# Status and Speciation of Silicon and Its Interaction with Physico-Chemical Properties

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## ABSTRACT

The effectiveness of three different extractants soil mixtures—HCl, HCl + $H_2SO_4$, and DTPA-TEA, in order to determine Si from soil and the forms of Silicon as influenced by different parent materials under acidic medium.
Seven forms of Silicon; namely water soluble, specifically adsorbed, oxides bound, organic matter bound, exchangeable, residual, total viz sequential fractionation.
Extractable Si value established in this study was (50.0 mg $kg^{-1}$), indicating negative effect on plant physiology. The physico-chemical properties decreased significantly with increase in soil depth vs soil parent materials. In addition, the forms of Si in the parent materials decreased in the pattern RES, bound residual fractions > EXC, soluble & exchangeable fractions > OM, organic matter fraction.

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Among the properties the silt fraction, pH & OM significantly and positively correlated with the forms of silicon, with negative correlation vs clay which maybe due to silicon adsorption by clayey fraction of the soil (redox). Therefore the soil maybe be maintained and conserved for farming activities.

*Keywords: Silicon (Si); adsorption; soil; chelates; speciation.*

## 1. INTRODUCTION

Parent materials mainly control soil type, total and available micronutrient viz soils [1]. The contents of micronutrients differ by prevailing environmental conditions in soils [2]. Mineral elements plays vital role in plants enzymatic activities and other plant functions [3]. The application of small quantities of these nutrients in soils with micronutrient deficiencies, enhance crop production [4], while large quantities added to the soil alters grain size and harmful to human health. There is a small window of concentration of these elements, where plant growth is optimal. Silicon an inorganic micronutrient exhibit a mechanism to buffer plant nutrient uptake and biofortification [5,6,7&8], which enhances optimum soil-plant processes. Berkhout et al. [9] revealed that there is a significant positive correlations between soil micronutrient contents vs malnutrition. And the deficiency of one micronutrients alters crop productivity [10].

Silicon adsorption/desorption of soil solution from weathering materials constitute the uptake and assimilation by vegetation and microorganisms [11].

The different forms of silicon present in the soils are categorize into: water soluble, non-specially and specially adsorbed, Fe-Al amorphous/crystalline occluded, Si and Ni oxide occluded, organically bond and residuals associated with soil silicates [12].

The utilization of silicon mainly in household, industrial applications, and construction is of importance to human activities [13]. The status of Si forms gives a better knowledge of it chemical reactions in soils. Majority of crops such as rice, groundnut, maize, yam, tomatoes, sugarcane etc. consumed in mid-west agro-ecological zone require adequate macro and micro nutrients for maximum growth and yield. According to [14], the concentration of silicon in plants depends primarily on the phylogenetic position of the plant, compared with the environmental effects that encompass silicon concentrations in the soil and soil solution and the pH for sustainability of these crops production, there is the need to examine and know silicon status of these soils.

The understanding of silicon concentrations of these areas will help to improve the soil type & fertility. Therefore, this study was aimed at assessing the status of Silicon in soils derived from different soil type in mid – western agro-ecological zones of Nigeria via HCl, HCl + $H_2SO_4$, and DTPA on mineral nutrients and relationship between the forms of Silicon and some physiochemical status of the soils investigated.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

The soil type collected for this study were from four locations of Mid-western, Nigeria: Sobe (basement complex, latitude $06^0$ M 50'59 N and Longitude $05^0$ 46 N), koko (alluvium, latitude $06^000'04$ N and longitude $05^028'2803$ E) , Uhonmora (Rhodic tropudalf –shale, latitude $06^030'45$ N and longitude $05^050'26$ ) and Iyanomo (coaster plain sand, latitude $6^o$ 05 and $6^o$ 25 N and longitude $5^o$ 35 E), Mid-western is in southern Nigeria.

