Sustainable Use of Chemical in Agricultural Soils and Implications for Precision Agriculture

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Abstract

This study characterized and assessed the geostatistical variations of some essential macronutrients (Ca, P, Fe, Na, K, Al, Mg and Ti) for further environmental monitoring, planning and remediation using geochemical analysis in two commercial farms. Twenty soil samples were collected at the depth of 50 cm to 70 cm below the subsurface from the study areas that is, Landmark university farm representing the northcentral and Covenant university farm representing southwest Nigeria, respectively. Inductively coupled plasma and mass spectrometry (ICPMS) was used to analyze the samples at the Acme laboratory, Canada. The statistical results indicate that the following pair of elements {Ca-Mg, P-Mg, Fe-P, Fe-Al, Ca-K, Mg-K, and Na-K} are significantly positively correlated at 0.05 significance in the areas. The mean and median test revealed that iron (Fe) and titanium (Ti) content are the same in both study areas. The findings among others imply that deficient essential nutrients can be applied as chemical fertilizers to farmland and thereby enhancing sustainable agricultural production.

Keywords: Geochemical analysis, geostatistics, macronutrients, precision agriculture, soil, sustainable agriculture

1 Introduction

Soil is a vital resource required for plant growth. The ability of a soil to supply elements necessary for plant growth is termed soil fertility. Soil degradation is a decline in soil quality and a consequence of intensive land use management (1). So, macro and micronutrients are the nutrients needed for the utmost plant growth but macronutrients are needed in larger quantities for basic plant growth and development (2-4). Essential macronutrients necessary for good soil functioning are further divided into primary macronutrients which include nitrogen (N), phosphorus (P) and potassium (K), and secondary macronutrients, magnesium (Mg), calcium (Ca) and sulphur (S). Aluminium (Al), iron (Fe) and thallium (Ti) are major elements in rocks although they appear as trace elements in water due to their slow mobility on the earth's surface (5). Micronutrients, also known as trace elements are needed in micro quantities and typically have a higher concentration in surface soil and decrease with soil depth (6). An increase in soil pH reduces the availability of micronutrients in soil except for molybdenum whose availability increases with increasing pH (6).

Plants take in other trace elements in varying degrees but may not be considered essential mineral elements. Therefore, soil fertility and plant nutrition should be studied simultaneously, as both essential and nonessential elements can be toxic to soil and plants if accumulated at a very high concentration (7-8). There is

nutrient deficiency whenever essential nutrients are not available to meet the need of a growing plant. Also, toxicity occurs when there is an excess of nutrients for plants' normal growth (9). Soil testing, plant analysis or visual field observations are the basic tools for identifying this deficiency or toxicity of nutrients in soils (9).

Because soil nutrients availability is highly variable in space and time (10-11), only a portion of the plant's root may have access to nutrient-rich patches. However, high nutrient availability in soil enables greater capacity for photosynthesis, increased carbon import, more root growth and higher nutrient uptake (12). The studies of soil nutrient variations, dispersion, mobility, heterogeneity, interaction with organisms and enzymatic activities have enhanced the practice of precision farming in several nations of the world such as Turkey, China, Brazil, India and the United States of America (9) (13-27), but limited researches exist in the tropics on the importance of soil nutrients. Most commercial farms in Nigeria have adopted the use of chemical fertilizers and animal manure to increase soil fertility without first-hand information on the nutrient status of the farms. When the nitrogen and phosphorus supplied by these chemical fertilizers are not fully utilized by the growing plants, they are lost from the farmlands and then negatively impact air and groundwater quality (28).

Precision agriculture is a site-specific management system

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that adopts information and technology of sources of data from the soil, nutrients, moisture, and crops. This information is used in farm management for optimum profitability, long-term sustainability of agricultural production and the protection of the environment (29-33). When precision farming is practiced, inputs such as fertilizers will only be applied where it is needed and when it is needed (34).

