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Soil Testing A Panacea to Crop Yield and Agricultural Sustainability – A Case for Farmers of South Eastern, Nigeria

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Abstract

Increasing human population is closely related with the increasing demand of food and pressure on available land with the rising demand on fertilizer that has not been sustainable at the farmer's level. This causes soil fertility decline, nutrient imbalance and low residual effect which are constraint affecting agricultural production in south eastern soils of Nigeria in particular and to large extent in tropical environment. Land available to be used for intensive crop production activities is limited and this demand for adequate soil testing that will x-ray the fertility status of the soil before crop planting. The characteristics and amount of nutrient elements of a soil and soil biodiversity is influenced by climatic conditions, erosion/leaching, drought, cultivation history/land use system, cropping history, kinds of pesticides/herbicides applied, type and methods of inorganic and organic fertilizer applied. Soil testing quantifies the total value of plant nutrient elements available in a sampled soil that will directly promote crop growth and yield. Due to its biophysical, biochemical, biological and physiochemical results, soil testing when appropriately interpreted and applied may be used effectively to promote sustainable crop production and environmental health in a tropical soil like south eastern, Nigeria.

Keywords: soil analysis, soil sampling, depth, chemical nutrients, extraction of plant nutrient elements

1. Introduction

Green plants can exist and increase independently of any animal life. All that is required is a supply of water, carbon iv oxide (CO_2) and several mineral elements to make the green plant in the presence of light a completely self-sufficient organism. Plants absorb mineral elements indiscriminately from soil medium, but the presence in a plant of any particular element does not of itself constitute proof that the element, is essential to its development. In addition the infertility problem of the soil such as an excessive salt content, acidity or basicity, toxic substance, disease organisms, low soil biodiversity, moisture stress, impenetrable layers and extreme nutrients development and release in soil, climatic conditions, pest infestation or damage and human error, exploitation of vegetation and bush burning, tillage and land use systems, high intensity rainfall coupled with erosive conditions, increase in population and urbanization, intensive agricultural activities on the available land all create different kinds of problems on the biological, biophysical, biochemical and physiochemical properties of the soil (Westerman, 1990, Edward, 1992, Samuel et al, 2003; Akirinde et al., 2005, Nweke 2018ab, 2019).

In view of this, therefore, soil testing becomes paramount important in agricultural production for any farmer interested in getting better result in crop yield and increase in profit. Soil testing is merely done to improve growth and yields, evaluate crop quality, minimize disease and for evaluating the soil for reclamation, fertilizer/manure applications, or for other needed purposes or modifications (Fitts and Hanway, 1976, Edward, 1992). Hence, soil testing could be explained as any chemical, biological or physical measurement that is made on soil. In a restricted sense, it is a means of assessing the available nutrient status of a soil. While in a broader sense, soil testing includes: - evaluation, interpretation, and manure/fertilizer recommendation, based on the result of soil chemical analysis. Apart from chemical method of analyzing soil fertility, biological method also exist. Soil testing is very accurate when the field is appropriately sampled and can serve as transfer agent of field, green house, and laboratory research into relative productions for soil needs of lime, fertilizer or any other soil amendment before crops are planted. Farmers test soil to determine how much each nutrient is available for plant growth. From the result of soil testing, they will decide how much fertilizer or manure that will be applied to reach a sufficient level of each nutrient. In order words, farmers can use three methods to find out nutrient shortages in plants;

- Soil testing

- Visual inspection of crops for deficiency signs may uncover clear shortages
- Tissue testing that measures nutrients levels in plant tissue itself (Tisdale and Nelson 1963; Fitts and Hanway, 1976).

A soil test is normally performed early in the season to allow the farmer to supply the necessary nutrients before the crop are planted. Therefore, the objective of soil testing among others will include:

a) to build or gain fertility status of a given field.

b) to predict the profitability of obtaining profitable response to lime and fertilizer (or any other soil amendment)

c) to evaluate the fertility status of soils

d) to provide a basis for recommendations on the amount of lime and fertilizer to apply (Fitts and Hanway, 1976, Edward, 1992).