### 2.2 (BCR) European Community Bureau of Reference Procedures for Metals

BCR method adopted [15], Seven forms of Silicon; namely (F1), water soluble, (F2), specifically adsorbed, (F3), oxides bound, (F4), organically bound, (F4), (F5), exchangeable, (F6), residual and (F7), total were determined by sequential fractionation, with a reference soil (SRM14513) for quality control. The Certified Reference Material was averagely 98% respectively.

### STEP 1. (Soluble silicon)

One gram soil was measured into a conical flask containing 10 ml of distilled water and shaked overnight (16 hours). The sample was filleted to 100ml. Silicon was determined using the atomic absorption spectrophotometer.

### STEP 2. (Exchangeable silicon)

Ten mls (10 ml) of 1M $MgCl_2$ was added to the residue from the soluble Silicon and shakes

overnight for 10 hours, the sample was filleted to 100ml. Silicon was determined using the atomic absorption spectrophotometer.

### STEP 3. (Specifically adsorbed silicon)

Eight mls (8 ml) of 1M sodium acetate was added to the residue from the exchangeable phase and equal to pH 5.0 with acetic acid and was agitated in a mechanical shaker for 5 hours, filtered to 100ml mark. Silicon was determined using the atomic absorption spectrophotometer.

### STEP 4. (Oxide bound silicon)

Forty mls (40 ml) of hydroxylamine hydrochroride ($0.5M$ $OHNH_2.HCl$) was added to the residue from the specifically adsorbed Silicon and shake for 6hours and occasionally agitated , filtered to 100ml mark. Silicon was determined using the atomic absorption spectrophotometer.

### STEP 5. (Organic bound silicon)

Three mls (3ml) of 0.02 M $HNO_3$and 5ml of 30% $H_2O_2$ (pH 2.0) were added to the residue of oxide bound and heated for 2 hours, and then 3ml of 30% $H_2O_2$ was added and heated again for another 3 hours, The sample was filleted to 100ml mark. Silicon was determined using the atomic absorption spectrophotometer.

### STEP 6. (Residual silicon)

The residue from the organic bound was digested with HF-HClO$_4$ until metals were dissolved and the sample was filleted to 100ml mark. Silicon was determined using the atomic absorption spectrophotometer.

### STEP 7. (Total silicon)

One gram (1 g) of soil sample was weighed, 15 ml of concentrated nitric acid ($HNO_3$) was added into a 250ml flask, the mixture allowed to stand for 1 hour. 5 ml of concentrated perchloric acid ($HClO_4$) was carefully added and heated until solution became clear and reduced to about 5 ml. 5 ml of 2M HCl was added, the sample was filleted to 100ml mark. Silicon was determined using the atomic absorption spectrophotometer.

### 2.2.1 Physico-chemical analysis

Soil pH (1:1) soil:water [15]. The sand, silt and clay fraction distribution [16] as modified by [17].Organic carbon via wet oxidation methods [18]. The exchangeable cations   acidity was determined by titration method as reported by [17]. Exchangeable cations via   ammonium acetate solution (1N NH4OAc) buffered pH 7.0. Ca and  Mg were determined from the extract of 0.01m EDTA (ethylenediaminetra-acetuc acid) titration method as described by [17] , while K and Na were determine using photometer [19]. Total nitrogen and available phosphorous was determine by [20]; [21].

### 2.2.2 Single acid extraction method (0.1M HCl)

Five grams (5 g) of soil was weighed into 250 ml flask , and 0.1 M HCl was added and shaken for 30 minutes. The sample was filleted to 100ml mark. Silicon was determined using the atomic absorption spectrophotometer.

### 2.2.3 Double acid extraction method (0.05 HCl IN 0.125H$_2$SO$_4$)

Five gram (5 g) soil was weighed into a 250 ml flask; 25 ml of the extract reagent (0.05 HCl + 0.125M $H_2SO_4$) were added and shaken for 15 minutes. The sample was filleted to 100ml mark. Silicon was determined using the atomic absorption spectrophotometer [15].