The study aims to quantify the essential macronutrients in the soils within the study area and geo-statistically compare the variability of these nutrients. The result of the study serves as quick reference material for farmers and agricultural decision-makers in the selected locations in southern and northcentral states of Nigeria.

2 Materials and Methods

Soil is a vital resource required for plant growth. The ability of a soil to supply elements necessary for plant growth is termed soil fertility. Soil degradation is a decline in soil quality and a loss of soil fertility.

2.1 Site Description

The main study areas are the two commercial farms of Landmark, University Omu-Aran (L1) and Covenant University Ota (L2). Omu-Aran falls within the north-central part of Nigeria bounded by Longitudes 40˚ 59'47.26" E and 50˚ 29'41.667" E, and Latitudes 80˚ 0' 14.8392" N and 80˚ 30'15.5664'N (Figure 1). On the other hand, Covenant University Ota is located in southwest Nigeria bounded by Latitude 6˚ 40' 41.0988"N and Longitude 3˚ 9' 49.6908"E.

Omu-Aran (L1) falls within the schist belt of the Basement complex while Ota CU farm (L2) falls within the sedimentary Basins of Nigeria (35-36). Omu-Aran experiences an average annual temperature of 24.9˚C and about 1273 mm of precipitation annually. Ota in Ogun State has an average annual temperature of 26.5˚C and an annual average rainfall of 1057.9 mm (37). Topography is one of the striking characteristics of Omu-Aran farm with an elevation range from 550 m to 575 m above the sea level. Ota (L2) has an elevation range from 49 m to 52 m above the sea level. Omu-Aran is well known for mining activities and farming but Ota is predominantly known for small scale farming and industrialization.

The two locations are commercial farms used for growing several crops such as vegetables, rice, palm trees and maize. There are continuous tillage and fertilizer application on the farmland in other to meet the demand and supply chain. To prevent soil degradation, the natural nutrient content of the farm soils should be investigated and necessary recommendations on the use of fertilizers are proffered on the soil.

2.2 Soil sampling and field work

Soil samples were collected along 20 traverses on the two selected farmlands between July and December 2018. The farms are commercial farms being managed by the two universities farm managers. The soil samples were picked just before the planting season at an undisturbed depth of 50 cm to 70 cm below the subsurface. In Landmark farm, 8 soil samples labelled soil 1 to soil 8 were collected along the traverses and 12 samples (soil 9 – 20) were collected from Covenant farm. Soil samples were bulked to obtain a composite sample of about 5 kg of fresh soils. Geographical coordinates were recorded at each sampling point

using Garmin Etrex 20, GPS unit. Soil samples were taken to Bureau Veritas of Acme Laboratory Canada.

2.3 Laboratory analysis of the samples

Soil samples collected were sealed, packaged and sent for analysis at Acme laboratories limited, bureau veritas Vancouver, Canada in December 2018. Eight essential elements necessary in good soils are mentioned in this paper. The eight macro elements are calcium (Ca), phosphorus (P), magnesium (Mg), titanium (Ti), aluminium (Al), sodium (Na), iron (Fe) and potassium (K). The prepared sample is digested to complete drying with an acid solution of (2:2:1:1) H_2O-HF-$HCIO_4$-HNO_3-HCL was added to the residue and heated using a mixing hot block. After cooling, the solutions are transferred to test -tubes and brought to volume using dilute HCL. A 0.25 g split of sample is analyzed using the inductively coupled plasma mass spectrometry (ICP-MS). The detection limit was 0.01 % for Ca, Mg, Al, Fe and K and 0.001 % for P, Ti and Na. The percentage composition in the samples was indicated in the result.

2.4 Statistical Analysis

The obtained data were analysed with statistical package for social sciences (SPSS) version 23. Averages of each variable as described by the data in the results were used for the analysis. The essential macronutrient data of the analysis from the two locations (L1 and L2) were subjected to descriptive statistics and correlation matrix at the 0.05 significance levels.

