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# Soil Physicochemical Properties as Influenced by Persistent Herbicide Weed Control in Some Communities in Ondo State, Nigeria

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**ABSTRACT:** This study identified areas where different types of herbicide were used for municipal weed control in selected residential communities in Akure, Akungba-Akoko and Owo in Ondo State, Nigeria. A survey of the communities was carried out to identify sites maintained with herbicides (test sites) and those without herbicide history (control sites). Composite soil samples collected from each site were analyzed using standard laboratory procedures for the determination of selected soil physical and chemical properties. The data obtained were subjected to statistical analysis of variance (ANOVA). Results obtained indicated that the soil texture of the study sites were mostly sandy loam while pH ranged from slightly acidic to neutral. Significant differences ($P < 0.05$) were observed in the organic carbon (OC) contents of soil samples from Owo as against the samples from Akure and Akungba-Akoko though Owo had the highest OC ($24.48 \pm 9.36$ g kg$^{-1}$) followed by Akungba-Akoko ($21.21 \pm 10.36$ g kg$^{-1}$) and Akure ($18.10 \pm 7.75$ kg$^{-1}$) which was the lowest. However, no significant differences ($P < 0.05$) were observed in the values of the micronutrients and exchangeable cations across all the sites. Conclusively, application of herbicides to weeds did not have significant effect on the soil fertility (in all the sites) in the short run (2013 - 2015) but more aggressive application could have deleterious effects in the long run because leaching is encouraged as a result of the sandy nature and low organic carbon content of the soil in the study areas.

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An herbicide is said to be persistent if it is present in the soil in its original or closely related to its phytotoxic forms (Sankaran *et al*., 1993; Sondhia, 2014). The remaining quantity of herbicide after weed control is referred to as its residue while its soil persistence is often described as its "half-life" which is the amount of time it takes to decompose 50 percent of the applied chemical to an herbicidal inactive form. Soil factors affecting herbicide persistence fit into three categories: physical, chemical and microbial (Hager e*t al*., 2000). Soil composition is a physical factor that measures the relative amounts of sand, silt, and clay (the soil texture) and the organic matter content of the soil. This factor affects herbicide persistence through adsorption, leaching and volatilization. Generally, soils that are high in clay/organic matter or both, have greater potential for herbicide carryover because there is increased adsorption to soil colloids with a corresponding decrease in leaching and loss through volatilization. This "tie-up" results in decreased initial plant uptake and herbicidal activity (William, 2015). Chemical properties of a soil which include the pH, total nitrogen, organic carbon, available phosphorus, exchangeable bases (sodium, calcium, potassium and magnesium) and the cation exchange capacity (CEC) indicate its nutrient status. Some herbicides are particularly affected by soil pH such that lesser amounts of these herbicides are adsorbed or adhered to soil colloids at higher soil pH, so they remain in the soil solution. Herbicides in the soil solution are available for plant uptake. Various nutrients and cations in the soil have been observed to affect both herbicide activity and degradation. The CEC, principally a function of clay-type and organic matter content, is directly involved in herbicide adsorption.

In recent times, the rate at which herbicides are applied to control weeds at residential areas in urban environment has increased rapidly especially in Nigeria (Bulu *et al*., 2017). This aggressive application has been reported to have adverse effect on the environment. The increasing use of herbicides with high potential mobility may pose serious environmental problems through offsite transport. This research was therefore done with a view to assessing the effects of the frequent use of herbicides for weed control around homes on the physical and chemical properties of soil in selected communities in Ondo State, Nigeria.

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## MATERIALS AND METHOD

The study was carried out in selected urban communities namely, Akungba-Akoko, Owo and Akure in Ondo State which are located in the South western part of Nigeria. The climate of the State is typically tropical of two distinct seasons. The rainy season begins in March and ends in September or early October with a short dry spell in August commonly known as August break while the dry season commences in October and ends in March (Odekunle, 2004). A general inspection of the communities was carried out to identify sites where weeds were managed by herbicide (test sites) and those without herbicide history (control sites) (Table 1).