### 2.2.4 DTPA-TEA  Extraction

Ten gram (10 g) of soil was weighed, 20 ml of diethylene triamine penta-acid (DPTA) and triethanol amine (TEA) mixture was added the sample was filleted to 100ml mark. Silicon was determined using the atomic absorption spectrophotometer.

## 2.3 Statistical Analysis

The data obtained were analyzed by Genstat computer package. The mean significant differences were separated at 5% level, while the relationship between some soil properties vs Silicon was shown.

## 3. RESULTS AND DISCUSSION

## 3.1 Determination of Si

Si was extracted with various extractants, the amounts of the metals removed were lowest from the single acid of extraction, and increased with subsequent chelates (Table 2). HCl, HCl + $H_2SO_4$, and DTPA were found to be the most effective extractants for determining Si respectively. The single and DTPA extraction methods were higher for Si significantly revealing

that the successive extraction is particularly effective for determining Si, as related to pH of the solution.

In addition, three successive extractions increased the pH of the mixture. Among the three methods, DTPA formed higher medium (pH = 7.3) and hence removed larger quantities of Si from the soil than the other extractants, vs depth (Table 2).

The DTPA (pH = 7.3) was higher than that of mixtures treated with HCl and HCl +$H_2SO_4$ . Therefore, DTPA removed higher quantities of silicon than the other two extractants. Ion exchange play an important mechanism for the removal of metals by soil chelates, our study show that acidic dissolution, especially the extractant-soil mixtures with acids or acidic extractants, may be a good alternative to ion exchange [22].

### 3.1.1 Si in soil

Si distribution fractions varied across the seven fractions via the soils depth. Silicon was mainly distributed in residual (F6) fractions, this show higher values of total Si, bound to the residual fractions, revealing that the total Si controls the available pool of silicon for plant uptake and its composition, this is in consonant with an experimental results for oxyanions (W), in the soils-plant system [23], total W controls the bioavailable pool, and a peak value of 93% of total W, bound to the residual fractions, implying that apart from minerals nutrients, this mechanism is similarly associated with metals respectively. The mechanism of Si vs parent materials across the soil depth generally, B>D>C>A, In addition, the forms of Si in the parent materials decreased in the pattern RES, bound residual fractions > EXC, soluble & exchangeable fractions > OM, organic matter fraction. Fractions of distribution is very important in assessing the efficiency of metal extraction through chemical chelates, as a result each fraction varies in the metal that is primarily bound [24]. Exchangeable Si, and Si bound to organic matter, and Fe-Mn oxides are removed by one of the following mechanisms—replacement by $H^+$, formation of complexes with DTPA and acidic dissolution.

### 3.1.2 Forms of silicon vs soil parameters

Organic carbon, sand, silt, calcium, magnesium, potassium, and phosphorus were positively and significantly correlated with all the forms of Silicon, while clay negatively and significantly correlated with all the forms of Silicon. Also in Soil B (Table 4) the clay content of the soil negatively and significantly correlated with all the forms of silicon, whereas the organic carbon, sand, silt, calcium, magnesium and phosphorus properties of the soils positively and significantly correlated with all the forms of Silicon. Similarly, in soil C the soil pH, organic carbon, sand, silt calcium, magnesium, potassium and phosphorus components positively and significantly corrected with all forms of Silicon while the clay content negatively and significantly corrected with all the forms of Silicon. Also, in Soil D the soil pH positively and significantly correlated with Soluble Silicon, Exchangeable Silicon, Carbonate Silicon, Iron oxide Silicon and Total Silicon. While the potassium content negatively and significantly correlated with Carbonate Silicon, Iron oxide Silicon and Total Silicon. The organic carbon, sand, silt, calcium, and magnesium positively correlated with all the forms of Silicon. The potassium content of the soil was also positively and significantly correlated with soluble Silicon and exchangeable Silicon.

## 3.2 Discussion

The increase in clay fraction with soil depth can be ascribed to clay illuviation into the subsoil thus suggesting pedogenic processes of clay lessivage which are wide spread occurrence in inter-tropical soils [25].

