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Importance Of Soil Organic Matter In Fertility Maintenance And Productivity Under Farming Management System In Abakaliki, Nigeria

James Nte Nwite

Department of Soil Science and Environmental Management, Faculty of Agriculture and Natural Resources Management, Ebonyi State University, P.M.B 053 Abakaliki

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Address For Correspondence:
James Nte Nwite, Department of Soil Science and Environmental Management, Faculty of Agriculture and Natural Resources Management, Ebonyi State University, P.M.B 053 abakaliki

ABSTRACT
Soil organic matter (SOM) is a source or sink for nutrients retention and supply and as a result characterize agricultural potential of soils. It is critical to fertility maintenance and enhancement of productivity. To this extent was this review carried out in order to underscore importance of SOM in soil fertility maintenance and productivity under farming management system in Abakaliki Agricultural Ecology of Nigeria. Extrapolation was used to access information. Abakaliki soil was formed during Mesozoic era spanning between 65 to 140million years ago and as such has become degraded with organic matter levels being as low as 0.5 to 1.5% which is below 2% minimum recommended to keep soil at optimal function. Although, there have been research efforts yet understanding of functions of SOM in enhancing soil fertility, quality and productivity remain primarily descriptive in nature. It is even more difficult to understand SOM due to its complexity given varied responses of soil organisms to their environment and on management efforts. There are maximum benefits accruing from increasing SOM in soil both from agricultural and environmental perspectives. Generally, increased soil organic matter in soil optimize CEC, nutrient retention and supply, water storage and release, aeration, structural stability and biological activity. Factors that promote SOM such as conservation, good tillage, crop rotation, aforestation and amendments are advocated while minimizing those engendering losses such as deforestation, slash and burn farming, deep tillage, over-grazing and over-fertilization. This would enhance not only SOM in soil but could ensure sustainable soil fertility and productivity in our farming agro system. Even though that SOM is the most extensively discussed subject area in literature, there still exists gap in knowledge such as Soil Organic Matter dynamics in different soils and different seasons. Further research effort is recommended in these areas.

KEYWORDS: Farming management system, Fertility maintenance, Critical, Productivity, Soil organic matter

INTRODUCTION

Soil organic matter is plant and animal residues either decomposed or in the process of decomposition and can be black or dark in colour. For instance, soil organic matter (SOM) is a complex and varied mixture of carbon-containing residues [1]. According to [1], soil organic matter is diverse organic materials such as living organisms, slightly altered plant and animal residues, and well decomposed plant and animal tissues that vary considerably in their stability and susceptibility to further degradation. It is materials which come from tissues of organisms, (plants, animals or microorganisms) that are currently or were once living [3] and can be complex and heterogeneous (non-uniform) and due to biological factors under which it was formed does not have a

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defined chemical or physical structure. According to the authors, it is not evenly distributed throughout the soil and could break down at various rates by multiple agents that are influenced by the unique environmental conditions in which they are formed. Soil organic matter is present in all soils all over the world and it is transformed and degraded as a result of soil microorganisms. Precipitation and temperature regulate SOM pool and also control composition of soil organisms.

The accumulation of SOM (Figure 1) is higher in cool and under humid conditions compared to warm and arid climates [3]. The author noted that different soil textures for example sand, silt and clay affect degree of susceptibility to decomposition. For instance sand sized fraction is more susceptible to decomposition and can give a higher turnover than the silt or clay size fractions.

Fig. 1: Soil organic matter contents in Abakaliki Area

Soil organic matter has been identified as a primary attribute of soil quality assessment for agricultural production [4]. [3] noted that SOM had been directly and positively related to soil fertility and agricultural productivity potential. The authors enumerated advantages of increasing or maintaining a high level of SOM to include reduced bulk density, increased aggregate stability, resistance to soil compaction, enhanced fertility, reduced nutrient leaching, resistance to soil erosion, increased biological activity and reduced emission of green house gases by carbon sequestration. Soil organic matter content of the soil is increased by leaving residues on the soil surface, rotating crops with pasture or perennials, incorporating cover crops into the soil or by adding organic residues such as animal manure, litter or sewage sludge [5]. Low activity clays which abound in Abakaliki, southeastern Nigeria are inherently low in nutrient status or fertility and productivity due to extremely low cation exchange capacity (CEC) [6]. This natural shortfall in fertility is made up for by rapid formation and accumulation of organic matter abundant in CEC [7; 8]. Unfortunately, this soil organic matter which is considered to be life wire of tropical soils is either depleted in the course of inevitable mechanical land clearing or as a result of continuous cultivation by farmers [6].

