_2O_5 with increased levels of SBG might be due to increased pH of post-harvest soils. Owino-Gerroh and

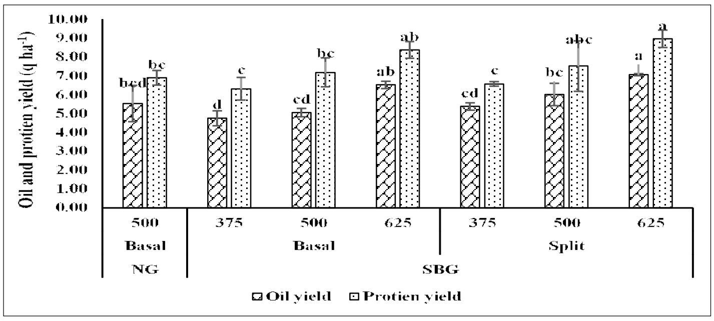

Fig 1: Effect of graded levels and time of application of SBG on oil and protein yield of groundnut is not clear.

Table 4: Effect of graded levels and time of application of SBG on pH and electrical conductivity of post- harvest soils of groundnut.

Gypsum sources	Time of application	Rate of application (kg ha^{-1})	pH 2018	pH 2019	EC (m Sm^{-1}) 2018	EC (m Sm^{-1}) 2019
NG	Basal	500	5.64	4.76	39.07 ab	98.27
SBG	Basal	375	5.70	4.82	38.93 ab	96.30
		500	5.68	4.86	40.70 a	98.07
		625	5.51	4.89	41.90 a	100.30
	Split	375	5.64	4.85	37.30 bc	102.53
		500	5.83	4.90	35.90 c	104.00
		625	5.84	4.92	40.23 ab	106.57
SEm±			0.17	0.03	0.98	2.55
LSD (P<0.05)			NS	NS	3.02	NS

Each value represents the mean value of three replications; values having same letters do not differ significantly at P≤0.05 according to LSD test; Basal application was done at the time of sowing and split application was done at two intervals (50% at sowing and 50% at peg initiation stage).

NG- Natural gypsum, SBG- Slag-based gypsum.

Table 5: Effect of graded levels and time of application of SBG on available P_2O_5, available S, exchangeable Ca and Mg of post-harvest soils of groundnut.

Gypsum sources	Time of application	Rate of application (kg ha^{-1})	Available P_2O_5 (kg ha^{-1}) 2018	Available P_2O_5 (kg ha^{-1}) 2019	Available S (kg ha^{-1}) 2018	Available S (kg ha^{-1}) 2019	Exchangeable Ca (c mol (p^+) kg^{-1} soil) 2018	Exchangeable Ca (c mol (p^+) kg^{-1} soil) 2019	Exchangeable Mg (c mol (p^+) kg^{-1} soil) 2018	Exchangeable Mg (c mol (p^+) kg^{-1} soil) 2019
NG	Basal	500	16.46 d	217.09 a	24.37 c	15.88 e	2.95 bc	1.67 c	1.23 a	0.56 b
SBG	Basal	375	16.52 d	205.26 b	24.61 bc	17.28 d	2.74 cd	1.68 c	0.77 c	0.57 b
		500	17.44 cd	219.92 a	24.37 c	18.39 cd	2.97 b	1.72 c	0.64 c	0.67 b
		625	17.84 bc	224.11 a	26.04 ab	18.95 c	3.15 ab	1.86 b	0.79 c	0.67 b
	Split	375	17.86 bc	150.45 d	23.65 c	17.83 cd	2.70 d	1.69 c	0.73 c	0.62 b
		500	18.62 ab	186.71 c	26.52 a	20.34 b	2.98 b	1.75 bc	0.78 c	0.77 ab
		625	19.42 a	229.08 a	27.00 a	21.74 a	3.29 a	1.99 a	1.04 b	1.05 a
SEm±			0.33	4.39	0.53	0.39	0.07	0.04	0.05	0.09
LSD (P<0.05)			1.04	13.53	1.65	1.21	0.22	0.12	0.18	0.28

Each value represents the mean value of three replications; values having same letters do not differ significantly at P≤0.05 according to LSD test; Basal application was done at the time of sowing and split application was done at two intervals (50% at sowing and 50% at peg initiation stage).

NG- Natural gypsum, SBG -Slag-based gypsum.

Gascho (2004) observed that the application of soluble Si in acid soil could increase the amount of available P_2O_5 through decreasing adsorption of P.

Available S

Among the different treatments, split application of 625 kg SBG ha^{-1} recorded significantly higher available S content in during *kharif*-2018 and 2019 (27.00 and 21.74 mg kg^{-1}, respectively) and lower available S content (23.65 mg kg^{-1}) was recorded with split application of 375 kg SBG ha^{-1} during *kharif* - 2018 and (15.88 mg kg^{-1}) during *kharif*-2019 with basal application of 500 kg ha^{-1} NG. Increased available S in post-harvest soil of groundnut was expected in split application of SBG is ascribed to the high solubility of added SBG due to its smaller particle size (Prakash *et al.* 2021). In acid soil, Sulphur applied through FGD gypsum and from other sources converts sulphite into sulphate through oxidation process in turn it increases the sulphates content in soil solution (Baligar *et al.* 2011).

