The Dynamics of Soil Physical Properties and Exchangeable Cations in Secondary Forests Regenerating from Degraded Abandoned Rubber Plantation (*Hevea brasiliensis)* in Orogun Area of Southern Nigeria

V.I. Ichikogu
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Abstract

The regeneration of soil physicochemical properties in three secondary forest fields aged 1, 5 and 10 years of age following the abandonment of degraded rubber (Hevea brasiliensis) plantation in Orogun were investigated. In addition a mature forest was selected and investigated as the control. Values of important indices of soil physicochemical parameters were ascertained for the three secondary forests categories and the mature forest. The results obtained revealed that there was no significant improvement or changes in soil particle size composition during the course of secondary forest regeneration. The concentrations of the exchangeable cations were higher in the mature forest than the different secondary forest categories. Soil bulk density decreased while water holding capacity and total porosity of soil increased with increasing age of secondary forest. Exchangeable cations improved in the first five year of secondary forest regeneration, after which their values declined by the tenth year in the topsoil (0-10cm layer). Similarly, exchangeable potassium and sodium improved significantly in the subsoil (10-30cm layer) by the fifth year of secondary forest regeneration from degraded abandoned rubber plantation, after which their values declined by the tenth year. However, exchangeable magnesium and calcium declined in the subsoil throughout the course of forest recovery. Effective cation exchange capacity in the topsoil and the subsoil increased linearly with increasing age of secondary forest, while soil pH decreased with increasing age of secondary forest. These results demonstrate that fallowing exerts beneficial effects on soil fertility (i.e. soil fertility improved as fallow age increased).

Keywords: Dynamics, Secondary forests, Degraded, Abandoned rubber plantations, Exchangeable cations, total porosity.

Introduction

Over much of southern Nigeria secondary forest conversion for subsistence agriculture, industrial logging and plantation agriculture continue to be the predominant causes of deforestation. These activities have left a large portion of the forest biome disturbed and in various states of natural regeneration (Brown and Lugo, 1990), stagnation (Fearnside and Guimaraes 1996, Samiento 1997, Silver et al 2000) or managed recovery (Fernandes and Matos 1995, Parrota et al 1997). The primary forests were cleared and used for plantation agriculture. However, most of the plantations are now abandoned because of poor productivity, plant diseases and death of tree plants arising from inappropriate tapping or other reasons. Therefore, most of the areas that were occupied by are now occupied by secondary forests in different stages of fallow. This land use change could alter the structure and function of any ecosystem, trigger off new feedbacks in terms of subsequent human use (Peet 1992, Buol 1994) and alter the physical and nutrient status of the soil.

Although highly altered, these lands are valuable for human use (Brown and Lugo 1990) and provide important ecosystem services such as watershed protection, sources and havens of biodiversity, erosion prevention, soil fertility recovery by improved fallows (Scalley et al., 2010) and atmospheric carbon sinks (Fearnside and Guimares 1996, Silver et al., 2000). However the potential of the abandoned land to recover and maintain these roles is dependent on the intensity of previous land use (Uhl et al., 1988, Nepstand

Department of Urban and Regional Development, Federal Ministry of Environment, Housing and Urban Development, Abuja, Nigeria. victorichikogu@yahoo.com

1990, Aide et al., 1995, Alves et al., 1997), soil nutrient limitations (Nepstand et al., 1996), and seed inputs and seedling establishment (Nepstand et al., 1996). These impediments to vegetation growth may be more extreme in abandoned tree plantation compared to shifting cultivation.

Plantation agriculture of rubber, which in most instances proved to be little more permanent than shifting cultivation, is a major cause of secondary forest in Nigeria. A large proportion of the plantations of rubber are abandoned today because of soil nutrient impoverishment, animal pests, plant diseases or other reasons, and as such large areas of secondary forest now developed on the sites that were occupied by rubber plantations.

In Nigeria, previous works on soil dynamics in secondary forests have tended to concentrate more on secondary forests regenerating from shifting cultivation agricultural practices (Aweto, 1978; Adedeji, 1984) and on plantation (Oladoye et al., 2007; Adedeji 2008). Studies on the analysis of the dynamics of soil in secondary forest regenerating from degraded abandoned rubber plantation have received minimal attention by researchers in recent times. Therefore, our understanding of the nutrient status of the soil and the natural regenerative ability of this secondary forest type, through soil fertility restoration is left wanting. The present study therefore examines the changes in the soil exchangeable cations and soil physical properties as the secondary forest progresses towards mature forest.

