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ORIGINAL ARTICLE

RESPONSE OF GROUNDNUT (*Arachis hypogaea L.*) TO VARYING RATES OF SULPHUR APPLICATION IN SELECTED SOILS OF NASARAWA STATE, NIGERIA

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ABSTRACT

Laboratory and pot experiments were conducted to evaluate the response of groundnut to the application of different rates of Sulphur in selected soils of Nasarawa State. The soils were from Awonge, Kawo, Doma North, Burum-Burum Road, Alwaza waje and Alwaza town. Four extractants (distilled water, 0.010M LiCl, 0.016 M KH_2PO_4 and 0.010M Ca (HPO_4) were evaluated for the determination of available Sulphur on these soils. The pot experiment considered at 5 Sulphur levels (0, 10, 20, 30 and 40kg S ha^{-1}) applied as K_2SO_4. The treatments were replicated three times and laid in a complete randomized design. The crop was grown in the pots and harvested after 12 weeks. The results showed that groundnut responded significantly to the applied rates of Sulphur in all the soils tested. The soils were low in their total S content and ranged from 17.12mg kg^{-1} in Kawo to 68.83mg kg^{-1} at Alwaza town. The KH_2PO_4 extractable-S varied from 0.23mg kg^{-1} in Kawo to 1.06mg kg^{-1} in Alwaza Waje. Water soluble S ranged from 0.9mg kg^{-1} in Awonge to 49.8mg kg^{-1} in Burum Road. On the average, the water-soluble S constituted 69.50% of total Sulphur. While the KH_2PO_4 extractable-S constituted 1.24% total Sulphur. The S content was significantly related to soil organic matter and clay content of soils. Similar trends of results were observed on farmer's field. Among the extractants evaluated 0.010M LiCl and 0.016 M KH_2PO_4 related significantly and positively with the yield parameters. The critical level of Sulphur for groundnut production was found to be 0.48mg kg^{-1} when KH_2PO_4 was used as an extractant. It was concluded that response to Sulphur application may be probable in soils of Kawo, Doma North and Burum-Burum Road, while response to applied S may not probable with soils of Alwaza Town and Alwaza Waje. 0.016 M KH_2PO_4 may be taken as the best extractant for available S in these Soils.

KEYWORDS: *Groundnut, rate, Sulphur, soils, pot*

INTRODUCTION

Sulphur (S) as a yield limiting nutrient factor is becoming increasingly important in many Nigerian soils. Occurrences of deficiency in various crops are becoming more frequent and extensive (Kang *et al.*, 2009; Adetunji and Adepetu, 2010; Obasi *et al.*, 2023). Soil Sulphur studies in Nigeria were pioneered by Greenwood (2019) and popularized by Bromfield (2021). Most of their studies were on groundnut and other legume crops in Northern Nigeria where they obtained significant response to the applications of Sulphur by the crops studied. Since then, other workers (Enwezor, 2019; Kang *et al.*, 2010; Adetunji and Adepetu, 2012, Obasi *et al.*, 2023) have reported responses of various crops in other agro-ecological

zones of Nigeria to the application of Sulphur. Groundnut (*Arachis hypogaea* L) is one of the cash crops grown in Nasarawa State. It is normally grown in rotation to improve the soil nutrients because of its ability to fix nitrogen. It is preferred to rice because of its relatively low labour in terms of weeding and the perennial problem of birds experienced in rice production. Apart from being a cash crop, it is consumed in large quantities in various forms and serves as one of the major sources of dietary protein. Sulphur is a constituent of methionine, cysteine and all of which are essential amino acids. In the past, it was being added to the soil through the application of single super phosphate which apart from supplying phosphorus also contains about 23% Sulphur and through sulphate of ammonium which contain more than 20% Sulphur. However, with the increase in the use of high analysis fertilizers, many Sulphur free fertilizers are now available in the market. Moreover, Sulphur containing pesticides that was commonly used in the past have largely been replaced by organic materials free of Sulphur. Nevertheless, the practice of slash and burn agriculture which leads to Sulphur loss is still very common among the people. Despite all these, the general assumption that Sulphur deficiency is not widespread and therefore does not constitute a significant problem to crop yield still persists. This may be particularly so in many Nigerian soils, especially where information on Sulphur status is unavailable. Nasarawa State falls in that category. More work is required in order to accurately predict Sulphur needs of various crops in different ecological zones of Nigeria. Therefore, this study evaluated response of groundnut to different rates of S application in selected soils of Nasarawa State.