In carrying out the study, simple random sampling technique was employed and composite soil samples were collected from the different experimental sites at Akungba-Akoko (6), Owo (6), and Akure (4). The reduced number of experimental sites in Akure was due to the absence of convenient experimental plot. At each sample plot, soil auger was used to collect soil at a depth of 0 – 15 cm at three sub-locations representing three replicates and a composite sample prepared from the replicates. Soil samplings were carried out three times at an interval of six months from 2013 to 2015 to give a total of 63 soil samples. The samples were air-dried and sieved with a 2.0 mm mesh. The physicochemical properties of the thoroughly-mixed soil samples (from three sub-locations within a major location) were analyzed using the following methods: The soil pH was measured with a pH meter using soil to water ratio of 1:1 (w/v); particle size analysis was determined using hydrometer method as outlined by Bouyoucos (1951); and the values of the exchangeable cations ($Ca^{2+}$, $Mg^{2+}$, $K^{+}$ and $Na^{+}$) were determined by employing the method of Thomas (1982). The micronutrients (Zn and Fe) in the soil were extracted according to the description of Viets and Boawn (1965) and their concentrations in the extracts read on the Atomic Absorption Spectrophotometer (AAS). Total organic carbon was determined following the wet digestion method as described by Walkley and Black (1934), whereas micro Kjeldahl procedure was used for the determination of total nitrogen (Bremner and Mulvaney, 1982). The available phosphorus was determined using Bray $P_1$ method (Olsen and Sommers, 1982).

**Table 1**: Location of the studied sites in Ondo State

| Community | Sites | Location | |
|---|---|---|---|
| Akure | | | |
| | HTS 1 | N07 13'36.2" | E005 11'55.8" |
| | HTS 2 | N07 13'39.6" | E005 11'56.7" |
| | HTS 3 | N07 13'42.4" | E005 11'58.2" |
| | NHTS (Control) | N07 13'26.4" | E005 11'38.3" |
| Owo | | | |
| | HTS 1 | N07°11’47.7 | E005°34’41.5 |
| | HTS 2 | N07°12’53.7 | E005°33’20.1 |
| | HTS 3 | N07°12’40.0 | E005°35’54.2 |
| | HTS 4 | N07°10’54.9 | E005°35’02.0. |
| | HTS 5 | N07°11’04.3 | E005°34’34.9 |
| | NHTS (Control) | | |
| Akungba-Akoko | HTS 1 | N07 28'39.9" | E005 44'18.9" |
| | HTS 2 | N07 27'17.0" | E005 44'03.9" |
| | HTS 3 | N07 27'18.7" | E005 44'02.8" |
| | HTS 4 | N07 29'06.5" | E005 44'11.8" |
| | HTS 5 | N07 28'20.0 | E005 44'10.8" |
| | NHTS (Control) | N07 28'56.7" | E005 44'25.8" |

*Data Collection and Statistical Analysis:* Data were collected on the above-mentioned physical and chemical properties and statistical tools employed to analyze them. Statistical comparison of means of data from the soil physicochemical parameters between the control (NHTS) and herbicide-treated sites (HTS) was carried out after ANOVA and mean separation was done by using Duncan Multiple Range Test (available in the SPSS 17 statistical package).

## RESULTS AND DISCUSSION

*Some physicochemical properties of soil samples from Akure, Ondo State*: The pH values of soil samples from all the HTS were lower than those from the control sites (Table 2), thus ANOVA indicated significant difference ($p<0.05$). The organic carbon, total nitrogen and available phosphorus contents of HTS 2 (28.99 ± 2.23, 2.99± 0.01 g $kg^{-1}$ and 12.29 ± 1.28 mg $kg^{-1}$ respectively) and HTS 3 (20.79 ± 0.15, 2.15 ± 0.01 g $kg^{-1}$ and 17.90 ± 0.38 mg $kg^{-1}$ respectively) were significantly different ($p < 0.05$) sequel to their higher values above those of the NHTS (12.62 ± 0.25,1.31 ± 0.29 g kg$^{-1}$ and 4.71 ± 0.19 mg kg$^{-1}$ respectively).