Study Area

Orogun is bordered to the north by the Ethiope River in Delta state. It is about a distance of 50 kilometers away from the city of Warri in Delta state Nigeria. It is located between latitude $5^0 20'$N and $5^0 36'$N and between longitude $5^0 30'$E and $6^0 06'$E (fig., 1).

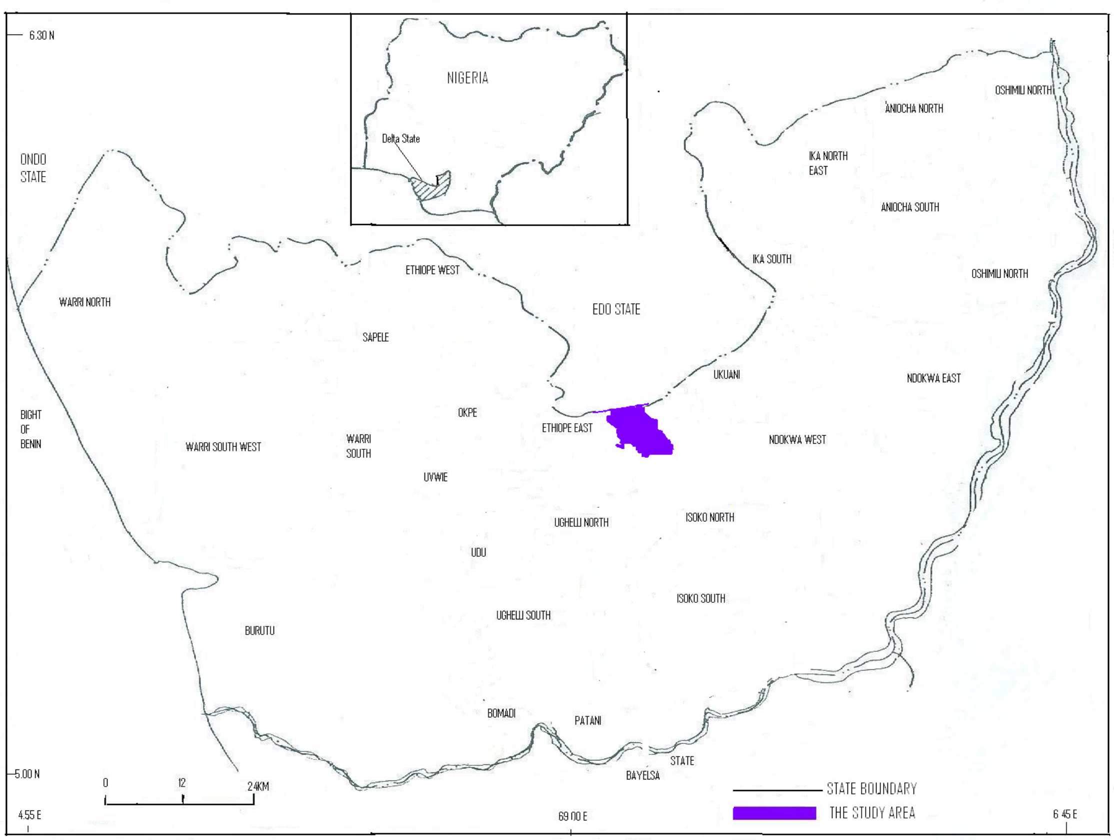

Fig 1: Map Of Delta State Showing The Study Area And The Local Government Areas

The climate is warm and humid throughout the year with mean annual rainfall of about 2000 to 2500 mm. Temperatures are high throughout the year with no sharp seasonal variations and mean annual range of 2^0C (Efe 2006). The natural vegetation is the tropical lowland rainforest of the moist evergreen type (Aweto 2002). Due to anthropogenic disturbances most of the original forest has been destroyed and the landscape replaced by secondary re-growth fallow at different stages of succession. The landscape is low-lying deltaic plain of southern Nigeria and is a featureless plain with vast expanses of almost flat surfaces, with land elevation of less than 25 meters above sea level. The soils are sandy, deeply weathered ferrallitic soils (Oxisoils).They were formed from unconsolidated sediments of sandstone parent material and have been intensely leached.