MATERIALS AND METHODS

The experiments involved laboratory studies, pot experiment and fields observation. Surface soil sample (0-15cm) were collected from six sites namely: Awonge, Kawo, Doma North, Burum-Burum road site, Alwaza Waje and Alwaza Town corresponding to four different parent materials on the groundnut producing area of Nasarawa State that have no previous history of S fertilization.

Laboratory Analysis

Sub samples of the soils were sieved to pass 2mm sieve for laboratory and pot experiments. The samples were analysed for the physical and chemical parameters using standard procedure. Four extractants were evaluated for the determination of available Sulphur. These were distilled water, 0.10 M Li CL, 0.016 M KH_2PO_4 and 0.10 M Ca $(HPO_4)_2$. Each extractant was employed for the extraction of available S in all the samples. Sulphur Solution or water-soluble Sulphur was extracted in distilled water and determined turbidimetrically as $BaSO_4$. Surface adsorbed S was estimated as the difference between available S and water-soluble S. available S was taken as the 0.016 M KH_2PO_4 extractable S. Total soil S was determined by digesting the samples using wet acid digestion (Page *et al.* 2019) activated charcoal, 0.05g per $25cm^3$ of the extracts and digest was used for decorating the extracts and or digest; while gelatin was used as a stabilizer. Sulphur in the extracts and or digest was determined turbidimetrically as $BaSO_4$ (Anjembe and Adetunji, 2022).

Pot Experiment

Sub samples of the sieved soils (4kg) were weighed into 20cm diameter experimental pots. Five levels of Sulphur (0, 10, 20, 30 and 40kg S ha^{-1}) were added as KSO_2SO_4. The treatments were replicated three times and pots were arranged in a complete randomized design.

The local variety (Ada-mma) of groundnut which is upright and early maturing was planted on the 11th June, 2016 and harvested on the 10th September, 2016 (12WAP).

Agronomic data (i.e. plants samples such as leaves, stems and grain yields) were collected and analysed to determine the response of groundnut to S application. The yield parameters were measured at harvest as follows; fresh weight biomass pot^{-1}, number of pods $plant^{-1}$, fresh weight of pods $plant^{-1}$, seed weight $plant^{-1}$.

Fields Observation

Six farmers' fields cultivated with groundnuts as a sole crop were selected to verify the findings of the pot experiment. On each farmer's farm, an area of land covering 5m × 5m was measured. Soil sample were taken from the measured area. Yield of groundnut from that area was collected and weighed. The soil sample taken from that area was analysed for extractable Sulphur using the four extractants. The Sulphur values were then correlated with the yield of groundnuts.

Data Analysis

Data collected was subjected to analysis of variances to test the significance of the treatments effect on the response of the crop in the pot and observation in the farmer's field. The amount of Available Sulphur extracted by the four extractants was correlated with the groundnut yield both in the pot experiment and farmer's field with the aim of determining the best extractant.

RESULTS

Properties of the soils investigated in the study are shown on Table 1. The pH ranged from 5.82 at Awonge to 6.68 at Burum-Burum Road with a mean value of 6.25. Clay content ranged from 9.8 % at Awonge and Burum-Burum Road to 13.8% at Doma North, Alwaza Town and Alwaza Town and Alwaza Waje. The soils were loam, sand and sandy-loam in texture. Organic matter content varied widely from 1.34 at Burum-Burum Road site to 1.85% at Doma North with a mean value of 1.60%. Total nitrogen ranged from 0.14% at Awonge to 0.28% at Alwaza Waje and Burum-Burum road with a mean value of 0.21%. Bray-1 P values ranged from 3.28 mg kg^{-1} at Alwaza town to 3.62 mg kg^{-1} at Doma North with a mean value of 3.45 mg kg^{-1}. Exchangeable acidity ranged from 0.33cmol kg^{-1} at Doma North to 1.66cmol kg^{-1} at Kawo. Cation exchange capacity varied from 4.78cmol kg^{-1} at Kawo to 6.35cmol kg^{-1} at Awonge.