Though the positive effect of soil organic matter in the soil had long been recognized one still wonders at our cultural agricultural practices which are inimical to organic matter regeneration in the soil in Abakaliki agro ecological environment in Nigeria. This is because of the “slash and burn” farming approach largely practiced by farmers where they burn the vegetation or destroy it without allowing a natural recycling order to take place. This system reduces availability of soil organic matter in the soil to a critical level. It is for this reason that this review is necessitated. The objective was to study characteristics of soil organic matter and its importance in soil fertility maintenance and productivity under farming management system in Abakaliki agro ecological environment.

Methodology And Description Of Location:

The review was carried out in Abakaliki, Nigeria. Extrapolation of information from previous studies was used in the study. The area is located by latitude 06º4′N and longitude 08º65′E in the derived Savannah of the Southeast agro-ecological zone of Nigeria. The climate of Abakaliki is described as tropical [9] which is characterized by hot (warm) season experienced from November to March and cold (cool) season from April to October. These seasons are broadly divided into dry and rainy reasons. There is bimodal pattern of rainfall which spreads from April to July and September to early November with a break in August. This break is called “August break”. At the beginning of rainfall it is characterized by heavy lightning and thunderstorm. It is violent, torrential and often lasting between 1 – 2hours [10]. The minimum and maximum annual rainfall ranges from 1700 to 2000m with an average annual rainfall of 1800mm. Temperatures vary within the year but with a fairly stable or mean range of 27^0C and 31^0C for rainy and dry seasons. Relative humidity is 80% during humid periods of the year which declines to 60% during warm season. Geologically, Abakaliki agro-ecological area is underlain by sedimentary rocks derived from successive marine deposits of the cretaceous and tertiary periods.

According to Federal Department of Agricultural Land resources [11]. Abakaliki agricultural zone falls within "Asu river group" and consists of olive brown sandy shales, fine grained sand stones and mudstones. The soil is shallow with unconsolidated parent materials (Shale residuum) within 1m of the soil surface. It belongs to the order ultisol and classified as typic haplustult. Abakaliki is largely agrarian and grows most common staple food crops spanning from root and cereal to vegetable crops such as yarn (*Dioscorea spp*), cassava (*Manihot spp*), maize (*Zea mays L.*) rice (*Oryzae sativa*), cocyam (*Colocasia esculenta*), vegetables, fruits and rears native livestock for their livelihood. There are no large scale commercial farmers but every household practice subsistence farming. Due to increase in population, there is continuous cultivation of soil.

Nature of Soil Organic Matter:

Fractionation is one of the processes where soil organic matter is separated into its various components such as humic acid, fulvic and humin. This method is no longer acceptable as it artificially defines the SOM fractions which practically do not exist in soils [12]. The method does not produce chemically discrete SOM fractions but heterogeneous and non-reproducible fractions [3]. Based on this, the authors recommended a more biologically and agriculturally meaningful method of describing SOM which is by dividing it into various "pools which are sorted by how easily the material is decomposed for example active or labile, slow or intermediate and passive or stable". Pools according to [3] are measurable organic matter components or theoretically separate entities and are concisely designated by fractions. This method of SOM classification is commonly used today than use of humic, fulvic acid and humin.

Active or Labile Fraction:

The active or labile fraction of SOM is the younger organic material, from recently deposited roots and residue, dead organisms, and waste products. It is the most biologically "active" fraction of the SOM since it serves as food source for the living and biological community []3. Labile implies that it is a part of SOM fraction which is more readily decomposed compared to the passive or stable fraction. This SOM fraction is generally less than five years old. Although, there are many ways to measure active fraction, however, one of the most commonly accepted methods is to measure the particulate organic matter (POM). Particulate organic matter is the microbially active fraction of soil organic matter [3]. The advantage of using POM than other techniques such as size and density of SOM, is that the latter shows strong response to soil management decisions such as in tillage [13; 14].

Passive or Stable Fraction:

The passive stable fraction of SOM is the newly converted original organic materials into chemically complex, nutrient poor compounds that few microbes can degrade or which can resist degradation. It is simply the product of decomposition and transformation of original plant and animal tissues by microorganisms. It is commonly referred to as "humus". This fraction makes up a third to a half of the entire SOM [3].

The stable fraction of SOM is poor in many nutrients and therefore not very important in soil fertility. However, the significance of stable humus fraction of soil lies in its very chemically reactive nature. It largely contributes to the soil's net chemical charge commonly known as cation exchange capacity and anion exchange capacity (ion-exchange phenomenon in soil). It is in this way that humus temporarily and reversibly binds plant nutrients in the soil and prevent them from being leached out, so that they are available for plants uptake. The stable fraction modifies and stabilizes toxic materials such as pesticides, herbicides and heavy metals so that they are less reactive or dangerous. It increases aggregation and reduces a soil's vulnerability to erosive for degradiative forces [14]. This saves soils as loss by erosion is prevented or highly minimized.

