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ASSESMENT OF SULPHUR IN RELATION TO SELECTED PROPERTIES IN SOILS OF ILORIN EAST LOCAL GOVERNMENT, KWARA STATE

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ABTSRACT
A study was conducted on the sulphur content and its relationship with some selected soil properties at Ilorin East Local Government, Kwara State in 2021. An analysis of twenty samples each from two depths (0 - 15 cm and 15 – 30 cm) of soil on the study site was conducted to determine selected physical and chemical properties, total and available sulphur content. Results showed that the total sulphur content ranges from 1.15 to 37.25 $mgkg^{-1}$, the available sulphur content (HCL) ranges from 0.04 to 2.5 $mgkg^{-1}$ and the available sulphur content (EDTA extracted) ranges from 0.1 to 4.5 $mgkg^{-1}$. There were positive correlations observed between the different forms of sulphur within the soils, although total sulphur showed a negative correlation to available suphur (HCL) in the surface soils. All the forms of sulphur showed a negative correlation with organic carbon content and pH. Sodium, calcium, and potassium correlated positively with different forms of sulphur. It was observed that, sulphur content of the soils of Ilorin East Local Government Area were generally deficient. The top layer of the soils was low in sulphur content. Equilibrium between the different forms of sulphur present in the soil was also observed.

Keywords: Available sulphur, Sulphur deficiency, Total sulphur,

INTRODUCTION
Sulphur (S) is an essential element for growth and development in plants, ranking fourth after nitrogen (N), phosphorus (P), and potassium (K) (Nakai and Mauyama-Nakashita, 2020). It is an important component for all living species, including plants. Sulphur is a component of proteinaceous amino acids such as methionine and cysteine, glutathione, vitamins (biotin and thiamine), phytochelatins, chlorophyll, coenzyme A, and S-adenosyl-methionine (Li *et al*., 2020). Sulphur is a non-metal element which reacts with several cations to produce sulphides and eventually sulphates. Sulphur exists in organic and inorganic forms and may also be found in the soil as adsorbed S, ester sulphate, elemental S, carbon bonded S, extractable S, and water-soluble S among others (Sutar *et al*., 2017). The main source of sulphate in soils is through clay content and organic matter addition from plant and animal sources and inorganic fertilizers. Due to the use of high-yielding crop types in multiple cropping systems as well as the continual application of pesticides, fungicides, and fertilizers that are sulphur-free, sulphur deficiency is becoming a severe problem for agricultural output. Sulphur deficiency is expected to rise due to improved efficacy in sulphur dioxide (SO_2) pollution control programs as a result of stricter environmental laws (Dhillon *et al*., 2019), the use of high-yielding cultivars, which leads to increased crop removal, reduced tillage intensity, increased use of low sulphur content fertilisers, decreased use of S-containing fungicides and insecticides, and continued losses through leaching and erosion of topsoil (Sharma *et al*., 2024). Furthermore, decreasing sulphur

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availability is associated with the loss of soil organic matter, which accounts for up to 95% of total sulphur in the soil. Organic matter is falling due to soil erosion, conventional tillage, and reduced organic carbon levels caused by global warming (Kong *et al*., 2022).

Sulphur deficiency was observed to be most severe in soils from guinea savannah, followed by those originating from savannah and least severe in soil from the rainforest zone (Isitekhale *et al.,* 2013). Improving crop sulphur nutrition requires an understanding of the sulphur condition throughout the root zone. The availability of sulphur is influenced by a number of soil conditions, and as a result, the status of various forms of sulphur in soils varies greatly depending on the type of soil (Mehmood *et al*., 2021). There has been numerous researches on the properties of soils of Ilorin Kwara State. However, there is limited data on the actual status of sulphur within the soils and its relationship with other soils properties. Considering the importance sulphur plays in plant metabolism, crop production and soil productivity, there is a gap in information that might be important to farmers, researchers and stakeholders. Hence, this study was carried out to determine the status sulphur in the soils of Ilorin East Local Government Area of Kwara State.

MATERIALS AND METHODS

Description of the study area

The research was carried out in Ilorin East Local Government Area of Kwara State, Nigeria in 2021. Ilorin West Local Government Area lies between Latitudes 8° and 15° N and Longitudes 4° and 5° E and shares boundary with Ilorin South, Ilorin West, Moro and Ifelodun LGAs (Kwara State Government, 2013). Ilorin East Local Government area lies within the Tropical wet and dry climate with the wet season stating around the end of March and ending in October and the dry season lasts from November to February.