Table 1: Some Properties of the Experimental Soils

Location	pH 1:2 H_2O	% Clay	Texture	% O.M	% N	(mg/kg) Av. P	Exchangeable Cations (CMol/kg)					
							Ca	Mg	Na	K	E.A	CEC
Awonge	5.82	9.8	LS	1.51	0.14	3.45	3.82	2.11	0.11	0.31	0.83	6.35
Kawo	6.41	11.8	LS	1.41	0.21	3.38	2.38	1.89	0.23	0.28	1.66	4.78
Doma North	6.47	13.8	SL	1.85	0.21	3.62	2.43	2.01	0.21	0.35	0.33	5.00
B/B Road	6.68	9.8	LS	1.34	0.28	3.32	2.35	2.03	0.23	0.34	1.50	4.95
Alwaza Town	6.52	13.8	SL	1.65	0.21	3.28	2.38	1.98	0.28	0.29	0.83	4.93
Alwaza Waje	6.40	13.8	SL	1.44	0.28	3.41	2.56	2.00	0.30	0.32	0.50	5.18

Sulphur fractions of the experimental soils are shown on Table 2. The total S values ranged from 45.0mg kg^{-1} at Awonge to 165.0mg kg^{-1} at Alwaza town. The Potassium Hydrogen Phosphate Extractable S varied from 0.23mg kg^{-1} at Burum-Burum Road to 1.06 mg kg^{-1} at Alwaza Waje. Water Soluble Sulphur varied from 0.98 mg kg^{-1} at Awonge to 49.81mg kg^{-1} Burum-Burum Road. On the average the water-soluble S constituted about 28.13% of the Total soil S, LiCl extractable S constituted 10.58% of the total S and Ca $(HPO_4)_2$ extractable constituted 0.50% the total Sulphur.

Evaluation of Extractants for Sulphur in the Experiment Soils

Amount of S extracted by the various extractants in the experimental soils showed that water extracted 49.81mg kg^{-1} of Sulphur from Burum-Burum Road soil (Table 2). This was the highest amount extracted by this extractant from the experimental soils. This was followed by Doma North (49.07mg kg^{-1}) Alwaza Waje (46.5 mg kg^{-1}), Alwaza town (43.58mg kg $^{-1}$) and Kawo (3.87 mg kg^{-1}) While the least amount of 0.98 mg kg^{-1} was extracted the highest amount of 20.86 mg kg^{-1} from Alwaza town, this was followed by 14.86 mg kg^{-1} from Awonge, 12.30 mg kg^{-1} from Doma North, Kawo 10.66mg kg^{-1} and Alwaza-waje 10.57mg kg^{-1} each. While the least amount of 3.63mg kg^{-1} was extracted from Burum-Burum Road. 0.010M Ca $(HPO_4)_2$ extracted the highest amount of Sulphur (3.43 mg kg^{-1}) from Alwaza town. This was followed by 1.42mg kg^{-1} from Doma North 1.33 mg kg^{-1} from Alwaza-waje, 1.16mg kg^{-1} was extracted from Burum-Burum Road, 0.84mg kg^{-1} from Kawo and the least amount was extracted from Awonge. 0.016 M KH_2PO_4 extracted (1.06mg kg^{-1}) in Alwaza-waje, this was followed by Alwaza-town (0.96mg kg^{-1}), 0.69mg kg^{-1} was extracted from Awonge, 0.29mg kg^{-1} from Kawo while the least amount of 0.23mg kg^{-1} was extracted from Burum-Burum Road. Water extracted the highest amount of 49.8mg kg^{-1} from Burum-Burum Road. The least amount of 0.98mg kg^{-1} was extracted from Awonge. 0.010M LiCl extracted the highest amount of 20.86mg kg^{-1} from Alwaza-town, 0.010M Ca $(HPO_4)_2$ extracted 3.42mg kg^{-1} from Alwaza-town, while 0.59mg kg^{-1} was extracted from Awonge, 0.016M KH_2PO_4 extracted 1.06 from Alwaza-waje, the least (0.23mg $kg^{-1)}$ was extracted from Burum-Burum Road.