The exchangeable acidity of all the HTS showed no significant difference except HTS 1 where a significant difference was recorded ($p > 0.05$) between herbicide-treated sites and the control. The exchangeable $Ca^{++}$, $Mg^{++}$ and $K^{+}$ contents of HTS 1 were 3.50 ± 0.01, 3.91 ± 0.06 and 0.46 ± 0.02 cmol kg$^{-1}$) respectively while that of HTS 2 were 4.09 ± 0.01, 1.81 ± 0.01 and 0.51 ± 0.01 cmol kg$^{-1}$ with a significant different ($p < 0.05$) owing to higher values than that of the control sites (2.62 ± 0.02, 1.69 ± 0.01 and 0.05 ± 0.01 cmol kg$^{-1}$ respectively). Significantly differences ($p < 0.05$) were obtained in manganese contents from HTS 1, 2 and 3 respectively (7.10 ± 0.10, 16.00 ± 0.01 and 6.60 ± 0.10 mg kg$^{-1}$) as well as copper (0.21 ± 0.01, 0.50 ± 0.03, 0.16 ± 0.02 mg kg$^{-1}$). HTS 1 and 2 were sandy loam while HTS 3 and NHTS were loamy sand.

*Some physicochemical properties of soil samples from Akungba-Akoko, Ondo State:* The pH ($H_2O$) of the soil samples from Akungba-Akoko HTS ranged from 6.33 (Site 5) to 7.40 (Site 4) as shown in Table 3 below. The pH of HTS 1, 4 and the control were not significantly different from one another but significantly higher compared to HTS 2 and 5. HTS 5 had the highest values of organic carbon and total nitrogen (36.02 ± 0.01 and 3.74 ± 0.01 g kg$^{-1}$ respectively) which were also significantly ($p > 0.05$) higher than that of the control site (23.75 ± 0.01 and 2.45 ± 0.01 g kg$^{-1}$).

All HTS did not differ significantly in the values of their exchangeable acidity compared with the control. The exchangeable $Ca^{++}$ from the control site (4.23 ± 0.01 cmol kg$^{-1}$) was significantly higher than those from the HTS while the exchangeable $Mg^{++}$content from HTS 5 was significantly ($p > 0.05$) higher than other HTS and the control which had the lowest value of 0.70 ± 0.10 cmol kg$^{-1}$. The $K^{+}$ content of the soil samples from HTS 5 did not differ significantly from the control but both were significantly higher than other HTS. The values of the micronutrients, iron, copper, and zinc from all the HTS were significantly lower than those from the control sites (32.50 ± 0.10, 0.57 ± 0.01 and 5.8 ± 0.01mg kg$^{-1}$). HTS 2 and the NHTS were loamy sand while others were sandy loam

*Some physicochemical properties of soil samples from Owo, Ondo State:* The physical and chemical properties of the soil samples collected from Owo HTS and NHTS are as presented in Table 4 below. While the pH of the HTS 1 - 4 and NHTS differed significantly from one other, HTS 5 and 6 did not vary significantly from each other.