The southeast farmers of Nigeria faces a horrendous challenges in their crop production activities following the nature of the soils of the area that are fragile in nature, acidic, prone to erosion menace due to high rainfall and temperature and are highly weathered. Hence the essence of good soil testing that will enable the farmer to track down the history of his soil/land and put the soil in proper use with less endangered to environmental degradation. The fact that most of these farmers are poor and uneducated compound the problem as this limit the practice and believe in the principles of soil testing as a means of improving their output and the life of their soils. Secondly they believe that the exercise is very costly and waste of resources thus the farmers abhors soil testing.

Therefore this study tend to articulate research based approach to the management of south eastern soils of Nigeria for sustainable food production, income generation to the farmer and delivery of healthier food to the populace. At the same time to encourage the farmers, provide guide lines and procedures of soil analysis for them to achieve better results as soil laboratory and soil researchers is much in the area to assist them.

2. Limitations of Soil Testing

Soil analyses have several limitations to its use. For instance, we only measure the total amount of nutrients absorbed. Hence chemical analyses of the plants are helpful information in the overall evaluation of the soil conditions for plants growth over years of study. Weed competition, diseases, or poor management which affect the amounts of nutrients absorbed are not evaluated and plants are the final proof of what nutrients were or are available to the plant. Another limitation is by the time a plant can be tested it is usually too late to add fertilizer. Therefore, to predict the needed modifications of soils to allow optimum plant growth, soils are tested for pH, soluble salts, available nutrients, element toxicities and various other soil properties. Soil test however, is not remedy for all the soil problems. According to Miller and Donahue (1992) it will not answer the problem of unsatisfactory plant growth when the cause is dry weather, compacted soil, critically low or high temperatures, in adequate soil drainage or low oxygen in the root zone, improper placement of fertilizer, salt accumulation, plant diseases, toxic elements and insect damage, competition from weeds or tree roots or untimely operations. These limiting factors need to be verified before soil test can be interpreted at least for proper fertilizer or organic manure recommendation. For example poor growth in plants may be associated with several interacting and interrelated factors rather than a single one. Maize roots for example require high amount of soil oxygen before they can absorb potassium normally. Miller and Donahue (1992) reported that in wet soil the water displaces a large amount of oxygen and maize roots was unable to absorb sufficient potassium although the soil tests high in available potassium. In this situation, additional potassium inform of fertilizer was needed in order to produce high yields of maize.

In like manner the work of Gingrich (1965) equally showed that when soil temperatures was 10^0C even on soils low in phosphorous there was no response to application of phosphorous fertilizer, but yield of wheat were doubled on the same low phosphorous soil with application of 19.7kg/ha of phosphorous when soil temperature were maintained at 18^0C and 32^0C. This shows that even with good supply of soil potassium and phosphorous some factors such as excess soil moisture and low temperatures respectively in these examples may limit potassium and phosphorous absorption by the plants. The same kind of effect can as well occur in compacted soils due to restricted oxygen. In all in tempts and purposes chemical soil analysis is a valuable diagnostic technique for helping to control, manage and provide answers to complex soil and plant nutritional problems as well as environmental problems/challenges. This however should be supported with a thorough inventory of soil and cropping information and plant analysis. Obtaining soil samples that represent the field area adequately and submitting the samples to a competent and certified laboratory that will ensure accurate test results and fertilizer recommendations were applicable are key steps for valid soil chemical test or analysis.

Soil test is grouped into four stages;

1. Soil sampling
2. Extracting and quantifying the available nutrients that is chemical analysis of soil
3. Interpretation of the results
4. Recommendations