The research area falls within the Southern Guinea Savannah ecological zone of Nigeria (Akpenpuun and Busari, 2017). The temperature ranges between 32°C and 37°C. The rainfall pattern is bimodal with the two peaks occurring usually in June and September respectively (Dike *et al*., 2020). The annual rainfall ranges from 990 mm to 1318 mm. The area is mainly covered by ferruginous and crystalline acid soils that have good potentials for the production of large variety of crops. The major rivers in the area are Asa, Oyun, Agba and Alalubosa.

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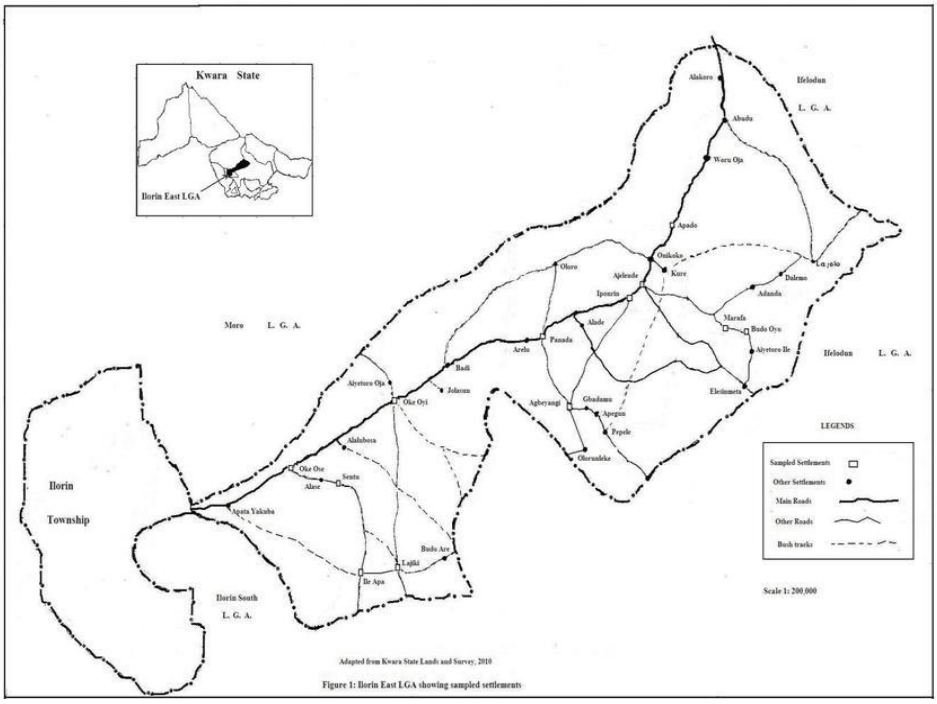


Figure 1*: Map of Ilorin East Local Government Area, Kwara State.* (Adefalu *et al*., 2013)

Soil Sampling

Twenty evenly distributed observation points were selected to represent Ilorin East Local Government Kwara State Nigeria. In each location, ten subsamples from 0-15 cm and 15 -30 cm depth were collected and mixed to form a composite sample. All composite soil samples were mixed, quartered, and reduced to 1 kg, and sealed in plastic bags. Each composite sample was further divided into three parts, to form three replicates. The soil samples were air-dried at room temperature, ground using mortar and pestle, and passed through a 2 mm mesh sieve to prepare for laboratory analysis.

Laboratory Analysis

Particle size analysis was determined using the Bouyoucos hydrometer method. The soil reaction (pH) of a 1:2.5 soil-to water suspension was measured using a digital pH meter (Rayment and Higginson, 1992). The total nitrogen content of the soil was determined by the Kjeldahl method (Bremner and Mulvaney, 1982), and Soil organic carbon was determined by a modified Walkley-Black method (Nelson and Sommers, 1996). The available phosphorus (P) was determined by the Bray Pl method (Olsen and Sommers, 1982). Available sulphur (S) was measured using 0. 1N HCL and 1% EDTA as an extractants (Tabatabai, 1996). Total sulphur was measured using perchloric acid extraction both utilizing the turbidometric method (Seal *et al*., 2005). The exchangeable bases (Ca, Mg, K & Na) were extracted from the soil using the ammonium acetate method, the extract was then analyzed for Ca and Mg by the use of atomic absorption spectrophotometer and the K^+ and Na^+ were determined by the use of flame photometer (Sparks, 1996). Effective cation exchange capacity (ECEC) was determined by the summation of exchangeable bases (Ca, Mg, Na, and K) and exchangeable acidity (Al and H). Pearson correlation was carried out to determine the relationship between the measured soil properties.