Exchangeable Ca^{2+} and Mg^{2+}

The variation in soil Ca^{2+} and Mg^{2+} content after basal and split application of different levels of SBG and NG are shown in Table 5. The content of Ca^{2+} and Mg^{2+} during *kharif*-2018 and 2019 significantly increased with increased levels of SBG and found higher with the split application of 625 kg SBG ha^{-1}, respectively during *kharif* 2018 and 2019 (3.29 and 1.99 c mol (p^{+}) kg^{-1} soil, respectively). Among the treatments significantly higher Mg^{2+} content was observed with application of 500 kg NG ha^{-1} in *kharif*-2018 and in split application of 625 kg SBG ha^{-1} in in *kharif*-2019 (1.23 and 1.05 c mol (p^{+}) kg^{-1} soil, respectively). During *kharif*-2018, significantly lower Ca^{2+} and Mg^{2+} content (2.70 and 0.64 c mol (p^{+}) kg^{-1} soil, respectively) was noticed with the split application of 375 kg SBG ha^{-1} and basal application of 500 kg SBG ha^{-1}, respectively. Basal application of 500 kg NG ha^{-1} recorded lower Ca^{2+} and Mg^{2+} content (1.67 and 0.56 c mol (p^{+}) kg^{-1} soil, respectively) during *kharif*-2019. The higher availability of Ca and Mg due to split application of SBG in acid soils may ascribed to increased base saturation of acid soils and also due to release Ca^{2+} during decomposition of SBG and increased nutrient availability through timely supply of Ca and Mg at sowing and peg initiation stage. The movement of exchangeable Ca^{2+} and Mg^{2+} in the soil as a result of gypsum application varies according to the rates applied, reaction time and soil type. There was a linear increase in exchangeable Ca content with gypsum rates in both the season (*kharif* 2018 and 2019) which can also be supported by previous findings of Mupangwa and Tagwira 2005 and Caires *et al.* (2006).

DTPA extractable micronutrients

Among different treatments significantly higher DTPA extractable Fe (24.63 and 23.38 mg kg^{-1}, respectively) was recorded with the split application of 625 kg SBG ha^{-1} in both *kharif*-2018 and *kharif*-2019. Significantly higher Mn content was (1.96 mg kg^{-1}) recorded with the split application of 500 kg SBG ha^{-1} during *kharif*-2018 (Table 6). However, during *kharif*-2019 higher Mn content (33.05 mg kg^{-1}) was noticed with the split application of 625 kg SBG ha^{-1}. Significantly lower Fe and Mn content was recorded with the basal application 375 kg SBG ha^{-1} during *kharif*-2018 and *kharif*-2019.

In post-harvest soil DTPA extractable Zn content vary significantly during *kharif*-2018 and *kharif*-2019. However, DTPA extractable Cu content didn't vary significantly during *kharif*-2018. Higher DTPA extractable Zn (1.98 mg kg^{-1}) and Cu (0.19 mg kg^{-1}) was recorded with Basal application of 625 kg SBG ha^{-1} during *kharif*-2018. While, during *kharif* 2019 higher DTPA extractable Zn (1.09 mg kg^{-1}) and Cu (1.61 mg kg^{-1}) content was recorded with split application of 625 kg SBG ha^{-1}.

In general application of SBG increased DTPA extractable micronutrient content in soil. It might be attributed to higher micronutrient content of applied SBG, specifically its iron (5.45 %) and manganese (0.086 %) content (Ashrit *et al*. 2015). External application of Ca and Mg decrease

Table 6: Effect of graded levels and time of application of SBG on DTPA extractable Fe, Mn, Zn and Cu of post-harvest soils of groundnut.

Gypsum sources	Time of application	Rate of application	Fe		Mn		Zn		Cu	
			(mg kg^{-1})							
			2018	2019	2018	2019	2018	2019	2018	2019
NG (kg ha^{-1})	Basal	500	16.80 d	20.21 c	1.62 cde	29.25 bc	1.59 b	0.78 c	0.17	1.58 a
		375	20.45 c	20.18 c	1.51 e	26.33 c	1.61 b	0.83 c	0.16	1.46 c
SBG (kg ha^{-1})	Basal	500	21.52 bc	22.28 ab	1.56 de	30.03 ab	1.66 b	0.94 b	0.15	1.49 bc
		625	23.17 ab	23.1 a	1.90 ab	32.94 a	1.98 a	1.05 a	0.19	1.58a
		375	20.00 c	21.29 bc	1.73 bcd	30.48 ab	1.58 b	0.83 c	0.16	1.5 bc
	Split	500	23.80 a	22.84 a	1.96 a	31.11 ab	1.59 b	0.99 ab	0.17	1.54 ab
		625	24.63 a	23.38 a	1.83 abc	33.05 a	1.71 b	1.09 a	0.17	1.61 a
SEm±			0.63	0.46	0.07	1.10	0.05	0.03	0.009	0.02
LSD (P<0.05)			1.94	1.44	0.22	3.40	0.16	0.1	NS	0.07

Each value represents the mean value of three replications; values having same letters do not differ significantly at P≤0.05 according to LSD test; Basal application was done at the time of sowing and split application was done at two intervals (50% at sowing and 50% at peg initiation stage).

