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Distribution of Available Sulfur in Some Soils of South Chad Irrigation Project Area, Lake Chad Basin, Borno State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author GM designed the study and participated in its coordination and carried out the field data collection and drafted the manuscript. Author ALN performed the statistical analysis, wrote the protocol and wrote the final draft of the manuscript and author MKS helped in drafting the manuscript and managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: A field study was carried out to evaluate the content and distribution of available sulfur in soils underlain by the Chad Formation under the South Chad Irrigation Project area, Borno State.
Study Design: Purposive sampling technique was employed based on homogeneity in general surface features especially vegetation, topography and morphology.
Place and Duration of Study: The study site includes the clay plains of the Lake Chad Basin where the South Chad Irrigation Project is located. The study was carried out in 2016.
Methodology: Seven profile pits were sunk at selected locations across the study areas and samples collected in each pedogenic horizons of the profiles. Surface and sub-surface samples were also collected for physico-chemical analyses using standard procedures. The available sulfur was determined turbidimetrically after extracting with calcium phosphate solution.
Results: Textural classes were generally clayey with islands of sandy loam. The soil reaction ranged from moderately acid to slightly alkaline. The percentage organic matter content was

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generally low, being higher in clay than sandy soil texture. The available sulfur content was low with a range of 2.0 to 6.9 mg/kg. The distribution of available S content decreased with depth. The results also indicated that available P in profile P6 is positively correlated (r = 0.989**) with the available sulfur content. There was little or no correlation between the available sulfur and soil pH in all the profiles, except profile P1 (r = 0.531*). Significant negative correlation between organic matter content and the available sulfur in profiles P1 (r = -0.817**), P5 (r = -0.527*) and P7 (r = -0.989**) were observed. Significant negative correlation (r = -0.562*) was also observed between available sulfur and clay content in profile P1. The significant negative correlation of available sulfur with clay and organic matter could be due to adsorptive properties of clay and organic matter fractions.

Conclusion: The soils were observed to be deficient in available sulfur. The low available sulfur status of the soils indicated that supplemental application of sulfur containing fertilizer and manure would be required for maximum cereals and vegetable crop production in the study area.

Keywords: Available sulphur; distribution; lake chad; irrigation; clay soil.

1. INTRODUCTION

Sulfur is one of the essential nutrient elements for plant growth which constitute about 0.20 to 0.50% of plant tissue on dry matter basis [1]. Sulfur is also one of the principal building blocks of protein and a key ingredient in the formation of chlorophyll [2], and s required for the synthesis of sulfur containing amino acids: cysteine, cystine and methionine. The deficiency of sulfur results in serious human malnutrition. Deficiency of sulfur in field crops had been reported to be a serious constraint to crop production worldwide [3,4]. Previously, sulfur deficiency had been reported in Nigeria for several crops including cotton, cowpea, maize and groundnut and for different parent materials [5]. The deficiency was attributed to introduction of higher yielding crop varieties, intensive cultivation and decreased use of farmyard manure. The low sulfur status of savanna soils can also be ascribed to frequent bush burning leading to volatilization of sulfur into the atmosphere [6], especially around Lake Chad area in Sudan savanna of northeastern Nigeria.

Agricultural productivity of the Sudan savanna zone of northeastern Nigeria is greatly influenced by the Lake Chad. The productive capacity of the predominant clay soils of the Lake Chad basin having high nutrient and moisture retention capacity is a source of sustenance to millions of farmers and pastoralists living around the lake [7]. The chief food crops produced in the area include rice, wheat, maize and vegetables through irrigation during the dry season [8]. The dwarf *Masakwa* sorghum is also grown on residual moisture in the black cotton soils [9]. The Chad basin is therefore very significant in its support for crops and livestock production [10] which makes it a major contributor to gross domestic productivity of the nation. Sulfur fertilization of crops especially vegetables like cabbage, lettuce and onions chiefly produced around the Lake Chad will certainly improve yield and quality of these crops.

In arid regions, less organic sulfur accumulates in the surface soils, but gypsum often present in the subsoil horizons supplies the inorganic fraction. While the total sulfur content decreases with depth, the sulfate sulfur increases apparently due to leaching of sulfate to lower layers [11]. Sulfate sulfur is relatively mobile in most soils as it possesses negative charges and thus easily repelled by soil colloidal surface [12]. Sulfate sulfur under certain condition reacts with hydroxyl groups exposed on the surface of clays and adsorbed at low pH when positive charges become prevalent on soil particle surfaces making it slowly available and less susceptible to leaching [1].