For the relationship, there was no significant ($p>0.05$) difference between Burum-Burum Road and Kawo in 0.016 M KH_2PO_4 for total S, there was significant difference ($p<0.05$) in Kawo and Alwaza Town while there was no significant difference in others.

Table 2: Amount of S extracted by the various Extractants in the Experimental Soils (mg kg^{-1})

Location	Extractants				
	Water	0.10 M LiCl	0.010M $Ca(HPO_4)$	0.016 M KH_2PO_4	Total S
Awonge	0.98	14.86	0.59	0.69	17.12
Kawo	3.87	10.66	0.84	0.24	15.61
Doma North	49.07	12.30	1.42	0.29	63.08
Burum-Burum Road	49.81	3.63	1.16	0.23	54.83
Alwaza-Town	43.58	20.86	3.43	0.96	68.83
Alwaza-waje	46.52	10.57	1.33	1.06	59.48
LSD ($p<0.05$)	0.03	0.03	0.04	0.02	0.01

At Awonge the highest fresh weight of biomass (116.1g) was obtained when 40kg ha^{-1} was applied as compared to other treatments (Table 3). In Kawo area, 10kg ha^{-1} S treatment produced the highest fresh

weight of biomass of 58.85g significantly greater ($p<0.05$) when compared to other treatments applied. However, in Doma North the highest fresh biomass of 77.55g was obtained when the soil in the pot received 40kg ha^{-1} S and was significantly different ($p>0.05$) from other treatments. Burum-Burum Road recorded the highest fresh weight of biomass yield of 80.60 g when 20kg ha^{-1} S was applied to the soil. The least biomass was 57.3g at the control. Application beyond 20kg ha^{-1} S progressively decreased the biomass yield at this location. At Alwaza-town 30kg ha^{-1} had the highest biomass of 63.35g which was significantly higher ($p<0.05$) than 20kg ha^{-1} S with a mean value of 58.4g and the least value of 55.0g was obtained from 40 kg S ha^{-1}. Similar trend of result was observed at Kawo and Alwaza-waje when 10kg S ha^{-1} was applied to the soil producing the highest fresh weight of biomass (66.35g) significantly higher than other treatments applied at the locations.

Table 3: Effects of Sulphur on the Fresh Groundnut Biomass in the Pot Experiment

Sulphur (Kg/ha)	Awonge	Kawo	Doma North	Burum-Burum	Alwaza-town	Alwaza-waje
0	76.10 ± 0.60^{c}	38.70 ± 0.50^{d}	67.15 ± 0.35^{b}	57.25 ± 0.05^{c}	61.35 ± 0.05^{ab}	45.10 ± 0.40^{e}
10	66.05 ± 0.35^{d}	58.85 ± 0.55^{a}	66.25 ± 0.45^{b}	67.30 ± 0.50^{c}	58.95 ± 0.55^{bc}	66.35 ± 0.45^{a}
20	76.50 ± 0.50^{c}	45.65 ± 0.05^{c}	43.10 ± 0.40^{c}	80.60 ± 0.60^{a}	55.00 ± 0.00^{c}	50.00 ± 0.20^{d}
30	85.00 ± 1.00^{b}	54.41 ± 1.38^{b}	64.60 ± 0.80^{b}	74.55 ± 0.85^{b}	63.35 ± 0.15^{a}	60.85 ± 0.15^{b}
40	116.15 ± 0.35^{a}	57.00 ± 1.00^{ab}	77.55 ± 1.75^{a}	61.90 ± 0.40^{d}	55.50 ± 2.50^{c}	54.85 ± 1.55^{c}
P-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

a,b,c,d: Means on the same column with different superscript are statistically significant ($p<0.01$).