The soils pH were moderately acidic. The acid nature of the soils could be ascribed to erosion and leaching of exchangeable bases which is characterized by extreme rainfall. These effects however affect soil nutrient as most basic cations are removed by leaching thereby leaving behind $Al^{3+}$ and $H^+$ that can cause soil acidity. For instance, $Al^3+$ causes acidity by hydrolysis reaction while $H^+$ is by direct dissociation [26]. Brady et al., 2007, reported that most micronutrients including Si is more available at low pH, in that they become soluble. In other words, at slight acid levels of soil, micronutrients are more soluble and their availability increase. The high organic matter content as observed in the study might be due to any of these factors: mineralization of organic matter and reduced burning, erosion, thick vegetation cover, cultivation with adequate return of crop residue [27]. Nitrogen a nutrient element has direct relationship with the organic matter which

supplies over 80% of soil nitrogen. This implied that low organic matter content will invariably affect the nitrogen content of that soil. The result of this study showed that nitrogen content varied among locations. The top 0 - 60 cm depth of koko, sobe and uhomora had high Nitrogen above the critical level reported by 1.5gkg$^{-1}$ [28]. Phosphorus is another major nutrient apart from nitrogen that is required by all plants irrespective of the age of the plant [29]. The P content of the top soils 0 – 30 cm depth varied among location was above critical level of 8 g/kg$^{-1}$ [30], which depicts that P content of the soils were generally high. The high content of P as observed in the study could be attributed to the high organic matter content. These findings were in agreement with [31], in their studies on P distribution and forms in Nigeria basement complex. The high P content may also be due to the low sorption capacity (fixation arising from high Fe and Al oxides) [32]. The exchangeable bases which comprise Ca, Mg, K and Na which varied among location were outwardly low; <5.0 cmol kg$^{-1}$ for Ca, <1.5 cmol kg$^{-1}$ for Mg, <18 cmol kg$^{-1}$ for K and <0.24 cmol kg$^{-1}$ for Na [30]. The low content of the basic cation could be as a result of intensive weathering of the environment, leaching which cause losses of colloidal material and low activity clay which were mostly the 1:1 clay mineralogy [27]. In a related study of the same ecological zone [33] reported same low content of basic cations and this low basic cations was attributed to the kaolinitic nature of the soil and low content of clay.

The values for the single acid extractable Silicon obtained in this study varied with location and depths and were generally above the critical level of 50.0 mg kg$^{-1}$ as reported by [33, 34], below which Silicon becomes deficient in soil. The degree of the extraction was more favorably disposed in alluvium soils compared to Shales, Basement complex and Coaster plain sand for Silicon, this may be due to the nature of the parent material.

The specifically adsorbed Silicon varied with depth and across locations and was higher at the upper depth, which is far below the critical level 50.0 mg kg$^{-1}$ and 100.0 mg kg$^{-1}$ as reported by [33,34], The oxides bound which is considered as Silicon occurred in Al and Fe oxides and hydroxide varied with soil depths and across the locations and was higher at the upper layer than the lower depth 50.0 mg kg$^{-1}$ as reported.

Silicon exchangeable varied with soil depths and across the various locations and tends to be higher at the upper soil depths. This fraction is believed to be part of the most readily available Silicon for plant uptake [35], mainly weakly absorbed by soil components. The lower amount of this fraction of Silicon may be refer to leachable [36].