**Table 2**: Physicochemical properties of soil from sites with and without herbicide treatment at Akure, Ondo State

| | Experimental locations | | | |
|---|---|---|---|---|
| Physicochemical parameters | HTS 1 | HTS 2 | HTS 3 | NHTS |
| pH ($H_2O$) 1:1 | 7.40 ± 0.08b | 7.30 ± 0.05b | 6.80 ± 0.31c | 7.60 ± 0.72a |
| Organic carbon (g kg$^{-1}$) | 10.02 ± 0.03d | 28.96 ± 2.23a | 20.79 ± 0.15b | 12.62 ± 0.25c |
| Total nitrogen (g kg$^{-1}$) | 1.04 ± 0.02d | 2.99 ± 0.01a | 2.15 ± 0.01b | 1.31 ± 0.29c |
| Available phosphorus (mg kg$^{-1}$) | 3.57 ± 0.46d | 12.29 ± 1.28b | 17.90 ± 0.38a | 4.71 ± 0.19c |
| Exchangeable acidity (cmol kg$^{-1}$) | 0.40 ± 0.01a | 0.30 ± 0.01b | 0.30 ± 0.01b | 0.30 ± 0.01b |
| Exchangeable cations (cmol kg$^{-1}$) | | | | |
| $Ca^{++}$ | 3.50 ± 0.01b | 4.09 ± 0.01a | 1.83 ± 0.03d | 2.62 ± 0.02c |
| $Mg^{++}$ | 3.91 ± 0.06a | 1.81 ± 0.01b | 1.46 ± 0.01d | 1.69 ± 0.01c |
| $K^{+}$ | 0.46 ± 0.02b | 0.51 ± 0.01a | 0.41 ± 0.01b | 0.05 ± 0.01c |
| $Na^{+}$ | 0.19 ± 0.01d | 0.28 ± 0.01c | 0.33 ± 0.01b | 0.40 ± 0.01a |
| Extractable micronutrients (mg kg$^{-1}$) | | | | |
| Mn | 7.10 ± 0.10b | 16.00 ± 0.01a | 6.60 ± 0.10c | 6.00 ± 0.01d |
| Fe | 51.70 ± 0.01a | 23.90 ± 0.01d | 44.50 ± 0.01b | 41.80 ± 0.01c |
| Cu | 0.21 ± 0.01b | 0.50 ± 0.03a | 0.16 ± 0.02c | 0.04 ± 0.02d |
| Zn | 2.21 ± 0.01c | 8.37 ± 0.02b | 13.05 ± 0.01a | 1.16 ± 0.01d |
| Clay (g kg$^{-1}$) | 94.00 | 74.00 | 54.00 | 94.00 |
| Silt (g kg$^{-1}$) | 234.00 | 214.00 | 154.00 | 94.00 |
| Sand (g kg$^{-1}$) | 672.00 | 712.00 | 792.00 | 812.00 |
| Soil textural classes | Sandy loam | Sandy loam | Loamy sand | Loamy sand |

*Means with the same letter(s) in each row are not significantly different ($p < 0.05$) according to Duncan's Multiple Range Test (DMRT)*
*HTS1 = Herbicide-treated site 1, HTS2= Herbicide-treated site2, HTS3 = Herbicide-treated site 3, NHTS = Non-herbicide-treated site*

HTS 4 had the highest value of organic carbon and total nitrogen (40.33 ± 0.02 and 4.22 ± 0.01 g kg$^{-1}$) content which were also significantly higher than those of the soil samples from the control site (30.81 ± 0.01 and 3.19 ± 0.01 g kg$^{-1}$). HTS 2, however, had the lowest value of organic carbon and total nitrogen contents (14.48 ± 0.03 and 1.50 ± 0.01g kg$^{-1}$) with significant difference at $p < 0.05$. The highest $Mg^{++}$ (1.76 ± 0.01 cmol kg$^{-1}$) and $Na^{+}$ (0.41 ± 0.01 cmol kg$^{-1}$) contents were recorded for the control site which were significantly higher ($p < 0.05$) than the values from the HTS. Variability were obtained for the values of the extractable micronutrients from all the sites although HTS 5 had the highest value of manganese, iron and zinc (32.20 ± 0.01, 15.10 ± 0.10 and 9.36 ± 0.01mg kg$^{-1}$respectively). All soils were sandy loam in texture.

*Some physicochemical properties of soil sample from Ondo State:* Table 5 shows the means of some chemical properties of soil samples collected from the HTS at Akure, Akungba-Akoko and Owo. Only the soil pH of 7.27 from Akure was significantly ($p < 0.05$) higher than those of soil samples from the other sites.