Methodology

Secondary forests plots of 1, 5 and 10 year old, and a mature forest, were selected for study. The choice of 5 year and 10 year was largely determined by the traditional practices of shifting cultivation in the study area. Abandoned farmlands are usually left for a period of five years before the land is cultivated, while very few people leave their land for as long as ten years depending on the availability of land for farming. Albeit, the fallows of one-year are not usually cleared for cultivation, they were studied so that they would provide a point of reference for assessing the initial status of the soil immediately the rubber plantation is degraded and abandoned and as well use it as the bases for measuring the rate of increase or decrease in soil exchangeable cations during the course of forest regeneration. The primary forest plots generated information about forest characteristics prior to cultivation and were used as reference points for assessing the rate of soil regeneration. It is instructive to note that all the secondary forests categories were set on fire at the end of the productive life of the rubber before the secondary forests plant species invaded the sites. All the secondary forests categories and the mature forest had the same parent material and were on comparable flat crestal interfluve sites to ensure that catenary variations in soil properties were minimized.

Within each of the secondary forest age categories, ten sample plots of 30 metre square quadrats were delimited for investigation. Soil sampling follows the procedure described by Boone et al (1999). Soil samples were collected from five points which were located randomly within the 30 metre square quadrats at predetermined depths of 0-10cm and 10-30cm (which shall be referred to as top-soil and sub-soil in subsequent sections) using a core sampler. The approach of sampling from predetermined depths was adopted in order to ensure comparability among samples collected from different sample quadrats in geographically separate locations since the thickness of the soil profile vary from place to place. The limit of the top 30cm of the soil was chosen for two reasons. Firstly, the limit of the visible humic horizons usually lies here and secondly, numerous observations of root distributions and direct measurement of labeled-phosphorus uptake (Nye and Foster 1960) indicates that in humid regions nearly all the feeding of the annual crops which replace the fallows takes place within this zone. A total of 100 soil samples were collected from each age category on the basis of 50 samples from topsoil and 50 samples from subsoil. These samples of soil were mixed into a composite of 10 composites for each soil depth (on the basis of five samples constituting a composite sample) for chemical analysis. In all eighty composite samples collected were air-dried, crushed thoroughly mixed and passed through a 2mm (No 10 mesh) sieve in readiness for analysis. Coarse primary particulates were discarded and the fraction that passed through the 2mm sieve was used for the analysis. Weighed sub samples were oven dried so that results for analysis carried out on air dried soils were expressed on the oven dried basis. Soil physicochemical parameters analyzed included particle size composition, bulk density, total porosity, water holding capacity, soil pH, exchangeable cations (exchangeable calcium, magnesium, sodium and potassium) and effective cation exchange capacity. The hydrometer method of Bouyoucos as described by Aweto 1981 was used to analyze particle size composition. Soil pH was determined using Beckman Zerometric pH meter (model 55-3) (Nwagu and Onyeze 2010). Soil water holding capacity at field capacity was determined by gravitational draining for 24 hours (Aweto, 1981). Bulk density was analysed by the core method (Aweto 1981). Total porosity values were calculated from bulk density values using an assumed particle density value of 2.65g/cm^3 (Vomocil 1965). Exchangeable calcium and magnesium were determined by atomic absorption spectrophotometer as described by Aikpokpodion2010 while potassium and sodium were determined on an EEL flame photometer (Molindo, 2008). Effective cation exchange capacity was determined by the summation method (Chapman, 1965).

Statistical Analysis

Analysis of variance test was used to test whether or not significant differences existed between the secondary forests age-categories and primary forest with respect to soil physical and chemical properties. Where differences exist, post hoc multiple comparisons of means were carried out with the use of the Least Significant Difference (LSD) to check for statistical differences in soil parameters between pairs of secondary forest, and between secondary forests and primary forest.

Results

Soil Particle Size Composition

Table 1 presents the summary of the physicochemical properties for the sample plots belonging to the different age categories.

The soils were predominantly sand-clay in textural composition. In the 0-10cm layer, the proportion of sand exceeds 80%, hence the amount of clay was small, being usually under 18%, while that of silt was less than 2% for the topsoil of all the fallow categories. The subsoil was also sandy but contains a higher amount of clay than the surface 0-10cm (table 1). The clay fraction of the soil increases down the profile in all the secondary forests categories and the mature forest (table 1) probably due to downward eluviations of clay from the topsoil. The silt content of the soil increased down the profile in the younger fallows (1-year and 5-yer old fallows), while in the 10-year old fallow and the mature forest the silt content decreased down the profile. Despite the differences in the age of the secondary forests, the soils were quite homogenous texturally. Analysis of variance test revealed that no significant differences existed among soils under the different age categories with respect to proportion of sand, silt and clay at 0.05 confidence level (Table 2). This indicates that secondary forests do not significantly modify soil particle size composition over time. This also suggests that the soils were similar, having formed from the same parent material under uniform environmental conditions. As such, any observed differences among the soils in respect of chemical or other soils physical properties would be largely due to differences in age of secondary forests. Thus the absence of any textural heterogeneity between plots validates the chronosequences sampling approach.