3 Results and Discussion

The results from the ICPMS analysis of the nutrients uptake in the soil samples are presented in Tables 1 to 9.

Sustainable precision agriculture practices require adequate knowledge of soil fertility. The condition of the soil at the beginning of the planting season is paramount to the type of crops and the amount of fertilizers to be added to the soil. This information will aid in the proper application of fertilizers that is, the type, quantity, and rate to be added. The soil analysis result indicates that the nutrients distribution in locations 1 and 2 are almost evenly distributed across the profiles except for aluminium (Al), iron (Fe) and potassium (K) that varies along the traverses (Table 1). For location 1, the median content of titanium is more than the mean value (Table 2). Geostatistical result for location 1 (Omu-Aran) suggests that the following nutrients are highly positively correlated at 0.05 level of significance P-Ca, Mg-Ca, P-Mg, Al-Ca, Al-Mg, Al-P, Ca-Na, P-Na, Mg-Na, Fe-P, Fe-Al, K-Ca, K-Ca, K-Mg, K-Al, K-Na (Tables 3 and 4). This result indicates that an increase in one of the nutrients automatically leads to an increase in the other and vice versa across the farmlands.

For Location 2, all the nutrients analyzed were somewhat evenly distributed across the traverses except for aluminum and iron (Fe) (Table 5). The median content of aluminum is more than the mean value in location 2 (Table 6). Elsewhere, the mean is greater than the median. Also, Tables 7 and 8 revealed that these paired nutrients are positively correlated that is, Ca-Mg, P-Mg, Ti-Ca, Ti-P, Ti-Mg, Fe-P, Fe-Al, Ca-K, Mg-K and Na-K across Location 2. This suggests that whenever there is an increase in the accumulation of one there will be in the other and vice versa.
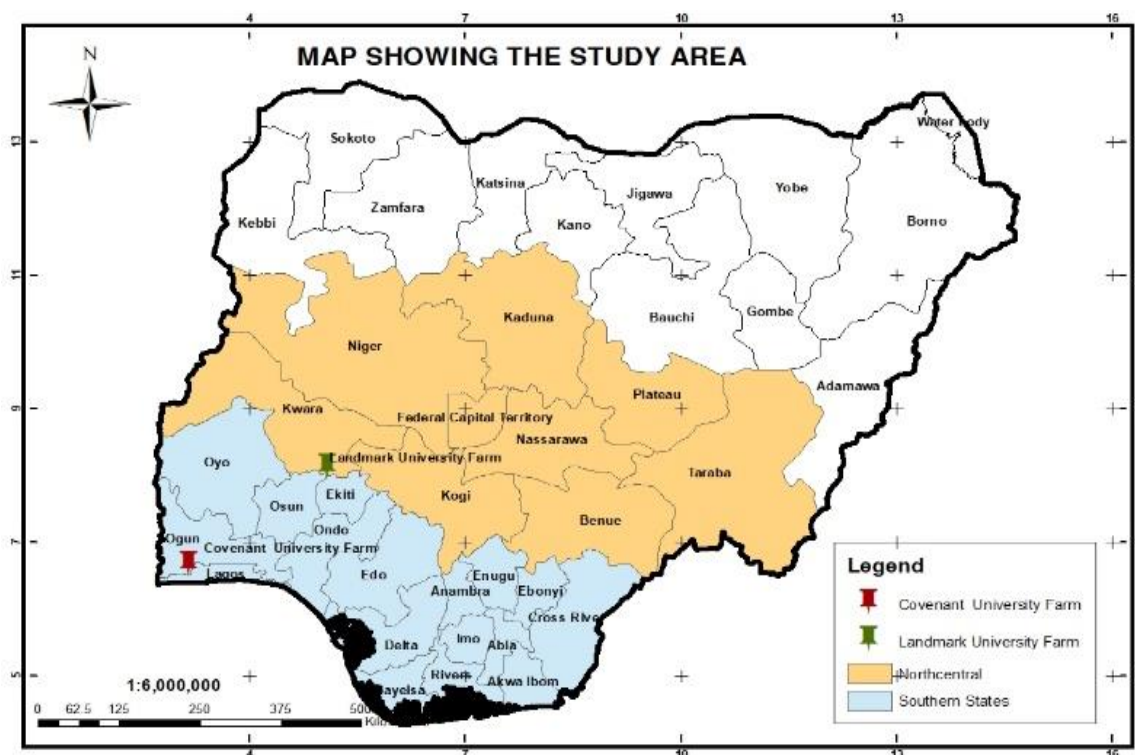
Figure 1: Map of Nigeria showing the study area.