The organic carbon contents of soil samples from Owo (24.48 ± 9.36 g kg$^{-1}$) were significantly ($p < 0.05$) higher compared to samples from Akure (18.10 ± 7.75 kg$^{-1}$), although values for soil samples from both communities did not vary significantly from those collected from Akungba-Akoko (21.21 ± 10.36 g kg$^{-1}$). The soil pH (Akure, 7.27 ± 0.31; Akungba-Akoko, 6.91 ± 0.46 and Owo, 6.58 ± 0.56) and the exchangeable acidity in cmol kg$^{-1}$ (Akure, 0.33 ± 0.05; Akungba-Akoko, 0.38 ± 0.08 and Owo, 0.38 ± 0.08) values did not differ significantly across the sites. Variable values were obtained for the extractable micronutrients and the exchangeable cations across all the sites.

**Table 3:** Physicochemical properties of soil from sites with and without herbicide weed control at Akungba-Akoko, Ondo State**.**

| | Experimental locations | | | | | |
|---|---|---|---|---|---|---|
| Physicochemical parameters | HTS 1 | HTS 2 | HTS 3 | HTS 4 | HTS 5 | NHTS |
| pH ($H_2O$)1:1 | 7.27 ± 0.25a | 6.40 ± 0.10c | 6.80 ± 0.10b | 7.40 ± 0.10a | 6.33 ± 0.15c | 7.30 ± 0.10a |
| Organic carbon (g kg$^{-1}$) | 9.65±0.01e | 9.64 ± 0.10e | 31.11 ± 2.63b | 17.07 ± 0.01d | 36.02 ± 0.01a | 23.75 ± 0.01c |
| Total nitrogen (g kg$^{-1}$) | 0.98 ± 0.01f | 1.03 ± 0.02e | 3.24 ± 0.01b | 1.76 ± 0.01d | 3.74 ± 0.01a | 2.45 ± 0.01c |
| Available phosphorus (mg kg$^{-1}$) | 3.68 ± 0.26c | 2.79 ± 0.14c | 3.41 ± 0.20c | 2.79 ± 0.10c | 7.98 ± 0.62b | 11.01 ± 1.32a |
| Exchangeable acidity (cmol kg$^{-1}$) | 0.33 ± 0.03a | 0.43 ± 0.03a | 0.40 ± 0.10a | 0.40 ± 0.10a | 0.30 ± 0.10a | 0.40 ± 0.10a |
| Exchangeable cations (cmol kg$^{-1}$) | | | | | | |
| $Ca^{++}$ | 1.13 ± 0.02e | 0.40 ± 0.10f | 1.73 ± 0.02c | 2.85 ± 0.01b | 1.58±0.01d | 4.23 ± 0.01a |
| $Mg^{++}$ | 1.04 ± 0.01c | 0.68 ± 0.01e | 1.60 ± 0.10b | 0.83 ± 0.02d | 1.93 ± 0.01a | 0.70 ± 0.10e |
| $K^{+}$ | 0.23 ± 0.11d | 0.25±0.01d | 1.23 ± 0.02b | 0.83 ± 0.02c | 2.06 ± 0.01a | 2.07 ± 0.01a |
| $Na^{+}$ | 0.36 ± 0.01b | 0.37±0.01b | 0.43 ± 0.03a | 0.28 ± 0.01c | 0.44 ± 0.01a | 0.35 ± 0.01b |
| Extractable micronutrients (mg kg$^{-1}$) | | | | | | |
| Mn | 12.70 ± 0.25b | 11.40±0.10c | 22.60 ± 0.10a | 4.26 ± 0.25f | 5.30 ± 0.10e | 9.40 ± 0.10d |
| Fe | 11.40 ± 0.10d | 9.33±0.15e | 15.37 ± 0.15c | 28.26 ± 0.25b | 15.20 ± 0.10c | 32.50 ± 0.10a |
| Cu | 0.13 ± 0.02c | 0.04 ± 0.01d | 0.14 ± 0.01c | 0.23 ± 0.02b | 0.15 ± 0.01c | 0.57 ± 0.01a |
| Zn | 0.40 ± 0.10c | 0.33 ± 0.02c | 0.40 ± 0.10c | 0.20 ± 0.10d | 0.86 ± 0.01b | 5.8 ± 0.01a |
| Clay (g kg$^{-1}$) | 114.00 | 54.00 | 54.00 | 94.00 | 80.00 | 40 |
| Silt (g kg$^{-1}$) | 134.00 | 94.00 | 274.00 | 194.00 | 174.00 | 214 |
| Sand (g kg$^{-1}$) | 752.00 | 852.00 | 672.00 | 712.00 | 746.00 | 745 |
| Soil textural classes | Sandy loam | Loamy sand | Sandy loam | Sandy loam | Sandy loam | Loamy sand |