Bulk Density, Total Porosity and Water Holding Capacity of Soil

Table 1 show that bulk density tends to decrease with increasing age of secondary forest whereas soil porosity and water holding capacity increase with increasing age of secondary forest. These suggest that the soil becomes less compact with increasing age of secondary forest. The values of bulk density and water holding capacity in the subsoil were higher than in the topsoil in all the categories of the secondary forests and the mature forest studied, while total porosity was higher in the topsoil than the subsoil. Analysis of variance for soil bulk density revealed that significant differences exist between the soils of the different secondary forest categories and the mature forest (Table 2). A post hoc comparison of the bulk density of the different age categories with each other and with the mature forest using least significant difference (LSD) revealed that with the exception of the 1-year and 5-year old secondary forest with no significance difference between their mean at 0.05 level of significance, significant differences exist between the mean of all the other secondary forest categories. The bulk densities of the topsoil and the subsoil of the mature forest were significantly lower than those of the 1-year 5-year and 10-year old secondary forest at $p < 0.05$ of the least significant difference test of means. Analysis of variance test for soil porosity showed a significant difference among the means of the various age categories and the mature forest topsoil. However, there was no significant difference between the 1-year old and 5-year old secondary forest in terms of total porosity at 0.05 level of significance of the least significant difference test of mean. The analysis of variance test for soil water holding capacity shows that significant differences exist between the different age categories and the mature forest at 0.0001 level of the F distribution. This shows that the older the forest the greater its ability to hold water.

Exchangeable Cations, Cation Exchange Capacity and pH of the Soil

Table 2 shows the concentrations of exchangeable calcium, magnesium, sodium and potassium, the cation exchange capacity and pH of the topsoil and subsoil of the sample plots. Magnesium and calcium showed similar pattern of variation in the course of soil regeneration, while the pattern of variation shown by sodium and potassium is the same. With the exception of sodium, the concentration of exchangeable cations in the subsoil of the mature forest was lower than the topsoil of the 1-year fallow. By the 5th year of fallow the level of exchangeable magnesium, calcium, potassium and sodium for the topsoil reach 84.26%, 77.85%, 56.17% and 75.82% of those of the mature forest respectively, while by the fifth year the build up of exchangeable sodium and potassium in the subsoil reached 191.78% and 56.83% respectively of their level in the mature forest as against 75.82% and 56.17% for sodium and potassium respectively in the topsoil. Similarly, while sodium increased by 54.35% in the topsoil by the fifth year of secondary forest regeneration, it increased by 55.22% by the fifth year in the subsoil, while when potassium increased by 36.22% in the topsoil by the fifth year of secondary forest regeneration from abandoned rubber plantation, it increased by 34.42% in the subsoil by the fifth year. The differences in the concentration of exchangeable cations (magnesium, potassium, calcium and sodium) in the topsoil of the different age categories and the mature forest were significant between the 1-year and the 10-year old secondary forests at the 0.05 significant level of the least significant difference of means. However, the differences in the concentration of exchangeable cations between the mature forest and each of the secondary forest categories on the one hand and between the 1-year and 5-year, and 5-year and 10-year on the other hand were significant at 0.0001 levels of significance of the least significant difference test of means.

Effective cation-exchange capacity increased significantly with the age of the forest. Analysis of variances test for the differences among the fallow categories and the mature forest showed that there was significant difference among them at $p < 0.0001$ significant level of the F distribution with respect to ECEC for both the topsoil and the subsoil.

Also the differences between each fallow category and the mature forest were significant at the 0.05 level of significant of the least significance difference test. However, the difference between the 1-year and the 10-year old secondary forest was not significant at 0.05 significant levels.