Fresh weight of pods obtained in the experimental soils is shown on Table 4. At Awonge the highest pod yield of 23.0g was obtained when 10kg S ha^{-1} was applied to the soil this is equivalent to 12.15tons per ha^{-1} was significantly different from all the other treatments in this location. Increasing the Sulphur rate beyond 10kg S ha^{-1} progressively reduced the pod yield. Application of 20kg S ha^{-1} produced significantly the highest pod yield of 16.50g. This is equivalent to 8.10tons per. Application beyond 20 kg S ha^{-1} significantly reduced the pod yield at this location. In Doma North, the highest pod yield of 36.10 g was obtained when 10 kg S ha^{-1} was applied to the soil. This is equivalent to 18.07tons S ha^{-1} significantly different from the other treatments applied (20, 30 and 40 kg S ha^{-1}) respectively. Increasing the Sulphur rate beyond 10kg S ha^{-1} significantly decreased ($p<0.05$) the pod yield at the location. Meanwhile, at Burum-Burum Road 21.80g was recorded when 30kg S ha^{-1} was applied.

Table 4: Effects of Sulphur Rates on the Fresh Weight of Pods (g/plant) in Pot Experiment

Sulphur (S) (Kg/ha)	Awonge	Kawo	Doma North	Burum-Burum	Alwaza-town	Alwaza-waje
0	17.50 ± 050^{b}	11.50 ± 0.50^{b}	14.70 ± 0.50^{c}	14.75 ± 0.05^{c}	12.80 ± 0.40^{b}	12.00 ± 0.50^{c}
10	23.00 ± 1.00^{a}	12.50 ± 0.50^{b}	36.10 ± 0.40^{a}	12.05 ± 0.25^{d}	17.20 ± 0.30^{a}	16.00 ± 0.80^{a}
20	19.30 ± 0.70^{b}	16.50 ± 0.50^{a}	13.10 ± 0.10^{d}	20.55 ± 0.45^{a}	16.85 ± 1.85^{a}	16.60 ± 0.60^{a}
30	21.90 ± 0.50^{a}	11.65 ± 0.65^{b}	16.40 ± 0.10^{b}	21.80 ± 0.50^{a}	13.00 ± 0.50^{b}	14.00 ± 0.20^{b}
40	$17.66\pm0.45^{\mathbf{b}}$	8.85 ± 15^{c}	15.65 ± 0.65^{bc}	17.20 ± 0.40^{b}	11.20 ± 0.50^{b}	14.00 ± 0.30^{b}
P-value	<0.01	<0.01	<0.01	<0.01	0.01	0.01

a,b,c,d: Means on the same column with different superscript are statistically significant ($p<0.01$)

This is equivalent to 11.29tons per ha^{-1}. Application beyond what significantly reduced the pod yield of groundnut plant. Alwaza-town had a pod yield of 16.85g (8.6 ton per ha^{-1}) obtained when 10kg ha^{-1} was applied. But in Alwaza-Waje area, 20kg ha^{-1} S produced the greater pod yield of 16.60g (8.5 tons per ha^{-1}). This was significantly different from all the other treatments applied. Application beyond this rate (20kg S ha^{-1}) significantly reduced the pod yield at this location. Number of pods obtained with the experimental soils is shown on Table 5. At Awonge the highest number of pods (29) recorded when 10kg S ha^{-1} was applied to the soil with the least yield of 11 pods when 40kg S ha^{-1} was applied. At Kawo the greater number of pods (24) was obtained when 20kg S ha^{-1} was applied and the least number of pods (10) was obtained when 10kg S ha^{-1} was applied to the soil. At Doma North the highest yield of 23 pods was produced when 30kg S ha^{-1} was applied. However, 20kg S ha^{-1} produced significantly the highest number of pods (20) at Burum-Burum Road location. Alwaza-town recorded the highest number of pods of 24 pods when 40kg S ha^{-1} was applied to the soil and the least pod yield was 15 at 30kg S ha^{-1} in this location. Decreasing the Sulphur rate progressively reduced the number of pods at this location. At Alwaza-waje the highest number of pods (24) was obtained when 10kg S ha^{-1} applied to the soil. The least value of 16 pods was obtained with 30kg S ha^{-1} which was significantly lower than all the other treatments. Increasing the Sulphur rate progressively reduced the number of pods at this location.