Means with the same letter(s) in each row are not significantly different ($p < 0.05$) according to Duncan's Multiple Range Test
Legend: HTS 1 = Herbicide-treated site 1, HTS2= Herbicide-treated site2, HTS3 = Herbicide-treated site 3, HTS 4 = Herbicide-treated site 4, HTS 5 = Herbicide-treated site 5, NHTS = Non-herbicide-treated site

The textural class of the soil from different study locations was sandy loam. This indicates appreciable quantity of sand in them. The predominance of sand in the soils may be due to the nature of the humid tropical soils of Nigeria that are generally sandy (Fashina *et al.*, 2015). Application of herbicide around the ambience of living has always been carried out during the rainy season which favours leaching of its components into ground water and streams. Removal, translocation and loss of herbicides residue from the soil profile due to the torrential rainfall will also take place (Faniran and Areola, 1987; Ogunkunle, 2013). This agrees with Stougaard *et al.* (1990) who reported that adsorption of herbicide to soil is highest in silty clay loam and least in the sandy loam soil. The sandy loam texture would partly enhance the removal of herbicides from the soils and increase their mobility in the soil environment (Stougaard *et al*., 1990). The implication of this is that more herbicide will be needed for weed control resulting in additional environmental pollution. The soils pH values were slightly acidic to neutral. The implication of this pH level is that less herbicide will be adsorbed at the soil surface. Adsorption of herbicide is pH-dependent with maximum adsorption occurring at low pH (Brady and Weils, 2002). This is also supported by the report of

Pang *et al*. (2007) which stated that the low water solubility of pesticide at low pH could contribute to the high adsorption level because the retention of a pesticide onto organic surface is often inversely correlated to its water solubility. This is in line with Rigi *et al*. (2015) who observed that the adsorption of herbicide in soil is negatively correlated with pH. Variations occurred in the concentrations of the organic carbon contents of the HTS relative to the control.