Despite the importance of sulfur in plant nutrition, studies on this element received little attention particularly in soils of Lake Chad basin of north eastern Nigeria. This study is aimed at evaluating the content and distribution of available sulfur status of soils formed on the clay plains of the Lake Chad basin around Ngala area of Borno state, Nigeria.

2. MATERIALS AND METHODS

A study was carried out on seven representative profile samples collected from soils formed on the clay plains of Lake Chad Basin, south of Ngala, Borno state, Nigeria. The sites on which the South Chad Irrigation Project is located lies between latitude 10º45' N and 12º30' N and longitude 13º40' E and 14º40' E. The area is underlain by the Chad formation which consists of thick and dry irregular beds of sand, silt and predominantly clay particles. The location is superficially flat featureless clay plains interspersed with occasional slightly elevated sand islands. The clay plains were interrupted with numerous drainage channels. The climate of the area is semi-arid tropical with a wide range of seasonal and diurnal temperature range of 24-30ºC. The period of rainy season varies from 3 to 4 months between June and September followed by a long dry season. The profile pits were sunk based on differences in vegetation, topography and surface visual color [13]. The variation in the locations was covered through purposive sampling. In addition, surface (0 - 15 cm) and subsurface (15 - 30 cm) samples were collected in ten locations about each profile pit. The subsamples taken from bulk samples were analyzed for physico-chemical properties to serve as reference materials.

Routine laboratory analyses were carried out to determine soil physical and chemical properties. The particle size distribution was determined according to the procedure reported by Gee and Orr [14]. Soil pH was determined in 1:2.5 (soil: water) suspension using glass electrode digital pH meter. Available phosphorus was determined by the sodium bicarbonate method [15] and organic carbon by the wet oxidation method [16, 17]. The exchangeable cations were determined by leaching the soil with a normal ammonium acetate solution (pH 7.0). Calcium and magnesium in the ammonium acetate extract were determined by atomic absorption spectrophotometer, while potassium and sodium were determined by flame photometry. The effective cation exchange capacity was determined by the summation method. Available sulfur was determined turbidimetrically after extracting with calcium phosphate solution. The sulfate concentration was measured using spectrophotometer at a wavelength of 420 nm [11].

The data collected were analyzed using descriptive statistics and correlation analysis was used to determine the relationship between available sulfur content and some selected soil properties with the help of statistical software *Statistix 10.0.*

3. RESULTS AND DISCUSSION

3.1 Physico-chemical Properties of Soils of the Study Area

The physico-chemical properties of the soils of the study area are presented in Table 1. The organic carbon content of the surface soils ranged from 0.27 to 1.02% and that of the sub-surface ranged from 0.28 to 0.73%. The organic carbon content is low in both surface and sub-surface in all the sites according to the criteria from [17]. The soil pH generally ranged from moderately acid to slightly alkaline in reaction. The CEC of the soils was generally high except at Ngala and Ndufu areas where the soils were predominated by the sand fraction. Calcium and magnesium dominated the CEC of the soils. The available P content was higher at the surface than subsurface layers simulating the trend indicated by soil organic matter. The higher available P at the surface layers might be due to mineralization of plant residues and other organic materials being accumulated at the surface [1]. The clay content was higher in the subsurface than the surface horizons. It showed that there was a clay illuviation process in the soil (Table 2).

The distribution of available sulfur and other chemical characteristics in the profiles of the understudied soils were presented in Table 3. The pH values of the heavy textured soils were higher than those of the coarse textured soils. This might be due to better drainage condition of sandy soils which favors leaching of the basic cations resulting in lower pH. The clay soils conversely possess high surface charges that retain cations. The percentage organic matter content of the soils was low. This was in agreement with earlier reports that the organic matter content of the savanna soils is low due to limiting climatic variables, especially low rainfall and high temperature [18]. The organic matter content decreased with depth from the surface to subsurface layers. The higher organic matter content of the surface horizons is accounted by decaying plant roots and leaf litter at the soil surface. The heavy textured soils contain more organic matter than coarse textured soil. The higher adsorptive capacity of clay which enhances clay - organic matter complex formation might have influenced the accumulation. The generally low organic matter content of these soils was also attributed to frequent bush burning, grazing and high rate of oxidation [6].