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RESULTS AND DISCUSSION

The results of selected physical and chemical properties of the soils in the locations are shown in Tables 1 and 2. The results revealed that, particle size distribution of the sampled points are majorly sand dominated with sandy loam textural class. The sandy nature of this soils can be attributed to nature of the parent material from which the soils are formed. Araujo *et al*. (2017) pointed out that soil mineralogy and texture are majorly dependent on soil's parent material. This was similar to the findings of Ibiremo *et al*. (2010) who observed high sand fractions in soils across eight local government areas of Kwara state.

The mean pH (H_2O) was slightly alkaline (7.347) at the 0-15 depth while at the 15 – 30 cm depth the mean pH was neutral (7.023). This might be due to conversion of forest land to agricultural land, leading to reduction in organic matter accumulation and increasing soil pH. with most of the land in the study area being converted for agricultural purpose over time. Allam *et al*. (2023) noted that conversion of forest land into agricultural land led to an increase in soil pH and bulk density, with a significant decrease in organic matter and water retention in soil.

The organic carbon content within the two depth across all sample locations were generally low with mean values of 0.012% and 0.001% in 0 -15 and 15 – 30 cm depth respectively. The low organic carbon content within this soils might be due to inherent low fertility of the soils and the effect of continuous cultivation of the land. This is in line with the report of Adegbite *et al*. (2020) who reported that Nigeria's savanna soils are low in organic matter and chemical degradation of the soil and low soil fertility.

Total Nitrogen of the sampled soils were low, with mean values of 0.025% and 0.018% at the 0-15 cm and 15 – 30 cm depths respectively. Excessive cultivation, inadequate management, and agricultural residue clearance can all contribute to low nitrogen levels. Erosion, insufficient fertilizer application, and crop residue clearance can all contribute to this issue on cultivated land. This low values can also be directly attributed to the low organic matter content of the soils. The result of this study lend support from that of Okeke *et al*. (2022) who stated that an increase in total nitrogen values is directly related with an increase in organic matter content and vice-versa. It also agrees with the findings of Owoade and Abolarin (2021) who reported similar findings of low nitrogen content in soils of Asa and Moro local government areas of Kwara State.

The available phosphorus content within this soils were generally low with mean values of 2.009 mg/kg and 2.06 mg/kg. This might be attributed to the fixation of phosphorus under alkaline conditions of the soils into insoluble forms. Lufega and Msanya (2017) noted that Low phosphorus content in parent materials, such as granitic rocks, and insoluble compounds as a result of P fixation under alkaline and acid conditions, is linked to the low available P in soils. The mean exchangeable magnesium content of the soils were medium at the 0-15 cm depth (0.459 cmol/kg) and 15- 30 cm depth (0.346 cmol/kg). Exchangeable calcium content were generally low with mean value of 0.084 cmol/kg at both depths. The mean exchangeable sodium content of the soils were medium at the 0-15 cm depth (0.147 cmol/kg) and 15- 30 cm depth (0.113 cmol/kg). The mean exchangeable potassium content of the soils were low at the 0-15 cm depth (0.125 cmol/kg) and 15- 30 cm depth (0.099 cmol/kg). The mean cation exchange capacity of the soils were low, with mean values of 1.285 cmol/kg and 1.256 cmol/kg at the 0-15 cm and 15 – 30 cm depths respectively. The low to medium ratings of the exchangeable cations were similar to the findings of Ugwa *et al*. (2022) who reported low to medium ratings of exchangeable cations (Ca, Mg, Na and K) in different agricultural land uses of Edo State, Nigeria.