Table 5. Effects of Sulphur Rates on the Number of Pods per Plant in Pot Experiment

Sulphur (S) Kg/ha	Awonge	Kawo	Doma North	Burum-Burum	Alwaza-town	Alwaza-waje
0	20.35 ± 0.65^{c}	15.45 ± 0.15^{c}	12.00 ± 1.00^{c}	16.50 ± 0.50^{d}	20.60 ± 0.30^{b}	21.00±1
10	28.50 ± 0.50^{a}	10.00 ± 0.00^{d}	20.50±0.50ab	18.00 ± 1.00^{b}	20.00 ± 1.00^{b}	24.00±0
20	18.45 ± 0.15^{d}	24.85 ± 0.55^{a}	22.50±0.50a	20.10 ± 0.80^{a}	21.50 ± 0.50^{b}	18.90±0
30	26.00 ± 0.00^{b}	20.00 ± 1.00^{b}	22.55±0.25a	17.50 ± 0.50^{c}	15.50 ± 0.50^{c}	17.00±1
40	11.50 ± 0.50^{c}	25.00 ± 1.00^{a}	19.20±0.90b	18.00 ± 1.00^{b}	23.90 ± 0.10^{a}	19.85±0
P-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

a,b,c,d: Means on the same column with different superscript are statistically significant ($p<0.01$)

At Awonge the highest seed weight of 6.75g was obtained when 10kg S ha^{-1} was applied to the soil (Table 6). This was significantly different from all the other treatments. Application beyond this rate (10kg S ha^{-1}) significantly reduced the seed weight at this location. Kawo had the highest seed weight of 4.20g with 20kg S ha^{-1}. The least seed weight of 2.55 g was recorded when 0kg S ha^{-1} was applied. At Doma North, the highest seed weight of 5.65g was obtained when 10kg S ha^{-1} was applied to the soil. This was significantly different ($p<0.05$) from all the other treatments. Application of 30kg S ha^{-1} produced significantly the highest seed weight of 7.8g at Burum-Burum Road location. This was significantly different from the other treatments (0, 10, 20kg S ha^{-1}) applied respectively. Alwaza-town recorded the highest seed weight of 5.50 g when 30kg S ha^{-1} was applied to the soil and the least seed weight 2.3g was obtained with 10kg S ha^{-1}. At Alwaza-waje location, 20kg S ha^{-1} treatment produced more seed weight of 5.0g significantly higher ($p<0.05$) as compared to other treatments applied.

Table 6. Effect of Sulphur Rates on Seed weight (g/plant) in the Pot Experiment

Sulphur (S) Kg/ha	Awonge	Kawo	Doma North	Burum-Burum	Alwaza-town	Alwaza-waje
0	4.70 ± 0.40^{bc}	2.55 ± 0.05^{b}	4.70 ± 0.20^{b}	3.55 ± 0.05^{c}	3.75 ± 0.05^{c}	3.1^{d}
10	6.75 ± 0.05^{a}	3.65 ± 0.25^{a}	5.65 ± 0.05^{a}	3.90 ± 0.00^{d}	2.30 ± 0.10^{c}	4.9^{b}
20	4.05 ± 0.15^{c}	4.20 ± 0.10^{a}	4.90 ± 0.10^{b}	6.70 ± 0.20^{b}	4.55 ± 0.05^{b}	5.0^{a}
30	6.20 ± 0.10^{a}	4.00 ± 0.10^{a}	3.00 ± 0.10^{c}	7.85 ± 0.05^{a}	5.50 ± 0.10^{a}	4.8^{c}
40	5.10 ± 0.20^{b}	3.65 ± 0.25^{a}	5.40 ± 0.10^{a}	6.10 ± 0.00^{c}	3.10 ± 0.00^{d}	3.0^{e}
P-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

a,b,c,d: Means on the same column with different superscript are statistically significant ($p<0.01$)

Yield Data on Farmer's Field

Groundnut yield data on the farmer's field is showed on Table 7. The results obtained indicated that in all the yield parameters, Awonge soil performed better, this was followed by Doma North in terms of pod yield and number. Alwaza-town soils produced the poorest yield in all the parameters studied.