The available P content of the sandy soils is generally higher (9 to 37 mg/kg) than that of the heavy textured soils (12 to 29 mg/kg). This might be due to the higher retentive capacity of clay soils for P [1]. The available P of the surface soils ranged from 12.2 to 37.5 mg/kg while that of the subsurface soils ranged from 12 to 28 mg/kg. The available S content of the soils of the study area was low with a ranged of 2.0 to 6.9 mg/kg. All the soils studied showed less than 4 mg/kg available S, the critical level for savanna soils indicating the low S status of these soils as reported by Raji [19]. The available sulfur content tended to decrease with depth following a similar trend to that of organic matter content.

From the results, clay soils showed higher base saturation than the coarse textured soils. The higher base saturation of the clay is ascribed to higher cation exchange capacity of the clay fraction while leaching of cations characterized the coarse textured soils. Although [20] reported that available sulfur was influenced by pH, organic carbon and clay content in hydromorphic soils, the soil pH seemed to exert little influence on the available sulfur content of the soils in this study.

3.2 Profile Distribution of Available Sulfur

The content and distribution of available sulfur in the soil profiles studied is presented in Table 3. The available S content in all the profiles ranged from 2.0 to 6.9 mg/kg. There was no specific pattern of distribution of sulfate S in some profiles while certain trends were observed in others. In profile P1 the available S ranged from 3.0 to 4.2 mg/kg. The content of available sulfur assumed a steady increasing trend down the profile in P1. However, there was a high concentration of available S in the surface soil of profile P2. The higher available S observed in this horizon might have resulted from transport and accumulation of sulfur containing organic materials on the soil surface, which were mineralized to the inorganic component by heterotrophic microorganisms [1].

The available sulfur content of profile P3 ranged from 2.8 to 3.0 mg/kg. The sulfate content decreased with depth in the profile. The distribution of available sulfur in profile P4 showed an increasing trend down the profile. As the profile is predominantly sandy, leaching of sulfate to lower layers is prevalent [21]. There was a high concentration of available sulfur in the surface horizon of profile P5 which has dominant sand fraction. The content of the element decreased uniformly with depth while the surface horizon recorded the highest value of 6.9 mg/kg in the study. The same decreasing trend was also observed in profile P6. The low available sulfur content of this profile might be due to high clay content of the profile which adsorbed and retained sulfate sulfur. The available sulfur content in profile P7 ranged from 2.0 to 3.70 mg/kg. No definite trend was observed in the distribution pattern of the available sulfur in this profile. An increase in available sulfur content is observed in the subsoil apparently due to illuviation of sulfate sulfur from the upper layers and retained by the dormant clay fraction in exchangeable form. The available sulfur content of the soils of the study area was low with a range of 2.0 to 6.9 mg/kg. Most soil samples recorded less than 4 mg/kg available sulfur, the critical level for savanna soils indicating the low S status of these soils as reported by Raji [19]. The available Sulfur content tended to decrease with depth following a similar trend to that of organic matter content. From the results, the clay soils showed higher base saturation than the coarse textured soils. The higher base saturation of the clay soils was ascribed to the higher cation exchange capacity of the clay fraction while leaching of cations characterized the coarse textured soils. Available sulfur was influenced by pH, organic carbon and clay content [20]. The soil pH however seemed to have little influence on the available sulfur in this study. The distribution of available sulfur in the various profiles understudied is depicted by Fig. 1.

In semi-arid soils, sulfates mainly occur as compounds of calcium, magnesium, potassium and sodium which constitute a greater proportion of the exchange complex. Due to high solubility of sulfate compounds particularly of potassium and sodium, leaching of sulfate to the subsoil was high [11]. The distribution pattern of available sulfur in this study is consistent with this phenomenon.

3.3 Relationship between Available Sulfur and Some Selected Soil Properties

To evaluate the influence of clay, organic matter, available P and soil pH on the available sulfur content, correlation analysis was used to determine the relationships. Detail of the correlation result is presented in Table 4.