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The available sulphur content extracted with both showed a reduction with depth. EDTA extracted available sulphur at 0 – 15 cm and 15 –30cm depth had ranges of 0.1 to 4.5 and 0.1 to 3.15 with mean values of 1.353 and 1.01 respectively. HCL extracted Available sulphur at 0 – 15 cm and 15 –30cm depth had ranges of 0.04 to 2.5 and 0.04 to 2.5 with mean values of 1.395 and 0.89 respectively. The available sulphur content of the soils were rated low. This might be the due to the effect of continuous cropping on the soils, low organic matter content and inadequate use of sulphur based fertilizers in crop production. This corroborates with the report of Sharma *et al*. (2024) who noted that increased use of low-sulphur fertilizers, decreased use of sulphur-containing fungicides and insecticides, and ongoing losses due to leaching erosion of topsoil and loss of soil organic matter are all directly related to a decrease in soil sulphur content. However, the total sulphur content was higher at the 15 - 30 cm depth, with a range of 1.35 to 37.25 with a mean value of 8.04, while at the 0 – 15 cm, the total sulphur content had a range of 1.3 to 5.33 with a mean value of 3.21. The difference in total sulphur content with soil depth might be due to leaching and sandy texture of the sampled soils, being sulphur a water soluble. Narayan *et al*. (2023) reported that at the field level, sulphur deficiency can be very variable since soil sulphur availability varies greatly with soil organic matter and texture. Sulphur shortage is common in sandy soil, poor organic matter, and higher elevation parts of a field.

Table 1: Descriptive statistics of selected soil properties at 0-15 cm depth

Soil Nutrient	NL	Minimum	Maximum	Mean	SD
Silt (%)	20	0	30	9.852	19.068
Clay (%)	20	6.48	8.48	6.63	0.489
Sand (%)	20	63.52	93.52	83.189	9.904
Organic Carbon	20	0.002	0.027	0.012	0.007
Organic Matter	20	0.006	0.046	0.023	0.012
E. A (cmol/kg)	20	0.14	0.84	0.381	0.178
Phosphorus (ppm)	20	0.188	3.942	2.009	0.946
Nitrogen	20	0.01	0.06	0.025	0.016
Mg (cmol/kg)	20	0.1	0.89	0.459	0.252
Na (cmol/kg)	20	0.03	0.35	0.147	0.091
Ca (cmol/kg)	20	0.02	0.17	0.084	0.039
K (cmol/kg)	20	0.06	0.23	0.125	0.052
CEC	20	0.76	1.93	1.285	0.394
pH (H_2O)	20	6.49	7.88	7.347	0.351
pH (KCL)	20	5.72	7.44	6.538	0.462
EC	20	0.104	0.84	0.293	0.186
S (EDTA)	20	0.1	4.5	1.353	1.188
S (HCL)	20	0.04	2.59	1.395	0.764
T.S	20	1.3	5.33	3.21	1.09

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Table 2. Descriptive statistics of selected soil properties 15 – 30 cm depth

Soil Nutrient	NL	Minimum	Maximum	Mean	SD
Silt (%)	20	0	4	1.03	1.35
Clay (%)	20	6.48	8.48	7.03	0.87
Sand (%)	20	87.04	93.52	91.94	1.92
Organic Carbon	20	0.001	0.024	0.001	0.006
Organic Matter	20	0.002	0.041	0.012	0.01
E. A (cmol/kg)	20	0.04	1.12	0.54	0.32
Phosphorus (ppm)	20	0.32	3.89	2.06	0.990
Nitrogen	20	0.01	0.04	0.018	0.009
Mg (cmol/kg)	20	0.05	0.79	0.346	0.178
Na (cmol/kg)	20	0.03	0.28	0.133	0.078
Ca (cmol/kg)	20	0.01	0.2	0.084	0.055
K (cmol/kg)	20	0.04	0.21	0.099	0.046
CEC	20	0.53	1.93	1.256	0.39
pH (H_2O)	20	5.66	8.59	7.023	0.783
pH (KCL)	20	5.72	7.44	6.538	0.72
EC	20	0.13	0.69	0.30	0.16
S (EDTA)	20	0.1	3.15	1.01	0.99
S (HCL)	20	0.04	2.5	0.89	0.73
TS	20	1.35	37.25	8.04	10.66