The residual Silicon fraction constituted the highest proportion of the total Silicon in the soil, they are resistant and may not solubilize under natural condition [37], and falls within the range of 50.0 mg kg$^{-1}$ as reported by [33,34], This fraction is however not related to Silicon available for plant uptake. The range obtained is comparable with that of [38], which ranged from 50.0 mg kg$^{-1}$ and 100.0 mg kg$^{-1}$ as reported by [33,34], and also similar to the findings of [39], (2.03 to 170.85 mgkg$^{-1}$) in the upper depth. Total Silicon in the soil are relatively high which indicates that Silicon exits in soils largely in unavailable form, and was generally distributed in the soil, this may suggest long term sustainability of crops grown in these soils. The higher content of Silicon in the surface of the soil maybe due to the associations of Silicon with organic matter. The results of the study showed that sand and silt fraction of the soil significantly and positively correlated with the forms of Silicon except for few forms across locations. This might be due to the fact that sandy soils enhances leaching of soluble cation that lead to acidity, with more cation displaced, Silicon gets adsorbed into the exchange complex and thus become more available at such acidic medium. Attractively, clay as a soil fraction which is known to have very strong affinity with micronutrients and is one of the fixation agents responsible for immobilization [26], and was found to have a negative but significant relationship. This was in agreement with the findings of [40], who indicated that fractions of readily available form of Silicon are more associated with the sand than clay and silt fraction. This align with the work of [41 & 42] who reported positive correlation of clay with some extractable Silicon. These differences reported could be attributed to the adoption of varied practices, mechanical implement, different soil management, cropping system and the nature of the parent material [25 & 26].

Soil pH were positively and significantly correlated with forms of Silicon in basement complex except in soluble Silicon which had a negative and non-significant correlation, while other parent materials were positively but not significantly correlated, these positive correlation

**Table 1.  Major soil physico-chemical properties**

| Soil ID | pH | OM[a] (gkg$^{-1}$) | Total Si ( mgkg$^{-1}$) | Total Ni (mgkg$^{-1}$) | Available P (mgkg$^{-1}$) | Ca  (cmol(+)kg$^{-1}$) | Na (cmol(+)kg$^{-1}$) | Mg (cmol(+)kg$^{-1}$) | K (cmol(+)kg$^{1}$) |
|---|---|---|---|---|---|---|---|---|---|
| Soil A | 5.42 | 32.41 | 31.93 | 23.63 | 8.51 | 0.66 | 0.15 | 0.24 | 0.28 |
| Soil B | 5.72 | 26.41 | 61.9 | 2.84 | 8.56 | 0.42 | 0.23 | 0.28 | 1.23 |
| Soil C | 6.49 | 25.81 | 50.17 | 26.24 | 6.43 | 1.92 | 0.66 | 0.24 | 0.32 |
| Soil D | 6.04 | 33.88 | 58.11 | 16.56 | 3.63 | 1.18 | 0.15 | 0.27 | 0.60 |

*[a] Organic matter*

**Table 2. BCR speciation of silicon**

| Location/parent material | Depth cm | Sol.Si | Ex.Si | Co$_3$ Si | Fe oxide Si | Org. Bond Si mg/kg | Res. Si | Total Si |
|---|---|---|---|---|---|---|---|---|
| A | 0-30 | 0.23a | 0.29a | 0.20a | 0.24a | 0.34a | 33.62a | 35.80a |
|  | 30-60 | 0.20a | 0.26a | 0.16a | 0.21b | 0.31a | 31.52b | 33.30b |
|  | 60-90 | 0.17b | 0.22b | 0.15b | 0.20bc | 0.28b | 29.93c | 31.48c |
|  | 90-120 | 0.16b | 0.20b | 0.13b | 0.17c | 0.26b | 27.75d | 29.15d |
| B | 0-30 | 0.21a | 0.44a | 0.16a | 0.24a | 0.35a | 68.38a | 70.58a |
|  | 30-60 | 0.18b | 0.39a | 0.14a | 0.19b | 0.33a | 59.30b | 64.45b |
|  | 60-90 | 0.15b | 0.34b | 0.11b | 0.17c | 0.31a | 57.38b | 59.58c |
|  | 90-120 | 0.11c | 0.30b | 0.09b | 0.14d | 0.29a | 51.40b | 53.00d |
| C | 0-30 | 0.28a | 0.76a | 0.32a | 2.40a | 0.48a | 55.45a | 58.60a |
|  | 30-60 | 0.21b | 0.59b | 0.27b | 0.37a | 0.44a | 50.52b | 53.00b |
|  | 60-90 | 0.16c | 0.46c | 0.20c | 0.31a | 0.37b | 45.38c | 47.33c |
|  | 90-120 | 0.12c | 0.30d | 0.14d | 0.22a | 0.31c | 40.27d | 41.77d |
| D | 0-30 | 0.24a | 0.55a | 0.25a | 0.30a | 0.36a | 58.90a | 66.42a |
|  | 30-60 | 0.19b | 0.48b | 0.21b | 0.29a | 0.33ab | 57.75a | 61.15b |
|  | 60-90 | 0.15c | 0.44c | 0.16c | 0.25b | 0.31b | 52.92a | 54.95c |
|  | 90-120 | 0.13d | 0.40d | 0.12d | 0.22c | 0.27c | 48.55a | 49.92d |