For profile P1, there was a significant negative correlation (r = -0.562*) between clay and available sulfur content. Profile P5 shows similar relationship with low correlation (r = -0.329). However, no correlation was observed between available sulfur and clay content in the other profiles. The inverse relationship is explained by

Table 1. Some selected properties of surface and subsurface soils of the study area

Sample location	Depth (cm)	OM (%)	Avail. P (mg/kg)	pH	Exchangeable Bases					Particle size distribution			Texture
					Ca	Mg	K	Na	CEC	Sand	Silt	Clay	
					← Cmol/kg →					← g/kg →			
Gajibo	0-15	0.27	23.1	6.7	9.10	20.30	1.08	4.02	34.5	413	147	440	C
	15-30	0.41	21.2	7.5	13.0	9.73	1.01	5.06	28.8	562	55	583	C
Dikwa	0-15	0.61	25.2	5.4	7.19	12.09	0.58	6.96	26.82	534	162	304	SCL
	15-30	0.45	17.15	6.5	10.13	12.71	0.77	13.04	36.65	160	240	600	C
Musuni	0-15	1.02	32.25	6.5	13.22	21.21	2.07	9.13	46.63	26	137	837	C
	15-30	0.65	17.31	6.6	14.53	15.32	2.23	11.65	43.73	30	124	846	SL
Ngala	0-15	0.48	29.32	6.8	3.19	15.27	0.43	0.42	19.31	748	48	204	SL
	15-30	0.44	37.15	6.7	5.76	5.02	0.41	2.01	13.20	779	26	194	SL
Ndufu	0-15	0.44	35.1	5.3	2.88	5.20	0.44	1.85	10.37	750	46	204	SL
	15-30	0.37	36.3	5.8	5.59	5.35	0.19	1.52	12.65	818	18	164	SL
Fulatari	0-15	0.80	28.1	6.2	15.25	8.0	0.56	5.48	29.29	415	71	501	SC
	15-30	0.28	15.2	7.1	14.60	11.0	0.54	1.41	27.55	420	86	404	SC
Mudu	0-15	0.82	30.5	6.4	11.81	29.6	0.56	1.30	43.27	541	71	388	SC
	15-30	0.73	27.5	6.3	15.02	11.4	0.47	2.57	29.46	425	84	491	SC

Depth: surface (0-15 cm), subsurface (15-30 cm), C = clay, SCL = sandy clay loam, SL = sandy loam

Table 2. Color and particle-size distribution of pedons in the study area

Location of profile	Depth (cm)	Color	Sand	Silt (g/kg)	Clay	Textural class
P_1 (Gajibo, 5 km East)	0 – 8	10YR 4/1 Brownish gray	413	147	440	Clay
	8 - 27	10YR 4/1 Brownish gray	562	55	583	Clay
	27 - 48	10YR 3/1 Brownish black	386	26	588	Clay
	48 - 74	10YR 4/1 Brownish gray	431	60	509	Clay
	74 - 100	10YR 6/2 yellow brown	597	19	384	Sandy clay
	100+	10YR 7/3 Dull orange yellow	716	49	235	Sandy clay loam
P_2 (Dikwa, 2 km East)	0 – 7	2.5YR 6/3 Dull yellow	534	161	305	Sandy clay loam
	7 - 28	2.5YR 5/2 Dark grayish yellow	161	240	599	Clay
	28 - 45	2.5YR 5/2 Dark grayish yellow	100	254	646	Clay
	45 - 75	2.5YR 5/2 Dark grayish yellow	96	283	621	Clay
	75 - 100	2.5YR 4/1 Yellowish gray	105	204	691	Clay
	100+	2.5YR 4/1 Yellowish gray	90	117	793	Clay
P_3 (Musuni)	0 - 24	5YR 3/1 Olive black	26	137	837	Clay
	24 - 48	5YR 3/1 Olive black	30	124	846	Clay
	48 - 72	5YR 6/1 gray	16	114	866	Clay
	72 - 100	5YR 6/1 gray	47	218	735	Clay
P_4 (Ngala, 2 kmSouth)	0 - 25	10YR 6/2 Yellow brown	748	48	204	Sandy loam
	25 - 65	10YR 6/3 Dull yellow orange	779	26	194	Sandy loam
	65 - 100	10YR 6/3 Dull yellow orange	661	44	295	Sandy loam
	100+	10YR 6/3 Dull yellow orange	599	60	341	Sandy loam
P_5 (Ndufu)	0 - 7	10YR 6/3 Dull yellow orange	750	48	204	Sandy loam
	7 - 29	10YR 5/3 Dull yellow brown	818	18	164	Sandy loam
	29 - 45	10YR 6/3 Dull yellow orange	728	19	253	Sandy clay loam
	45 - 76	10YR 5/3 Dull yellow brown	541	60	399	Sandy clay
	76 – 110	10YR 5/3 Dull yellow brown	429	83	488	Sandy clay
P_6 (Fulatari)	0 - 30	10YR 5/2 Gray yellow brown	415	71	499	Sandy clay
	30 - 86	10YR 6/4 Dull yellow brown	420	86	404	Sandy clay
	86 - 110	10YR 6/3 Dull yellow orange	635	167	309	Sandy clay loam
P_7 (Mudu)	0 - 15	10YR 5/2 Grayish yellow brown	541	71	388	Sandy clay
	15 - 30	10YR 4/2 Grayish yellow brown	425	84	491	Sandy clay
	30 - 55	10YR 4/2 Grayish yellow brown	320	126	854	Clay
	55 - 80	10YR 5/3 Dull yellow brown	253	97	650	Clay
	80 - 100	10YR 5/2 Gray yellow brown	353	66	581	Clay