Table 1: Results for macronutrients analyzed from soil samples from Landmark farm (Acme Lab. Canada).

Analytes (%)	Ca	P	Mg	Ti	Al	Na	Fe	K
MDL	0.01	0.001	0.01	0.001	0.01	0.001	0.01	0.01
Soil 1	0.06	0.024	0.07	0.548	5.47	0.012	2.75	0.04
Soil 2	0.05	0.019	0.06	0.480	4.46	0.007	2.29	0.03
Soil 3	0.04	0.023	0.06	0.620	5.61	0.008	2.81	0.04
Soil 4	0.05	0.022	0.07	0.603	6.50	0.007	2.98	0.04
Soil 5	0.07	0.021	0.07	0.583	5.78	0.008	2.75	0.04
Soil 6	0.04	0.026	0.07	0.591	6.99	0.008	3.24	0.04
Soil 7	0.44	0.069	0.25	0.599	9.33	0.493	4.19	2.46
Soil 8	0.52	0.049	0.20	0.408	7.29	0.767	2.66	2.90

MDL – measurement detection limit

Table 2: Descriptive statistics for the analysed soil samples from Landmark farm

Statistic	Ca	P	Mg	Ti	Al	Na	Fe	K
Arithmetic mean	0.1588	0.0316	0.1063	0.5540	6.4288	0.1638	2.9588	0.6988
Geometric mean	0.0887	0.0284	0.0900	0.5492	6.2882	0.0241	2.9166	0.1103
Harmonic mean	0.0639	0.0263	0.0804	0.544	6.1559	0.0107	2.8791	0.0503
Quadratic mean	0.2451	0.0358	0.1271	0.5582	6.5764	0.3224	3.0057	1.3449
Median	0.055	0.0235	0.0700	0.5870	6.1400	0.0080	2.7800	0.0400
SD	0.1997	0.0178	0.0746	0.0735	1.4816	0.2970	0.5658	1.2285
Skewness	1.4790	1.7470	1.5610	-1.4130	0.9310	1.6930	1.6210	1.4790

Table 3: Correlation matrix for the pair of nutrients in soil samples for Landmark farm

R	P	Mg	Ti	Al	Na	Fe	K
Ca	0.906	0.957	-0.502	0.732	0.989	0.42	0.999
P		0.987	-0.156	0.895	0.844	0.744	0.914
Mg			-0.281	0.855	0.908	0.646	0.961
Ti				0.141	-0.582	0.499	-0.487
Al					0.669	0.894	0.746
Na						0.315	0.988
Fe							0.438

Table 4: Significance table for the correlation matrix for Landmark farm (L1)

p value	P	Mg	Ti	Al	Na	Fe	K
Ca	**0.002**	**0.000**	0.205	**0.039**	**0.000**	0.300	**0.000**
P		**0.000**	0.712	**0.003**	**0.008**	**0.034**	**0.001**
Mg			0.500	**0.007**	**0.002**	0.084	**0.000**
Ti				0.739	0.130	0.208	0.221
Al					0.070	**0.003**	**0.034**
Na						0.448	**0.000**
Fe							0.278

Table 5: Result for soil analysis for Covenant farm (L2) from Acme Laboratory, Canada