NG- Natural gypsum, SBG- Slag-based gypsum.

Table 7: Effect of graded levels and time of application on nutrient use and uptake efficiency in groundnut.

Gypsum sources	Time of application	Rate of application (kg ha^{-1})	Nutrient use efficiency (kg kg^{-1})			Nutrient uptake efficiency (kg kg^{-1})		
			Sulphur	Phosphorus	Calcium	Sulphur	Phosphorus	Calcium
NG	Basal	500	26.25 c	24.56 a	22.28 c	0.31 c	0.17 bc	0.97 de
SBG	Basal	375	31.87 ab	21.66 a	27.08 ab	0.37 ab	0.16 c	1.22 ab
		500	27.63 bc	24.43 a	22.97 c	0.32 bc	0.18 bc	1.04 cde
		625	25.31 c	27.21 a	20.60 c	0.31 c	0.21 ab	0.96 e
	Split	375	33.98 a	22.87 a	28.93 a	0.39 a	0.16 c	1.29 a
		500	28.98 bc	25.40 a	24.13 bc	0.37 ab	0.18 bc	1.15 abc
		625	26.43 c	28.04 a	21.55 c	0.36 ab	0.24 a	1.12 bcd
SEm±			1.61	1.68	1.31	0.01	0.01	0.05
LSD (P<0.05)			4.98	NS	4.04	0.05	0.04	0.15

Each value represents the mean value of three replications; Values having same letters do not differ significantly at P≤0.05 according to LSD test; Basal application was done at the time of sowing and split application was done at two intervals (50% at sowing and 50% at peg initiation stage).

NG- Natural gypsum, SBG- Slag-based gypsum.

the adsorption of Zn and Cu thereby increase their availability in soil (Zhu and Alva 1993). Applied gypsum sources increase the SO_4^{2-} concentration in the soil solution which could convert Mn-containing minerals such as manganite to $Mn_2(SO_4)_3$, where Mn is present in the oxidized form (Mn^{3+}). Thus, addition of gypsum sources increases the solubility of $Mn_2(SO_4)_3$ thereby increasing the Mn availability in the neutral soil (Elrashidi *et al.* 2010).

Nutrient use efficiency and uptake efficiency

Nutrient use efficiency of calcium and sulphur varied significantly with the basal and split application of gypsum to groundnut (Table 7). The higher sulphur and calcium use efficiency (33.98 and 28.93 kg produce/kg S and Ca utilized, respectively) was recorded with split application of SBG @ 375 kg ha^{-1} and found to be on par with the treatment with basal application of SBG @ 375 kg ha^{-1}. The minimum sulphur and calcium use efficiency (25.31 and 20.60 kg produce/kg S and Ca utilized, respectively) was noticed with the application of 625 kg ha^{-1} SBG as basal.

Basal and split application of SBG significantly influenced the nutrient (S and Ca) uptake efficiency among the different treatments. Significantly higher S and Ca uptake efficiency of 0.39 and 1.29 kg kg^{-1} was recorded with application of SBG @ 375 kg ha^{-1} as split respectively. In general, split application of SBG recorded higher ca and S nutrient uptake efficiency when compared to basal application.

Better nutrient use and uptake efficiency of sulphur and calcium with split application of SBG might be due to better utilization and uptake of nutrients by the crop. The lower use efficiency of sulphur may attributed to the leaching losses, higher mobility, adsorption and higher oxidation rate of sulphur prior to plant uptake in soils having pH <5.0. Acid soils with low base saturation have high leaching capacity and usually show lower use efficiency (McLay and Ritchie 1995). Further, the use efficiency of applied sulphur normally varied from 8-12% in different crops. Blake-Kalff *et al*. 1998 reported that, oil seed crops have ineffective xylem-to-phloem transfer of SO_4^{2-}, because of its higher accumulation in the vacuoles of the mature leaves compared with the middle or younger leaves. The results evidently suggested that the oilseed crops are inherently inefficient in S utilization within the plant.

CONCLUSION

This study highlights the importance of split application of slag-based gypsum, nutrients uptake and its use efficiency. Experimental results reveal that split application of 625 kg SBG ha^{-1} recorded higher pod, kernel, haulm, oil and protein yield when compared to other treatments. Further, higher nutrient content in post-harvest soils were noticed with the split application of 625 kg SBG ha^{-1}. Higher uptake and use efficiency of Ca and S were recorded in treatment which received 375 kg SBG ha^{-1} as split. However, uptake and use efficiency of P were noticed in treatment which received 625 kg SBG ha^{-1} as split. Therefore, split application of slag based gypsum may be considered as best strategy to increase overall productivity of groundnut by improving soil and crop nutritional status.

Conflict of interest: None.

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