Relationship between Soil Properties as it affects Sulphur Content

Correlation coefficients of the soil parameters are presented in Table 3 and 4. Positive correlation was observed between pH (H_2O) and available sulphur and total sulphur content in the soil. This is similar to the findings of Nisaba *et al*. (2023) who observed positive and highly significant correlation between the pH and different forms of sulphur. Organic carbon content within this depth showed negative correlation with pH, available sulphur and total sulphur. This is similar to the findings of Zhao *et al*. (2023) who observed negative correlation between organic carbon and soil pH. This negative relationship between organic carbon and sulphur was contrary to the findings of Chaudhari *et al*. (2020); Khandare *et al*. (2024) who reported positive correlations between all forms of sulphur with organic carbon content of soils. Positive correlation was recorded between all forms of sulphur within the soil. Rajkonwar *et al*. (2016) observed that sulphur may exist in a condition of dynamic equilibrium, as evidenced by the presence of positive correlations among all fractions of sulphur in a soil, irrespective of the level of sulphur present in the soil. Similar findings were reported by Basumatary and Das (2012) who noted that a positive relationship occurred between all forms of sulphur in soils of Assam. All forms of sulphur also had positive correlation with most the chemical properties of the soil apart from organic carbon and organic mater. Chaudhari *et al*. (2020) observed positive correlations between different forms of sulphur with tested soil properties, with the only negative correlation occurring with sand content and soil pH.

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Table 3: Correlation matrix of selected soil properties at 0 -15 cm depth

	OC	OM	P	N	Mg	Na	Ca	K	C.E.C	pH (H2O)	pH(KCL)	S(EDTA)	S(HCL)	T.S
OC	1.00													
OM	0.72	1.00												
P	-0.30	0.06	1.00											
N	-0.33	-0.37	-0.06	1.00										
Mg	-0.26	-0.07	0.35	0.26	1									
Na	0.09	-0.01	-0.24	-0.58	-0.12	1								
Ca	-0.13	-0.04	-0.19	0.05	0.39	0.20	1							
K	0.11	-0.06	-0.18	-0.17	0.43	0.28	0.53	1						
C.E.C	-0.32	-0.39	-0.12	0.58	0.51	-0.09	0.50	0.26	1					
pH (H20)	-0.19	-0.21	-0.45	0.13	0.03	-0.08	0.05	0.20	0.15	1				
pH (KCL)	0.13	0.36	0.13	-0.08	0.13	-0.05	-0.27	-0.11	-0.24	0.06	1			
S (EDTA)	-0.23	-0.39	-0.05	0.24	0.35	0.20	0.11	0.37	0.58	0.35	-0.27	1		
S (HCL)	0.29	-0.01	-0.54	-0.05	0.28	0.31	0.29	0.74	0.27	0.39	0.11	0.44	1	
T.S	-0.05	-0.08	-0.24	0.06	0.09	-0.01	0.25	0.42	0.12	0.28	0.10	0.20	0.57	1

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Table 4: Correlation matrix of selected soil properties at 15 – 30 cm depth

	OC	OM	P	N	Mg	Na	Ca	K	C.E.C	pH (H2O)	pH(KCL)	S(EDTA)	S(HCL)	T.S
OC	1.00													
OM	-0.21	1												
P	-0.22	0.11	1											
N	-0.18	0.06	-0.13	1										
Mg	-0.19	-0.08	-0.29	-0.19	1									
Na	-0.13	0.33	-0.24	0.18	0.50	1								
Ca	0.19	-0.24	0.00	-0.01	0.00	0.13	1							
K	-0.06	-0.07	-0.25	-0.31	0.35	0.40	0.31	1						
C.E.C	-0.26	0.62	-0.05	-0.12	0.50	0.60	-0.10	0.21	1					
pH H20	0.11	-0.10	0.22	0.07	0.02	0.12	-0.29	-0.14	0.08	1				
pH KCL	-0.18	-0.23	0.22	-0.21	-0.19	-0.04	-0.17	-0.03	-0.41	-0.21	1			
S (EDTA)	0.00	-0.14	-0.02	-0.02	-0.01	0.01	0.43	0.35	-0.05	-0.10	-0.08	1		
S (HCL)	-0.09	-0.02	-0.26	0.12	0.06	0.08	-0.09	0.32	-0.06	-0.05	-0.24	0.26	1	
T.S	-0.26	-0.22	0.03	0.39	-0.32	-0.31	0.42	-0.09	-0.40	-0.38	0.25	0.01	0.13	1

CONCLUSION AND RECOMMENDATION

From the results obtained, it was observed that the sulphur content of soils in the Ilorin East Local Government Area was generally deficient. The top layer of the soils was low in sulphur content. Equilibrium between the different forms of sulphur present in the soil was also observed. However, there is a need to improve the sulphur content within this soil through good management practices such as incorporation of organic matter and balanced fertilizer application.

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