3. Soil Sampling

Soil laboratories use the most modern testing method and tools and the material to be tested is the sample provided by the farmer. Therefore it means that the result will be no better than the sample itself. In view of this the field should be sampled in such a way that the chemical analysis of collected sample will reflect the field true nutrient status. Bearing in mind that soils are highly variable both horizontally and vertically and in nutrient content from location to location and from spot to spot. Though all the samples are not expected to yield the same result but rather have to reflect on the true variations within the field. Furthermore it is very important to provide a sample that will be a representative of the whole land about which information will be needed since it is not possible to test all the soil in the field. According to Miller and Donahue (1992) if the sample is to represent the top 30 cm take equal portions of soil from all of the that depth. Some soils of uneven relief and that have been graded and levelled may have different depths of top soil over much different sub soils such as dense clayey B horizons. The layers of soils with different colour should not be mixed as the lower 5-10 cm of a 30 cm deep core may be in quite different soil than the top part of the core. The sub samples from all parts of a uniform field (e.g. cultivation, history of land use system, cropping history etc) the sample is to represent can be mixed together to form a composite. The abnormal areas (e.g. depression, hill, valley, waterlog etc) in the field should be sampled separately though both should be sent for chemical analysis for comparison. This becomes necessary because samples properly taken to represent the field will lead to a desired result. While poorly taken samples not only will it be an economic waste but will cause disaster for the farmer to take wrong implementation on his farm activities. Therefore for the farmer to take wise action he should be guided on the fact that the land to be tested should be divided into sampling areas of uniform texture, topography, cropping, manure/fertilizer (organic or inorganic depending on the one in use by the farmer), cultivation and land use history. For example coarse textured field should be sampled separately from adjacent or a closed by fine textured field. Each soil type in this case becomes a sampling area. More so if a field received fertilizer or manure last year and half did not, each section should be sampled and tested separately. In such situation each composite sample can represent up to 1-5 ha (dependent on the hectares under production) to reduce cost for the farmer. The work of Shickluna (1981) emphasized that if topography, texture, structure, tillage, drainage, colour of top soil and management history are uniform throughout the field each composite sample can represent up to 5 ha. A soil map or soil survey report if available can be an advantage to the farmer as it can be used to determine boundaries and sampling areas within the field. This is one of the major problems of southeast farmers as they don't have a soil survey report or soil maps of their soils thus more predicaments in assisting and proffering solution to their soil problems, documentation and tracking down the history of their soils. The frequency and depth of testing depend on the type of crop and cultural practice. For most annual crops sampling every two or three years should be adequate though this might have been when the farmer has understood his/her field needs. Intensive crops like vegetables and fruits benefit from annual sampling while greenhouse crops should be tested more often. For crops that occupy the soil longer than one season like permanent crops the soil should be tested before any of the crop is planted. Any change in the cropping practice should be preceded by soil testing. Though there is no standard depth for sampling soils, field or annual crops grown by conventional tillage used by virtually all the farmers in Nigeria, 0-25 cm of soil should be sampled. For the ridge or mound systems commonly practiced in south east, Nigeria samples should be removed from the sides of the ridges or mounds depending on the one practiced. While in no-tillage (Flat) practiced mostly in southern part of southeast and south-south, Nigeria samples should be collected from less than 10cm from the top soil. This is because the no tillage system permits an acid layer to form at the soil surface and this layer according to Scott and Hanway (1960); Fitts and Hanway (1976) can harm seed germination. Another important aspect in soil sampling is handling, crushing, mixing and sub-sampling of the sample prior to laboratory analyses. The soil sample should be properly dried, sieved, mixed and sub-sampled to obtain a representative of the soils in the field. This can be done by quarterly.

However it has being shown that drying the soil samples cause changes in the properties of many soils and the dried sample may no longer be representative of the soil in the field. For instance potassium availability both to plants and to chemical extraction in the laboratory may be greatly increased or decreased by drying of some soils (Scott and Hanway 1960). The most general practice is to air-dry the soil samples after they have been taken and extreme moist samples are sent to the laboratory where they are put in the cabinet where air is forced over them to increase the rate of drying. Avoid the use of sun or heat drying as this will falsely influence the result of certain elements/compounds except for soil nitrate test. After the air dry the samples can then be crushed and mixed. In sampling for greenhouse and container plants the soils should be sampled before planted to the crop. They then monitored periodically for any growth problem. In sampling for a crop of potted plants first any material on the soil surface should be removed and a core of soil is then taken. The core of soil should include soil from the top to the bottom of the pot or flat. Several containers should be sampled and tested.