Table 7. Yield Data on Farmer's Fields

Location	Yield (kg plot $^{-1}$)	Yield (kg ha $^{-1}$)	Yield (tons ha $^{-1}$)
Awonge	2.12	848	0.85
Kawo	1.82	721	0.72
Doma North	2.09	836	0.84
Burum-Burum Road	1.96	787	0.79
Alwaza town	1.24	496	0.49
Alwazawaje	1.26	505	0.50
LSD (<0.05)	0.02	14.82	0.01

Table 7 showed the relationship between extractable sulphur and yield parameters in the experimental soils. The results obtained indicated that extractant (0.010M LiCl S and 0.016M (KH_2PO_4) correlated positively and significantly with all the yield parameters in experimental soil except seed weight and fresh weight biomass which correlated negatively and significantly with distilled water and 0.010M $Ca(HPO_4)$.

Table 8. Relationship between Extractable S and Yield Parameters in the Experimental Soil

	Yield Parameters		
Extractant (S)	Seed Weight (g)	Pod Number	Fresh Biomass (g)
Water S	-0.19	0.26^{**}	-0.05
0.10M LiCl S	0.10	0.02^{*}	0.01
0.10M [$Ca(HPO_4)$]S	-0.10^{*}	0.18^{*}	-0.16^{*}
0.016M [KH_2PO_4] S	0.21^{*}	0.36^{**}	0.05^{*}

***** Indicates statistical significance at 0.05 %, ****** indicates statistical significance at 0.01%

The total Sulphur content of the soils is generally low. However, the range (17.12 to 68.83mg k^{-1}) was within reports of earlier studies (Watson, 2006; Enwezor, 2019; Kang *et al.*, 2022). KH_2PO_4 extractable-strange from 0.2mg kg^{-1} at Burum-Burum road to 1.06mgkg^{-1} at Alwaza Waje with a mean of 0.58mg kg^{-1} which is lower than the mean of 6.7mgkg^{-1} reported by Adetunji, (2022). This is probably due to the fact that the practice of slash and burn is still very common among the people of the state as well as the seasonal

indiscriminate burning of vegetation by wild fires which prevent the accumulation of organic matter that is the store house of most soil nutrient, Sulphur inclusive.

Significant response was observed at all locations with the application of sulphur. The yield values obtained (0.72, 0.49 and 0.50) tons ha^{-1} respectively, from some location such as Kawo, Alwaza-town and Alwaza-waje were relatively very poor. This could be attributed to their initial low Sulphur status which was the lowest among the soil with the total S status of (15.61 and 17.12mg kg^{-1}) at Kawo and Awonge respectively. The KH_2PO_4 extractable-S values were also low. This could probably because of their low organic matter content which is the store house of soil Sulphur. Their clay content is also low in Awonge and Burum-Burum of this is that S released into these soils through the process of mineralization would be leached from the profile due to a limited number of active sites which are provided by clay for adsorption. Thus, the applied Sulphur on these soils could not have been utilized rather, lost through leaching, the sandy nature of these soils helps this loss to a greater extent. Sulphur could be best applied split in these soils as this will guarantee a continuous availability of the nutrient to the crop throughout the growing period. Losses through leaching will also be minimized. It was observed during sampling that these soils were intensively and continuously cropped. Fallowing could be done to allow the soil recover from nutrient depletion. Crop residues management as well as cover cropping could be of enormous benefit.

Doma North, Awonge, Alwaza waje and Alwaza town soils achieved the highest yield in terms of pod yield with 10kg S ha^{-1}. This implies that these soils would require S fertilization up to 10kg S ha^{-1} for optimum production. Kawo soil would produce optimum pod yield with only 20kg S ha^{-1} while pod number will be highest with only 20kg S ha^{-1}. On the whole, Doma North soil is better for groundnut pod production followed by Awonge, Burum-Burum Road, Alwaza town, Alwaza waje and Kawo soil performed worse.