**Table 4:** Physicochemical properties of soil from sites with and without herbicide weed control at Owo, Ondo State.

| | Experimental locations | | | | | |
|---|---|---|---|---|---|---|
| Physicochemical parameters | HTS 1 | HTS 2 | HTS 3 | HTS 4 | HTS 5 | NHTS |
| pH ($H_2O$)1:1 | 6.10 ± 0.10d | 5.70 ± 0.10e | 6.80 ± 0.10b | 6.60 ± 0.10c | 7.10 ± 0.10a | 7.20 ± 0.10a |
| Organic carbon (g $kg^{-1}$) | 26.36 ± 0.11c | 14.48 ± 0.03f | 18.56 ± 0.02d | 40.33 ± 0.02a | 16.33 ± 1.00e | 30.81 ± 0.01b |
| Total nitrogen (g $kg^{-1}$) | 2.73 ± 0.01c | 1.50 ± 0.01f | 1.92 ± 0.02d | 4.22 ± 0.01a | 1.69 ± 0.01e | 3.19 ± 0.01b |
| Available phosphorus (mg $kg^{-1}$) | 3.47 ± 0.65c | 2.20 ± 0.01d | 4.27 ± 0.39b | 5.60 ± 0.23a | 4.23 ± 0.13b | 5.56 ± 0.12a |
| Exchangeable acidity (cmol $kg^{-1)}$ | 0.40 ± 0.10ab | 0.30 ± 0.10b | 0.30 ± 0.00b | 0.30 ± 0.10b | 0.50 ± 0.10a | 0.30 ± 0.10b |
| Exchangeable cations (cmol $kg^{-1}$) | | | | | | |
| $Ca^{++}$ | 0.70 ± 0.10d | 4.19 ± 0.10b | 4.84 ± 0.02a | 4.87 ± 0.02a | 1.57 ± 0.02c | 2.01 ± 0.01c |
| $Mg^{++}$ | 0.84 ± 0.01e | 1.51 ± 0.01c | 1.69 ± 0.01b | 1.83 ± 0.10a | 1.01 ± 0.01d | 1.76 ± 0.01a |
| $K^+$ | 0.12 ± 0.01c | 0.46 ± 0.01b | 0.96 ± 0.01a | 0.50 ± 0.10b | 0.13 ± 0.01a | 0.41 ± 0.01b |
| $Na^+$ | 0.40 ± 0.00a | 0.29 ± 0.02c | 0.31 ± 0.01b | 0.28 ± 0.01c | 0.32 ± 0.01b | 0.41 ± 0.01a |
| Extractable micronutrients (mg $kg^{-1}$) | | | | | | |
| Mn | 5.00 ± 0.02e | 6.10 ± 0.10d | 2.80 ± 0.01f | 26.50 ± 0.01b | 32.20 ± 0.01a | 22.80 ± 0.10c |
| Fe | 6.07 ± 0.06f | 8.20 ± 0.10e | 12.4 ± 0.10c | 9.30 ± 0.10d | 15.10 ± 0.10a | 14.30 ± 0.10b |
| Cu | 0.16 ± 0.01b | 0.21 ± 0.01a | 0.17 ± 0.01b | 0.11 ± 0.01c | 0.09 ± 0.01d | 0.12 ± 0.01c |
| Zn | 1.67 ± 0.01d | 0.05 ± 0.01f | 2.76 ± 0.01c | 7.16 ± 0.01b | 9.36 ± 0.01a | 0.38 ± 0.01e |
| Clay (g $kg^{-1}$) | 60.00 | 80.00 | 60.00 | 60.00 | 80.00 | 60.00 |
| Silt (g $kg^{-1}$) | 184.00 | 174.00 | 234.00 | 234.00 | 154.00 | 194.00 |
| Sand (g $kg^{-1}$) | 756.00 | 746.00 | 706.00 | 706.00 | 766.00 | 746.00 |
| Soil textural classes | Sandy loam | Sandy loam | Sandy loam | Sandy loam | Sandy loam | Sandy loam |

*Means with the same letter(s) in each row are not significantly different (p <0.05) according to DMRT*
*Legend: HTS 1 = Herbicide-treated site 1, HTS 2= Herbicide-treated site 2, HTS 3 = Herbicide-treated site 3, HTS 4 = Herbicide-treated site 4, HTS 5 = Herbicide-treated site 5, NHTS = Non-herbicide-treated site*

**Table 5:** Physicochemical properties of soil from sites with and without herbicide weed control at Ondo State, South-Western Nigeria