Analytes (%)	Ca	P	Mg	Ti	Al	Na	Fe	K
Soil 9	0.06	0.049	0.07	0.346	7.63	0.013	10.13	0.23
Soil 10	0.01	0.039	0.05	0.323	8.29	0.009	13.64	0.19
Soil 11	0.02	0.046	0.05	0.348	8.01	0.008	13.8	0.15
Soil 12	0.05	0.031	0.07	0.375	8.32	0.010	7.20	0.21
Soil 13	0.02	0.039	0.06	0.349	8.56	0.009	9.15	0.23
Soil 14	0.02	0.033	0.06	0.370	8.17	0.008	7.45	0.17
Soil 15	0.07	0.016	0.06	0.269	3.32	0.714	2.42	0.53
Soil 16	0.08	0.031	0.15	0.586	4.17	0.525	3.72	0.80
Soil 17	0.18	0.072	0.39	0.993	7.59	0.208	11.71	0.75
Soil 18	0.18	0.052	0.25	0.49	6.56	0.200	15.86	0.79
Soil 19	0.03	0.072	0.10	0.586	4.19	0.015	11.00	0.31
Soil 20	0.05	0.019	0.06	0.573	3.73	0.021	1.68	0.40

Table 6: Descriptive statistics for the data collected from soil samples from Covenant farm (L2)

Statistic	Ca	P	Mg	Ti	Al	Na	Fe	K
Arithmetic mean	0.0643	0.0386	0.1050	0.4588	6.0785	0.1253	7.9729	0.3443
Geometric mean	0.0471	0.0347	0.0816	0.4321	5.6028	0.0278	6.1145	0.2344
Harmonic mean	0.0341	0.0312	0.0705	0.4115	5.0698	0.0132	4.3255	0.1280
Quadratic mean	0.0827	0.0423	0.1417	0.4925	6.4641	0.2493	9.2974	0.4312
Median	0.0500	0.0360	0.0600	0.3725	7.0750	0.0115	8.3000	0.2300
SD	0.0540	0.0181	0.0988	0.1860	2.2820	0.2237	4.9634	0.2694
Skewness	1.5010	0.7050	2.3410	1.9830	-0.395	2.0360	0.0120	0.7930

Table 7: Correlation matrix for the pair of nutrients in soil samples for Covenant farm (L2)

R	P	Mg	Ti	Al	Na	Fe	K
Ca	0.333	0.879	0.623	-0.126	0.363	0.177	0.734
P		0.625	0.558	0.410	-0.200	0.776	0.319
Mg			0.838	0.135	0.263	0.390	0.767
Ti				-0.059	0.085	0.118	0.587
Al					-0.386	0.706	-0.088
Na						-0.270	0.681
Fe							0.185

Table 8: Significance table for the correlation matrix for Covenant farm (L2)

p value	P	Mg	Ti	Al	Na	Fe	K
Ca	0.245	**0.000**	**0.017**	0.668	0.203	0.544	**0.003**
P		**0.017**	**0.038**	0.145	0.493	**0.001**	0.266
Mg			**0.000**	0.646	0.364	0.167	**0.001**
Ti				0.841	0.772	0.688	**0.027**
Al					0.173	**0.005**	0.765
Na						0.351	**0.007**
Fe							0.527

Table 9: Statistical comparison between Landmark and Covenant farms

Element	T	p value	U score	p value
Ca	1.31	0.231	105	0.3936
P	-0.87	0.397	79.5	0.4128
Mg	0.03	0.974	108.5	0.2748
Ti	1.7	0.107	126	**0.0222**
Al	0.44	0.668	94	0.9185
Na	0.32	0.756	80	0.4325
Fe	-3.74	**0.002**	67	0.0945
K	0.81	0.447	75	0.2601

Table 10: Food and agricultural organization standard for macronutrients in soil

Parameters / Ratings	Nitrogen (%)	Potassium (%)	Calcium (%)	Magnesium (%)	Sodium (%)	Phosphorus (%)
Low	<0.08	0.077	<0.0005	NS	<0.0789	< 0.0007
Medium	0.08 – 0.15	0.077 – 0.21	0.0005 – 0.004.6	NS	0.0789 – 0.0157	0.0007 – 0.002
High	> 0.15	> 0.21	0.04.6	NS	0.0157	> 0.002