In both the 0-10cm layer and 10-30cm layer of the soils, there was a decline in soil pH during the first ten years of the regeneration of secondary forest from degraded abandoned rubber plantation. The mean pH values of topsoil per sample plot for the 1-year, 5-year and 10-year age categories and for mature forest were 6.14, 5.81, 5.3 and 6.0 respectively. While the corresponding values for sub-soils were 5.70, 5.45, 4.66 and 5.24 respectively (see table 1).The differences observed in soil pH in the various age categories and the mature forest was shown to be statistically significant at the 0.001 level of the F distribution (Analysis of variance). Nevertheless, the differences between the 1-year old secondary forest and the mature forest on the one hand, and the difference between the 1-year old secondary forest and the mature forest on the other hand were not significant at $p = 0.05$.

Discussion

The results showed that when compared with the critical values for southern Nigerian soils the values reported for exchangeable calcium for the mature secondary forest in this study fall within the range reported by Aborishade and Aweto (1990) (971.9mg/kg), Aweto and Iyanda (2003) (953.9mg/kg) and Aikpokpodion (2010) (1024ppm) but lower than the values reported by Aweto (1978)

(1392.8ppm) and Ukpong (1994) (2144.3ppm) and higher than the values reported by Aweto (1987) (100ppm) Molindo (2008) (90.18ppm) and Molindo et al (2009) (12.85ppm). The values reported for the concentration of calcium in the fallows of the 1-year and 10-year old fallows are slightly lower than the values reported by Aweto (1978) for fallows of similar age in Ijebu-Ode area of south-western Nigeria, while the value reported for the calcium concentration of the 5-year fallow in this study (714.7ppm) is similar to the value reported for a three-year fallow (708.6ppm) regenerating from swidden fallow studied by Aweto (1978). Comparatively, the concentration of magnesium in the soils of this study are higher than the values reported by Aweto and Iyanda (2003) (102.1mg/klkg), Aweto (1987) (60mg/kg), Molindo (2008) (27.96mg/kg), Molindo et al (2009) (60.78mg/kg), lower than the values reported by Aborishade and Aweto (1990) (384.1mg/kg), Elvira, Brown and Lugo (1991) (2114.97mg/kg) and Ukpong (1994) (2144.28mg/kg), but similar to the values reported by Aweto (1978) (212-359ppm) as against 255.6-381.2ppm for this study. The concentration of magnesium in the soil of this study area was high and adequate for the growth of crops in the study area. Lombin and Fayemi (1979) reported that some highly leached soil are near the deficiency level and require magnesium fertilization. They anticipated serious magnesium deficiencies in Nigeria in the near future but this study shows the contrary and agrees with the findings of Aborishade and (1990) who reported value higher than 60ppm which is considered adequate for the soils of the tropics. The concentration of potassium of the topsoil of this study area ranged from 25.4mg/kg – 61.6mg/kg. The various values from all the investigated secondary forests fall within the rating class of low (below 175ppm) hence the soil studied could be said to be low in potassium. Although, Aborishade and Aweto (1990) and Aikpokpodion (2010) reported values (234.6ppm and 218.9ppm) which are considered adequate for soil of the tropical areas, the values reported in this study are relatively similar to the inadequate or low values reported by Aweto (1978), Molindo (2008) and Molindo et al (2009).

The soils contained more than 80% sand on the average while the percentage of clay was about 16% on average. This might have predisposed the soil exchangeable cations to leaching depending on the pattern and intensity of rainfall. Mokunye and Melsted (1973) tested nine temperate and tropical soils and found that the distributions of exchangeable cations present were - clay fraction of the soil contained 51-70% of the total cations present; silt fraction contained 22 to 42% of the total cations and sand contained 0.1 to 11% of the total exchangeable cations. They also found that severe weathering, soil erosion and clay eluviations all tend to reduce exchangeable cation content of surface soil horizons. The report of Choudhury and Khanif (2000) stated that, there were exchangeable cations deficiencies in rice grown area where irrigation scheme was carried out. The high concentration of sand, heavy leaching due to heavy rainfall as experienced in the study area and annual mining of nutrients by the rubber trees prior to the invasion of the land by secondary forest might be responsible for the depletion of calcium, potassium and sodium in the soils.