*Mean value with same letter(s) are not significantly different at 5% level of probability*

**Table 3. The amount of Si removed with various extractants**

| Location/parent material | Depth (cm) | Single Acid | Double Acid mg/kg | DPTA |
|---|---|---|---|---|
| A | 0-30 | 8.93a | 19.65a | 28.50a |
|   | 30-60 | 8.28ab | 18.40ab | 26.00b |
|   | 60-90 | 7.49bc | 16.40c | 22.68c |
|   | 90-120 | 6.74c | 13.47c | 19.85d |
| B | 0-30 | 10.77a | 27.02a | 50.92a |
|   | 30-60 | 8.76b | 23.43a | 46.70b |
|   | 60-90 | 7.46bc | 18.65b | 43.25b |
|   | 90-120 | 5.97c | 15.57b | 38.73c |
| C | 0-30 | 10.28a | 17.48a | 31.55a |
|   | 30-60 | 7.97b | 13.68b | 25.52b |
|   | 60-90 | 5.19c | 10.19c | 21.27c |
|   | 90-120 | 3.20d | 8.45d | 17.95d |
| D | 0-30 | 8.68a | 21.85a | 43.12a |
|   | 30-60 | 7.90b | 18.82b | 37.23b |
|   | 60-90 | 6.81c | 14.90c | 32.65c |
|   | 90-120 | 6.19c | 11.29d | 26.40d |

*Mean value with same letter(s) are not significantly different at 5% level of probability*