Table 3. Distribution of available sulfur and other chemical characteristics of pedons in the study area

Profile no. and location	Depth (cm)	pH	O.M (g/kg)	Avail. P (mg/kg)	Avail. S (mg/kg)	Ca	Mg	K	Na	TEA	CEC
						←			(Cmol/kg)		→
P_1 (Gajibo)	0 – 8	6.7	4.70	23.10	3.25	9.10	20.26	1.08	4.02	0.25	34.71
	8 – 27	6.7	5.80	18.30	3.00	13.00	9.73	1.01	5.06	0.30	29.10
	27 – 48	7.5	7.00	21.20	3.50	13.95	9.20	0.96	6.30	0.15	30.56
	48 – 74	7.1	3.80	17.30	3.20	11.25	17.56	0.34	8.91	0.17	38.23
	74 - 100	7.9	2.80	16.15	2.90	8.90	15.78	0.43	7.82	0.07	33.00
	100+	8.1	2.50	18.26	4.20	7.74	3.00	0.38	6.52	0.21	17.85
P_2 (Dikwa)	0 – 7	5.4	10.6	25.12	5.25	7.19	12.09	0.58	6.96	0.12	26.82
	7 – 28	5.9	9.50	19.31	2.05	10.13	12.71	0.77	13.04	0.15	36.80
	28 – 45	6.5	7.80	17.15	4.33	13.98	12.07	2.51	13.26	0.19	42.01
	45 – 75	6.4	8.50	15.35	4.65	13.63	14.15	1.06	17.39	0.21	46.44
	75 - 100	6.2	7.00	13.21	3.45	15.38	16.33	1.37	10.21	0.18	43.47
	100+	6.1	5.90	10.41	3.30	18.50	8.70	1.42	9.89	0.20	38.71
P_3 (Musuni)	0 – 24	6.6	17.6	32.25	3.00	14.22	21.22	2.07	9.13	0.11	46.75
	24 – 48	6.6	11.2	17.31	2.96	14.50	15.32	2.22	11.65	0.21	43.90
	48 – 72	7.3	10.5	13.25	2.80	17.02	12.20	2.21	11.96	0.19	43.58
	72 – 100	7.8	9.80	9.23	2.98	13.82	19.16	2.16	15.93	0.23	51.30
P_4 (Ngala)	0 – 25	6.8	8.30	29.32	3.00	3.19	15.27	0.43	0.42	0.09	19.40
	25 – 48	6.8	7.60	37.15	3.35	5.76	5.00	0.42	2.00	0.11	13.29
	48 – 72	6.6	5.50	23.26	3.56	9.20	12.39	0.68	2.67	0.13	25.07
	72 – 100	7.0	3.60	19.31	3.70	15.88	10.22	0.72	2.69	0.15	29.66
P_5 (Ndufu)	0 – 7	5.3	7.50	35.10	6.90	2.88	5.20	0.44	1.85	0.19	10.56
	7 – 29	5.8	6.40	36.30	3.50	5.59	5.35	0.19	1.52	0.21	12.86
	29 – 45	5.3	4.60	22.20	2.98	8.79	15.44	0.19	1.69	0.19	26.30
	45 – 76	6.7	3.80	17.40	2.75	12.22	2.60	0.49	3.48	0.17	18.96
	76 – 110	6.7	2.60	15.35	2.50	12.58	15.75	0.68	2.78	0.23	32.02
P_6 (Fulatari)	0 – 30	6.2	13.8	28.10	3.25	15.25	8.0	0.56	5.48	0.07	30.16
	30 – 86	7.1	4.80	15.20	3.20	14.60	11.00	0.54	1.41	0.13	27.68
	86 – 110	7.5	2.00	12.10	3.00	7.35	3.90	0.38	1.96	0.15	14.24
P_7(Mudu)	0 – 15	6.4	14.1	30.5	3.15	11.81	29.60	0.56	1.30	0.12	43.39
	15 – 30	6.4	12.5	27.5	3.65	15.02	11.40	0.47	2.57	0.10	29.56
	30 – 55	7.7	8.50	22.5	3.70	17.02	10.57	0.57	1.52	0.14	29.82
	55 – 80	7.5	7.50	17.5	3.05	16.39	20.60	0.68	2.78	0.11	40.56
	80 – 100	7.3	5.20	15.5	2.95	27.88	8.60	0.43	1.53	0.13	38.57