The progressive build up of exchangeable cations in the soil till about the fifth year of soil regeneration and the decline in their concentration by the tenth year of fallow was due to rapid nutrient immobilization by the trees which have become fully established by the tenth year. The lower concentrations of exchangeable calcium, magnesium and sodium in the subsoil of the 10-year age category than the 1-year category and the higher concentrations of exchangeable calcium, magnesium and sodium in the topsoil of the 10-year than the 1-year old secondary forest categories lend credence to the assertion that leaching of nutrients from the topsoil to the subsoil is more rapid in the young fallows than the older fallows. In addition, it also suggests that the roots of the woody fallows of the older secondary forests were more efficient than those of the *Chromolena odorata* (forb fallow) which characterize the 1-year fallow, in mining nutrients from the subsoil.

There was a progressive improvement in soil water holding capacity and total porosity over time, while bulk density decreased with increasing age of secondary forest.

CONCLUSION

This work demonstrates the regenerative capacity of tropical secondary forests to rebuild the soil nutrient capital following the abandonment of degraded rubber plantation. Even though the secondary forests were close to each other, soil nutrients were significantly higher in the 5-year and 10-year old secondary forests than the 1-year old secondary forest due to improvement in soil nutrient as a result of soil fertility rejuvenation due to fallow. The management of the soil of regenerating secondary forests following the abandonment of degraded rubber plantation through fallowing as practiced in the study area would be a significant contribution towards the rejuvenation of the soil in secondary forests regenerating from degraded abandoned rubber plantation. Therefore, fallowing as practiced in the study area should be encouraged and sustained.

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Table 1: Mean values of physicochemical properties of soil in the different secondary forests.

Soil properties	Topsoil 1-year	Topsoil 5-year	Topsoil 10-year	Topsoil Forest	Subsoil 1-year	Subsoil 5-year	Subsoil 10-year	Subsoil Forest
Sand (%)	82.00	84.07	83.05	80.69	80.01	81.03	80.80	79.18
Silt (%)	1.85	1.11	1.71	1.81	2.29	1.18	1.28	1.61
Clay (%)	16.15	14.82	15.24	17.52	17.71	17.69	17.93	19.22
WHC[1]	40.29	48.16	51.28	59.35	46.32	50.77	61.40	64.04
BD	1.16	1.14	1.08	1.01	1.24	1.19	1.12	1.09
Porosity[1]	56.11	56.98	59.13	61.89	53.55	55.09	57.97	58.80
pH	6.14	5.81	5.30	6.00	5.700	5.45	4.66	5.24
K [2]	25.4	34.6	28.38	61.6	10.4	13.98	11.61	24.6
Mg [2]	255.6	321.2	239.3	381.2	119.2	113.6	110.2	120.9
Ca [2]	610.2	714.7	617.10	918.30	332.10	313.70	221.60	287.4
Na [2]	23.18	50.80	43.50	67.00	21.50	48.04	21.13	25.05
C.E.C [3]	7.14	9.07	8.04	10.18	5.41	6.22	6.09	5.79

NOTE: [1] = % [2], = mg/kg [3], = cmol/kg, BD =Bulk density, WHC = Water holding capacity.

Table 2: Summary of the results obtained by analysis of variance for soil physicochemical properties

Soil properties	Source of variation	Degree of freedom	Sum of square	(MSE) Variance estimate	F values	F probability	Decision
Sand	BS	3	66.16	22.06	0.950	0.2351	NS
	WS	36	833.05	23.14			
Clay	BS	3	0.8234	0.2744	0.797	0.4533	NS
	WS	36	12.3876	0.3441			
Silt	BS	3	1.104	0.368	0.976	0.2240	NS
	WS	36	13.572	0.377			
Bulk Density	BS	3	0.1102	55.95	21.96	0.0001	Significant
	WS	36	0.0724	2.55			
Porosity	BS	3	167.84	0.0367	18.26	0.0001	Significant
	WS	36	91.72	0.0020			
WHC	BS	3	95.56	31.85	43.17	0.0000	Significant
	WS	36	26.56	0.74			
Ph	BS	3	4.05	1.35	12.27	0.0001	Significant
	WS	36	4.04	0.11			
Mg	BS	3	80891.22	26963.74	77.78	0.0000	Significant
	WS	36	13157.27	365.48			
Ca	BS	3	618983.99	17193.99	75.29	0.0000	Significant
	WS	36	8221.64	283.38			
Na	BS	3	9621.89	3240.83	1017.68	0.0000	Significant
	WS	36	114.636	3.18			
K	BS	3	8208.506	2736.17	211.91	0.0000	Significant
	WS	36	464.834	12.91			
ECEC	BS	3	738.0472	246.02	2259.10	0.0000	Significant
	WS	36	38.6574	1.07			