Doma North will still be the best soil if the purpose of production is biomass with Awonge and Burum-Burum road again coming behind. The critical level of S for groundnut production on the experimental soils was found to be 0.48mg kg^{-1}. This implies that at Sulphur values below this, high response to the application of Sulphur fertilizer is probable where as little or no response is expected for soils with 0.016 M KH_2PO_4 extractable (available) Sulphur above this value. This implies that soils in Nasarawa State with available Sulphur values below 0.48mg kg^{-1} are Sulphur deficient. Among the experimental soils, Alwaza town, Awonge, Alwaza Waje, Doma North and Kawo had Sulphur (available) values above 0.48mg kg^{-1}. Increasing that response on these soils is not possible.

The Sulphur values of the experimental soils indicated that Alwaza town soil had the highest Sulphur status with the total Sulphur at 68.83mg kg^{-1}. Doma North followed with 63.08mg kg^{-1}, Alwaza-waje 59.48mg kg^{-1}, Burum-Burum Road had 54.83 mg kg^{-1} and Awonge with 17.12 mg kg^{-1} while Kawo had the least status of 15.61mg kg^{-1}. The amount of S extracted showed that water extracted the highest amount from Burum-Burum Road, Doma North, Alwaza waje and Alwaza town. The amount extracted by water was highest at Alwaza waje followed by Alwaza town and Awonge following the same trend with S status of these soils. However, apart from water that extracted lower values from other locations, the other extractants extracted higher amounts from these locations.

Water extracted more Sulphur than all the other extractants at Burum-Burum Road and Doma North. Water extractable Sulphur values were also higher than LiCl extractable value at Alwaza town and Doma North in the experimental soils and at Alwaza town and Awonge on the farmer's fields respectively. This could probably be as a result of the ability of water to remove more organic Sulphur. Results with water are also known to be inconsistent. This had earlier been reported by Burd (2022), Maynard *et al.* (2023).

Again, the status of the experimental soils indicated that Kawo at Burum-Burum Road. Ca (HPO_4) at Alwaza Town which was the highest across the extracts, KH_2PO_4 extracted the least amount at Burum-Burum Road. Yield data in terms of pod weight shows that the best yield was obtained at Doma North. This was followed by Awonge. However, on the average, Doma North had the best mean yield; the least yield in terms of this parameter was obtained at Alwaza town and Alwaza Waje which was significantly lower than the other soils. The biomass was again best at Awonge ($40kg^{-1}$ ha S) and again least at the level of fertilization at Kawo and Doma north, again following the same trend with the total Sulphur status of the soils and water extractable S. A correlation study on the amount of extractable Sulphur and the yield parameters of the test crops shows that 0.016 M KH_2PO_4 extractable Sulphur correlated positively and significantly with yield parameters. There was a negative and significantly relationship with the yield with distilled water and 0.10 M Ca (HPO_4). This suggests that among the four extractant evaluated (distilled water, 0.016M KH_2PO_4, 0.010M Ca (HPO_4), 0.010M LiCl and 0.016 M KH_2PO_4 are the best extractant for these soils. It was also shows that distilled water and 0.010M Ca (HPO_4) among the four that correlated negatively with the yield of the farmers plots following the same trend in the pot experiment. The order of correlation shows that water >LiCl) >Ca (HPO_4) > KH_2PO_4 in the pot experiment. The data on the farmers plot however indicate that water >LiCl>Ca (HPO_4) > KH_2PO_4, the variation obtained in the order of performance of the extractants between the pot and farmers field could be as a result of some factor that could not be controlled on the farmers' field.

CONCLUSION

It can be concluded that all the soils under investigation are moderates and low in their Sulphur status. The results also showed that groundnut responded significantly to different rates of Sulphur fertilization. The results further revealed that the critical level of Sulphur for the production of groundnut in the soils was established at 0.48mg kg^{-1}. It was also observed that out of the four extractant evaluated for the extraction of available Sulphur in these soils, 0.010M LiCl S and 0.016M KH_2PO_4 sulphur extractants correlated positively and significantly with the yield parameters. This study therefore recommended that farmers in the study area should adopt the practices of crop residue management that conserve soil organic matter which enhanced soils sulphur to improve fertility status for optimum productivity. Furthermore, the inclusion of Sulphur in routine analysis of soils in Nasarawa State should be encouraged while the seasonal bush fires should be discouraged.

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