| Physicochemical parameters | Akure | Akungba-Akoko | Owo |
|---|---|---|---|
| pH ($H_2O$)1:1 | 7.27 ± 0.31a | 6.91 ± 0.46a | 6.58 ± 0.56a |
| Organic carbon (g $kg^{-1}$) | 18.10 ± 7.75b | 21.21 ± 10.36ab | 24.48 ± 9.36a |
| Total nitrogen (g $kg^{-1}$) | 1.87 ± 0.80b | 2.20 ± 1.08ab | 2.54 ± 0.98a |
| Available phosphorus (mg $kg^{-1}$) | 9.62 ± 6.13a | 5.28 ± 3.26b | 4.23 ± 1.25b |
| Exchangeable acidity (cmol $kg^{-1}$) | 0.33 ± 0.05a | 0.38 ± 0.08a | 0.35 ± 0.12a |
| Exchangeable cations (cmol $kg^{-1}$) | | | |
| $Ca^{++}$ | 3.01 ± 0.90a | 1.99 ± 1.28b | 3.03 ± 1.71a |
| $Mg^{++}$ | 2.22 ± 1.03a | 1.13 ± 0.49b | 1.44 ± 0.39b |
| $K^+$ | 0.36 ± 0.19b | 1.11 ± 0.78a | 0.43 ± 0.29b |
| $Na^+$ | 0.30 ± 0.08a | 0.37 ± 0.06a | 0.34 ± 0.05a |
| Extractable micronutrients (mg $kg^{-1}$) | | | |
| Mn | 8.93 ± 4.28b | 10.94 ± 6.20b | 15.90 ± 11.97a |
| Fe | 40.48 ± 10.69a | 18.68 ± 8.88b | 10.90 ± 3.38c |
| Cu | 0.23 ± 0.18a | 0.21 ± 0.18a | 0.14 ± 0.04a |
| Zn | 6.20 ± 5.03a | 1.34 ± 2.09c | 3.56 ± 3.59b |

*Means with the same letter(s) in each row are not significantly different (p < 0.05) according to DMRT*

The organic carbon contents of soils from the study were very low according to the rating of Landon (19191) (> 20% very high, 10-20% high, 4-10% medium, 2-4% low and < 2%very low). Low organic carbon contents were, however, obtained in the soil of some of the HTS in Akure and Owo. Poor root growth of weeds due to their suppression by herbicide might be the reason for decline in the organic carbon content. Organic carbon favours the adsorption of herbicide to their surface, hence increasing its persistence in the soil (Bansal, 2010; Rigi *et al*., 2015). The low content of organic carbon present in the soil will encourage low adsorption of the herbicide and its residues to the soil surface thus reducing its persistence and efficacy in the soil. The implication of this is that higher quantities of herbicide would be needed to effectively control weeds in the environment. The total nitrogen content of the sites studied were of low to medium fertility status according to Singh (2002) rating (< below 0.15% low, 0.15 - 0.20% medium and > 0.20% high). The low status of the nitrogen content of the soil followed the same pattern as the soil organic matter. The reported decrease may be due to high sensitivity of nitrogen fixing bacteria to the herbicide (Zafar *et al*., 2014). The available phosphorus in the control sites were low compared to the HTS except from some sites in Akure which were of medium fertility level according to the rating of Singh (2002) (< 8 ppm low, 8-20 ppm medium and > 20 ppm high). High concentration of the exchangeable bases ($Ca^{++}$, $Mg^{++}$, $Na^+$ and $K^+$) and micronutrients (Cu) were recorded on the experimental sites. This could be attributed to the chelating ability of most herbicide compounds to form complexes with the exchangeable bases (Sebiomo *et al.*, 2012). The absence of vegetation on the sites to take up the available minerals may also increase the concentration of these ions in soil. Low concentration of calcium ions were observed in most of the soil samples from Akungba-Akoko. This could be linked to the fact that the radical application of herbicide in the environment exposed the soil surface to torrential rainfall and resulted in leaching of the calcium ions. Reduced concentration of iron and zinc were also recorded on the sites. This is not in agreement with the work of Sebiomo *et al.* (2012) who reported significant increase in iron and zinc concentrations in soils treated with atrazine, primextra, paraquat and glyphosate herbicides.

*Conclusion:* It could be inferred from this study that the level of effectiveness of herbicides in the sites investigated was low considering the fact that torrential rainfall is prevalent in these sites. The low organic matter content available in the sandy loam nature of the soil also resulted in low adherence of the herbicide to soil particles. This ineffectiveness of the herbicide will necessitate addition of more herbicide to eradicate weeds in the environment leading to more chemicals in the soil and the environment at large.

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