4. Depth to be Sampled

Most often farmers are advised to collect a composite sample from a given area for sample field soil for chemical test. The purpose being to minimize the influence of micro-non uniformity (Reed et al.,1953), thorough examination should be made on the field to be sampled for differences in soil characteristics and past treatment. For example the following should be considered; topography of the field, texture, structure such as surface crusts or tillage pans, drainage, colour of top soil and past management. However where great variations in any of these features exist the field should be divided for taken a composite of sample from each predetermined area. A composite of sampling from two distinctly different areas is not representative of either area. A soil sample should be taken from each area that seems to have different fertility level. Most often the best way to achieve this uniformity is to use area soil survey report where it is available which is an excellent source of information about the kinds of soils in each field on a farm and should be sampling purposes. The number of borings recommended to make the composite sample ranges from 5 to 25 (Graham 1959; Iowa State Univ, Coop. Ext. Serv. 1963). In southeast, Nigeria 5-20 composite samples are recommended per hectare to address all abnormally of which range depends on the strength of the farmer's pocket. Where each borings contributes equally to the composite sample, the analytical result provides an estimate of the mean fertility level of the area (Peck and Melsted 1973) the accuracy depends on the range of fertility in the area and the number of borings drawn for the composite. With regard to the depth to be sampled an experience has shown that there is no standard depth for sampling soils. Initially, soils are sampled to plough depth which was interpreted to be 15-20 cm deep (Miller and Donahue 1992). If possible it is advisable to sample different depths for different analysis though this is dependent on the farmer's pocket (ability to offset the cost of analysis). For instance for salt problems the recommended depths may be 0-10cm, for no-till field the sampling depths might be shallow, for nitrate measurements, two depths are recommended 0-30cm and 30-60cm, 60-90cm can also be sampled (Miller and Donahue 1992). For south eastern soils of Nigeria it is advisable that the farmer sampled 0-30cm as that will serve all the purpose needed to be addressed. However it is utmost important that the farmer sample the depth which is recommended by the laboratory that will analyze the samples of which most soil laboratory in south east in particular and Nigeria in general recommend from 0-25cm or 0-30cm depth for crop production activities. This is because its recommendation will be based on correlation studies using the soil depth they have recommended. In taking soil samples cost other than sampling number and quality usually determines the number to be sampled. Hence the idea of using one composite sample where uniformity in field exist avoid taken few sub samples and deeper soil depths as non-representative sample cannot result in accurate soil test assessment of that field.

The commonly used sampling tools are augers, corers, shovel, trowels, soil tubers, jack knives etc but the commonly used tools in Nigeria are soil augers, corers and shovels. The most important factor in selecting a sampling tool is that it will obtain uniform cores and slices of equal volume to the desired depth at all spots in the composite area (Peck and Melsted 1973). Since good sampling is facilitated by proper equipment. Reed et al.(1993) described the characteristics of ideal sampling equipment as follows:

1. Ability to take a small enough equal volume of soil from sampling site so that the composite sample will be of an appropriate size to process for analysis.
2. Be easy to clean
3. Be adaptable to dry sandy soil as well as to fairly moist sticky soil
4. Be rust resistant and durably constructed to resist bending or breakage
5. Be relatively easy to use and thus provide for fairly rapid sampling of a field.

The more comprehensive the information provided the better will be the soil amendment or fertilizer recommendation interpreted from the soil analysis. Therefore, according to Miller and Donahue (1992), it was advised that the following should accompany the soil sample to the testing laboratory;

- Information on previous crop grown
- Crop (s) to be grown

- When was the field last limed, manured or fertilized (type of lime, and manure) and rates of application
- Depth of ploughing
- Soil management practices to be adopted
- Is the field well drained, intermediate or poor
- The kind or type of irrigation, (fertilizer, or soil amendment) to be used
- Other special problems such as temperature, hardpan, elevation etc, that may affect plant growth