**Table 4. Correlation coefficient between forms of silicon and some properties of soils**

|   |   | Sol.Si | Ex.Si | Co$_3$ Si | Fe oxide Si | Org. Bond Si | Total Si |
|---|---|--------|-------|----------|-------------|--------------|----------|
| A | pH | 0.203 | 0.215 | 0.212 | 0.517 | 215 | 0.468 |
|   | Org.carbon | 0.899* | 0.854* | 0.941* | 0.810* | 0.967* | 0.932* |
|   | Silt | 0.919* | 0.866* | 0.933* | 0.904* | 0.948* | 0.938* |
|   | Clay | -0.883* | -0.821* | -0.917* | -0.872* | -0.948* | -0.923* |
|   | Ca | 0.949* | 0.894* | 0.858* | 0.879* | 0.894* | 0.934* |
|   | Mg | 0.934* | 0.917* | 0.836* | 0.853* | 0.843* | 0.914* |
|   | K | 0.860* | 0.935* | 0.851* | 0.891* | 0.892* | 0.906* |
|   | P | 0.901* | 0.949* | 0.917* | 0.859* | 0.953* | 0.915* |
| B | pH | -0.182 | -0.194 | -0.017 | -0.283 | -0.178 | 0.878* |
|   | Org.carbon | 0.866* | 0.957* | 0.866* | 0.873* | 0.818* | 0.933* |
|   | Silt | 0.912* | 0.976* | 0.903* | 0.882* | 0.895* | 0.953* |
|   | Clay | -0.822* | -0.93* | -0.961* | -0.849* | 0.911* | -0.916* |
|   | Ca | 0.854* | 0.956* | 0.803* | 0.886* | 0.748* | 0.951* |
|   | Mg | 0.837* | 0.887* | 0.903* | 0.908* | 0.858* | 0.965* |
|   | K | 0.860* | 0.989* | 0.756* | 0.897* | 0.859* | 0.950* |
|   | P | 0.852* | 0.945* | 0.857* | 0.896* | 0.878* | 0.945* |
| C | pH | 0.919* | 0.908* | 0.916* | 0.891* | 0.886* | 0.844* |
|   | Org.carbon | 0.919* | 0.896* | 0.968* | 0.974* | 0.978* | 0.938* |
|   | Silt | 0.932* | 0.895* | 0.953* | 0.945* | 0.928* | 0.923* |
|   | Clay | -0.944* | -0.923* | -0.984* | -0.964* | -0.945* | -0.942* |
|   | Ca | 0.832* | 0.799* | 0.840* | 0.828* | 0.850* | 0.954* |
|   | Mg | 0.679* | 0.758* | 0.766* | 0.765* | 0.777* | 0.667* |
|   | K | 0.779* | 0.728* | 0.693* | 0.699* | 0.771* | 0.653* |
|   | P | 0.942* | 0.906* | 0.952* | 0.949* | 0.959* | 0.918* |
| D | pH | 0.584* | 0.642* | 0.497 | 0.618* | 0.286 | 0.790* |
|   | Org.carbon | 0.973* | 0.912* | 0.931* | 0.874* | 0.692* | 0.926* |
|   | Silt | 0.951* | 0.947* | 0.957* | 0.911* | 0.706* | 0.957* |
|   | Clay | -0.840* | -0.839* | -0.906* | -0.809* | -0.841* | -0.753* |
|   | Ca | 0.842* | 0.864* | 0.797* | 0.772* | 0.797* | 0.920* |
|   | Mg | 0.817* | 0.801* | 0.819* | 0.933* | 0.673* | 0.929* |
|   | K | 1.000* | 0.899* | -0.776* | -0.800* | -0.508* | -0.782* |
|   | P | 0.970* | 0.884* | 0.908* | 0.867* | 0.811* | 0.949* |

was in line while the negative correlation obtained may be due to larger solubility of Silicon in acidity, type of parent material, climatic factors and diverse agronomic practices. The positive correlation obtained between organic matter and forms of Silicon suggests a strong association between extractable Silicon, and organic matter, indicating Silicon being a composite part of organic matter. This result was in line with the studies on micronutrients reported by [43 &44], who reported that the positive correlation between extractable Silicon, and organic matter could be tied to the organic constituent of the soil since the organic constituent of a given soil provide more exchange site for boron adsorption in the soil. The positive relationship between N, P, K, Ca, Mg indicates synergistic relationship of these nutrient elements with Silicon.

## 4. CONCLUSION

The findings of the study showed that the soil were textually sand and sandy loam, ranged from moderately acidic to slightly alkaline, low in organic matter, total N and available P. The basic cations and ECEC indicated low fertility status of the soil. The extractable Silicon content of the soil varied from one location to another and concentrated more at the surface than the lower soil depth. Generally, the extractable Silicon content decreased with increased soil depth. The soil Silicon level could be said to be below the critical level established method for available Silicon. The extractable Silicon seem to be more in terms of the amount extracted at the top soil across the various locations. This was followed by double acid extraction method, while the least was obtained with single acid extraction method. The residual Silicon had the highest content and this showed that silicon exist largely in the unavailable form, due to the bound fractions in soils. The correlation between extractable Silicon, and soil properties (Sand, Silt, Clay, pH, Organic matter, Nitrogen, Phosphorus, Magnesium, and CEC showed their influence on Silicon availability. Generally, the value of extractable Silicon established in this study showed that they were not within the sufficiency range (50.0 mg kg$^{-1}$) and may have negative effect on crop production but application of organic fertilizers might trigger Silicon from the deficient level to a more sufficient level in these locations. However, the soil must be maintained and conserved.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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