NS – Not supplied Source: Akande (39) and FAO (40) Soil bulletin No 63

Comparing the nutrient accumulation for Locations 1 and 2, the following paired nutrients: Ca-Mg, P-Mg, Fe-Al, Ca-K, Mg-K, and Na-K are positively correlated (Tables 3 and 7). The result further revealed that titanium (Ti) and iron (Fe) content in the soils of the two sites are the same, correlation notwithstanding (Table 9) as previously observed by Lyu et al. (38). Iron and Titanium have been found to have antagonistic and synergistic relationship when Fe is deficient in soil/plant, Ti help induce genes related to Fe acquisition thereby improving the overall quality of crop yield (38).

Soil testing of 0.015 % calcium (Ca) is considered normal for nutrient uptake and greater than 0.015 % slows the nutrient uptake by plants (3). Although, all elements analyzed were below the FAO soil quality guidelines (Table 10) except for magnesium

(mg) limits that were not stated. Cover crops should be rotated with other crops all year round to increase the green manure and supply the necessary depleted nutrients the soil needs. Also, animal dung and manure of organic origin should be added to chemical fertilizers to boost the soil fertility of the study area.

3.1 Implications of findings on Precision Agriculture

The results of this study have the implications for improving soil fertility of the farmlands and other farmlands with the same nutrients variability. L1 soils are richer in calcium (Ca) than the L2 soils. Also, the iron (Fe) concentration in L2 farm exceeds significantly that of L1 soils. The implication of this is that, plants that are tolerant of calcium-rich soils such as Fenugreek plants should be planted in L1 soil. However, excessive calcium uptake by plants may result in disturbances of ion balance which is detrimental to other nutrients such as magnesium and potassium **(41-42)**. Basically, a small amount of iron (Fe) is required for plant growth but crops such as sweet potatoes and radishes that enjoy iron-rich soils can be planted in L2 soil **(43)**.

Appropriate fertilizers should be added to where it is needed instead of the traditional application of fertilizers to the entire farmland. For nutrient drain effects as a result of erosion on Omu-Aran farm as observed during the soil samples collection, cover crops such as canola, mustard, oats, wheat and alfalfa should be planted on the elevated portion of the farmland and land tillage be drastically reduced to retain soil fertility.

4 Conclusion

The nutrient status of the agricultural soils in the two sites has been investigated. All essential soil elements determined were lower in value than the FAO standard guidelines (Table 10). The study has revealed that potassium (K), aluminum (Al), titanium (Ti) and calcium (Ca) are more in the soils of Omu-Aran (L1) than in the soils samples from Ota (L2). Ota soil is, however, richer in iron (Fe) and magnesium (mg). The findings on the nutrient status have implications for precision agriculture To improve the soil fertility of the two sites investigated, only fertilizers that are enriched in deficient nutrients analyzed should be used. Also, soil management practices and timely irrigation should be adopted as this will help to reduce calcium-related disorders in the soil and allows a steady supply of calcium throughout the crop season. Geostatistical results for the two locations revealed that these paired macronutrients are positively correlated that is, Ca-Mg, P-Mg, Fe-Al, Ca-K, Mg-K, and Na-K. The correlation at 0.05 level of significance suggests that an increase in the accumulation of one of the paired nutrients leads to an automatic increase in the other. Thallium (Ti) and iron (Fe) have the same concentration in the soils of the two sites correlation notwithstanding. These findings can be used as basic information for the promotion and establishment of sustainable agriculture in the areas investigated. Further investigation is required to determine other trace elements (micro and macronutrients) that were not analyzed in this study. Finally, the world health organization (WHO) and environmental protection agencies should frequently supply the public with soil quality standard guidelines in other to breed healthy crops and improve overall human health.

Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing.

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