5. Chemical Analysis of Soil (Soil Testing)

Many extracting solutions and procedures for removing nutrients from the soil have been proposed. But none remove exactly the same amount that plant roots obtain (Fitts and Hanway, 1976). One of the oldest methods of testing soil samples is by the use of chemical reaction that provides colour changes. The exact colour depends on the amount of available minerals in the soil. For pH test the colour depends on the soil pH. These simple chemical tests are easy to use but they are not reliable. Since the result are based on the technique of the tester and what he/she see. Moreover these tests may not provide an accurate measurement of the absorbed elements that affect plant growth like potential acidity and exchangeable potassium. Nevertheless such test can be useful in the field where one cannot drag equipment about or find a source of electricity. The above explained tests are however been largely replaced in laboratory testing or analysis by sophisticated modern instruments and tools such as the digital pH meter, atomic absorption spectrophotometer (AAS), flame photometer, calorimeter, autoclave etc. These tools rapidly and accurately measure amounts of mineral in soil samples. Though the instruments are costly they greatly improve laboratory operations by allowing faster testing and greater reliability. Furthermore the introduction of atomic absorption instruments in laboratories creates a favourable condition for much greater research in the area of micronutrients use and extraction of micronutrients from soil (Fitts and Hanway 1976).

Soil pH is one of the most enlightening attributes of a soil as it is one of the most effective indices for agricultural sustainability in humid tropical soils of southeast, Nigeria. The acidity, neutrality or basicity of a soil has much to do with the solubility of various compounds, the relative bonding of ions to exchange sites and the activity of various micro-organisms (Nweke and Nsoanya 2013). Soil pH can indicate something about percentage base saturation depending on the predominant clay type, the degree of dissociation of H-ions from cation exchange sites or the extent of H-ion formation by hydrolysis of Al (Mclean 1973). Since most of the plant essential elements in soil reach maximal or near maximal available of plant nutrients. The most common solution ratio used for measuring soil pH in soil testing is 1:1 (weight bases), though 1:2.5 and 1:10 ratio is also used quite often in soil test because 1:1 weight bases can lead to the closing of the membrane which can easily be cracked. Under normal circumstances the pH measured in water is always higher than the one measured in salt solution. The pH difference range from about 0.5-1.5 pH unit reason being that in measuring of soil pH it determine in most cases already dissociated H^+ or Al^{3+} ion contained in the outer solution especially with water but with salt solution it determine not only the H^+ ion of external solution but also those of internal solution

$$[Soil]H + K^+ + Cl^- \rightleftharpoons [Soil]K + H^+ + Cl^-$$

In highly weathered tropical soils like the Alfisol, Oxisol and Ultisol (soils of south east, Nigeria) the reverse cases occur in many occasions especially with the B horizon of such soil. The soils are called ferrallitic or fersiallitic, the pH measured with salt solution is higher than those measured in water.

$$[Exchanger]OH + K^+ + Cl^- \rightleftharpoons [Exchanger]Cl + K^+ + OH^-$$

In these highly weathered soils they have very low silicate to sesquioxide (SiO_2/R_2SO_2) ratios. This phenomenon is caused by the fertility that in such highly weathered soils there is preponderance of positive charges on the soil surfaces for that reason they absorb a lot of anions instead of cations especially if the ratio is below 0.5 which is mostly found in B horizons of these soils. As a result of differences in cation contained in the soil the soil pH can vary from pH3-pH10 depending on soil condition, weather (climate) and cations present in the soil. As H^+ ions are replaced by metallic cation in the process of soil development pH value increases but this increase in soil pH vary from cation to another depending on the extent of hydrolysis and dissociation.

$$[Exchanger]Me^+ + H^+ + OH^- \rightleftharpoons [Exchanger]H + Me^+ + OH^- \text{ (Me is metallic from base)}$$

But in soils that are highly saturated with hydrogen ions (H^+) some of the H^+ ions can be replaced with equivalent amount of Al, Ca, or Na when this happen there will be a sequence where by hydrolysis increases in that order as a result of reduction in the binding power of the cation in the soil complex that is Al < Ca < Na (hydrolysis sequence) also the extent of dissociation originating from metallic bases (MeOH) increases because there is an increase in the OH group. This increase in the OH leads to an increase in the soil pH. The consequence of this relation as a first approximation is that monovalent cations induce usually stronger pH increases than the divalent cations and the latter cause stronger pH increases than trivalent cations. In humid areas however soil pH are always measured both in water and salt solution but in the arid and semi-arid areas soil pH is advised to be measured only in water. The reason is that in the arid and semi-arid areas the soils are already saturated with salts. So there is no need to increase the salt solution. The pH measured in salt solution however, gives a more realistic value and do not fluctuate very much than soil pH measured in water. In other words the pH measured in water fluctuates very much. From the results of the analysis lime, Fertilizer or any other soil amendment of choice can be suggested for application.