Table 4. Coefficients of correlation between available S content and some soil properties

Profile no. & location	Available S & clay content	Available S & O.M content	Available S & avail P	Available S & pH
P1 (Gajibo)	-0.562*	-0.817**	-0.274^{ns}	0.531*
P2 (Dikwa)	0.031^{ns}	0.00693^{ns}	-0.316^{ns}	-0.074^{ns}
P3 (Musuni)	0.060^{ns}	0.191^{ns}	0.774**	0.141^{ns}
P4 (Ngala)	0.037^{ns}	-0.235^{ns}	0.611*	0.190^{ns}
P5 (Ndufu)	-0.329^{ns}	-0.527*	0.667*	0.337^{ns}
P6 (Fulatari)	0.002^{ns}	-0.421^{ns}	0.989***	0.212^{ns}
P7 (Mudu)	0.167^{ns}	-0.969***	0.272^{ns}	-0.346^{ns}

** - Significant at 5% level probability level; ** - Significant at 1% level probability level; *** - Significant at 0.1% level probability level*

the high sulfate sulfur retention capacity of clay marked by decreased available sulfur. In the same vein, significant negative correlations were recorded between organic matter content and available sulfur in profiles P1 (r = -0.817**), P5 (r = 0.421*) and P7 (r = 0.969***). This negative correlation could be ascribed to the amphoteric properties of soil organic matter which tends to develop positive charges under certain conditions which adsorb SO_4^{2-} S [22]. This encourages sulfate adsorption and reduces sulfur availability. However, no significant correlation was observed between organic matter and available sulfur in profiles P2, P3 and P4. Significant correlation was however observed between available sulfur and available P contents in profiles P4 (r = 0.611*), P5 (r = 0.667*) and P7 (r = 0.774**). The reason alluded to the positive relationship was that both sulfur and phosphorus are important constituents of soil organic matter which responded to microbial mineralization resulting in the release of soluble inorganic components.

The results also show that there was low correlation between available sulfur and soil pH in all the profiles, except P1 (r = 0.531*). Soil pH is an important factor in microbial mineralization of organic sulfur [21], but seems to have less influence on the available sulfur content of the soils understudied.

4. CONCLUSION

The soils of the study sites were classified as sandy loam, sandy clay loam and clay textural classes. The soil reaction of the site varied from slightly acid to moderately alkaline. Being predominant in high activity clay, the soils have high cation exchange capacity and base saturation. The available sulfur content of the soils was generally less than 4 mg/kg, the critical available sulfur level for savannah soils. This shows that soils of the study site were deficient in available sulfur status. Available phosphorus was found to be positively correlated with available sulfur content, while the clay fraction and organic matter content were negatively correlated with available sulfur. The soil pH does not influence sulfate sulfur content of the soils understudied. The low available sulfur status of these soils suggests that supplemental addition of soluble sulfur containing fertilizer like single super phosphate, which is the most cheaply availability sulfur containing fertilizer in the area, and manure are required for optimum cereals and vegetable crops production in the clay plains of the study area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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