Phosphorous is washed from the sample with acid solution; the solution is then put in spectrometer this particular method measure soluble phosphorous only, while insoluble forms are not measured. The resulting value can be in available phosphorous indicates how much phosphorous is free for plant growth. In the case of potassium the sample is washed with the solution that replaces potash on the cation exchange sites. The resulting value indicates the exchangeable potassium the amount that is readily available for plant growth. The test for nitrogen is difficult to test accurately, so some laboratories base nitrogen needs on the amount of nitrogen stored in the soil organic matter, effect of last year's crop, other cropping practices and the farmer's production goals. Nitrate-nitrogen can however be carried over the year where leaching and denitrification are less. In this case test is valuable; the top 6cm-9cm soil should be sampled for nitrates. Other important tests might include testing for soluble salts, cation exchange capacity (CEC), calcium, magnesium, sulphur and trace elements known to be problem in the area (Barber et al., 1961, Scott and Hanway, 1960, Hanway et al., 1962, Edward 1992, ETC 2008; Zhang et al., 2004; Nweke 2017). According to Brady and Weil (1999) it is advisable to send the sampled soils to laboratory located in the same region or location from which the soils are sampled (collected) they may have access to data correlating analytical results to plants responses on soils similar nature.

6. Interpretation of Result

Laboratory results are only reliable if they have been validated on soil similar to the one been sampled. The purpose of interpretation of data revolves on the purpose or objectives for which the information was collected. The result must be based on research about fertilization and nutrient levels on soils like the sampled soil. As differences in climate and crops exist farmer therefore should use local laboratory whose recommendations will be based on the local conditions, such laboratories may be associated with a university or a state agriculture experimentation station such as state agricultural development programmes (ADP) that exist in every state in south east, Nigeria. After analyzing the soil sample the laboratory issues a computer printed report (for those using computer). The report will include test results, interpretation of the results as well as fertilizer/manure and lime recommendations where necessary. Part of interpretation is to translate the raw numbers as low, medium or high. These numbers however vary from laboratory to laboratory. A low category may imply that a yield response to a high category is unlikely. It is through this that soil laboratory testers make their interpretation and recommendation to the farmers.

7. Conclusion and Recommendation

Soil test is a cost-effective and eco-friendly to the farmer with regard to soil management technology. The results generated from the field sampled and tested have many profound advantages when properly implemented over the non-sampled and untested field. The soil test result when implemented help to improve the physiochemical and biological properties of agricultural soil; it can act as a panacea for soil reclamation, enhancement of soil fertility and control of pathogens for sustainable agriculture. Finally it is advisable that a farmer samples his farm every year prior to planting so that over the years he can track his soil test level using chart to determine whether nutrient levels in his farm are being maintained, increased or depleted.

Soil test interpretations help in determining the effectiveness and proper use of fertilizers, lime and other soil amendments. Soil testing is the best tool farmers will use to determine how much fertilizer is needed to avoid both under and over fertilization. The interpretations, however does not include rates, method, type or time of application of fertilizer, lime or manure. Neither does it tell the farmer the form of a nutrient that may be most desirable to apply. Nevertheless the information obtained from a soil fertility evaluation and improvement performance to a farmer is more than just whether or not a nutrient is below or above the supposed level in the soil. Rather it should as well instruct the farmer on the time, rates and method of application of the fertilizer, manure or lime. Therefore soil testing is extremely important to any farmer in making the decision as to which nutrients should be included in the fertilizer and lime inputs of his field. It is only on that basis will he maximize profit in his agricultural ventures.

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