Soil Organic Matter Level in Abakaliki As Influenced By Farming Management:

Soil organic matter levels in mineral soils vary widely worldwide and range from trace amounts up to 20% [3]. Generally, soils which have 20% organic matter or more organic material to a depth of 35cm is considered as "organic soil" and taxonomically referred to as histosol [3]. On world scale, histosols make up only about 1% and the soils in Abakaliki of southeastern Nigeria have SOM levels which range from low to moderate values of 1.5 – 3.0% [5]; [15] of the total soil weight.

The reasons for these low levels of SOM in the soils of this area compared to other parts of the southeast such as Anambra state is not farfetched. Part of this reason is that the soils of this region are relatively quite old having been exposed since invasion of lower Benue river. These soils are believed to have been formed during the "Mesozoic Era" which spans between 65million to 140million years ago. Consequently, the soils of Abakaliki agro-ecological area of Nigeria have much longer time to decompose, erode, weather and even leach out considerably much of the SOM that was originally present. As a result, the SOM levels are less than 1% in most parts of Abakaliki agroeconogy.

Since Abakaliki soils are old, they have been very much weathered; and robbed of their SOM content and nutrients as younger soils have. This situation is exacerbated by rapid urbanization which until 120years covered area. This aggravated deterioration of the SOM as it removed in large amounts of SOM. The dominance of forest vegetation in this region does not help matters as SOM and nutrients are recycled downwards through illuviation unlike in grass land vegetations. This contributed to low levels of SOM in the soil. Farmers in the area practice "slash and burn" and intensive continuous cultivation largely because of small land mass and expanded population. These practices are depletive and act as nutrient mining on soil as well as SOM. Abakaliki is traversed and dotted by expanse of upland than floodplains. The upland soils have lower SOM than the floodplains. Incidentally, upland soils make up about 75% of the total land mass in the area.

According to [3], there is currently no universally accepted SOM threshold value for determining maximum agricultural productivity. However, [16] suggested that different soil types have different organic matter levels at which they are most agricultural productive. So while a weathered soil in Abakaliki area may give maximum productivity at 1%, the same SOM value may indicate a degraded soil with limited soil productivity in Enugu or Anambra areas of Nigeria. Generally, researchers [17]; [18] have demonstrated that soil organic matter levels less than 0.5% may be limiting to soil productivity and agricultural yields irrespective of the soil type. Although, predictions of rates of SOM decomposition and plant nutrients release is quite different due to that they are controlled by many different, yet related, physical, chemical and biological properties it is easy to understand how to increase SOM in the soil [3]. Certainly, when the input of organic materials into the soil exceeds the rate of loss from decomposition, erosion and leaching SOM will effectively appreciate. Some of the practical steps in increasing SOM in the soil include crop rotation, shifting cultivation, incorporation of surface residues into the soil, amendments in forms of organic and inorganic inputs and use of appropriate tillage techniques [3].

Role of Soil Organic Matter in Maintenance of Soil Productivity:

The role of soil organic matter in maintenance of soil fertility and productivity can be captured in three broad categories of physical, biological and chemical [3]. Many but varied interactions occur among these aspects of SOM [19]. In addition, active and stable fractions would play different but significant roles in specific SOM functions.

Cation Exchange Capacity:

Cation Exchange Capacity (CEC) can be defined as the total sum of exchangeable cations (both positively and negatively charged ions) that a soil can hold [1] at a particular time. Generally, CEC determines a soil's ability to retain positively charged plant nutrients such as NH_4^+ Ca^{2+}, Mg^{2+}, K^+ and Na^+ [3]. Therefore, as CEC increases for a soil, there is a higher potential for it to retain more of these plant nutrients and reduces the tendency for leaching. Furthermore, soil CEC influences the application rates of lime and herbicides required for optimum effectiveness. It is the stable fraction otherwise known as humus of SOM that is the most important fraction for contributing to the CEC of a soil.

Table 1 shows different soil textures with their differing capacities for CEC. The results showed that organic matter contributed more to exchange capacity than the soil textures and clay mineral. The trends of the results follow the order of organic matter > vermiculite > clay > clay loam/silty clay loam > silt loam > sandy loam > sand. This implies that interaction between texture and organic matter components in soil could have a tremendous influence on CEC potentials and by extension on sustenance of soil productivity.

Table 2: Ranges of CEC for each soil texture and organic matter

Texture	CEC ($Cmolkg^{-1}$)
Organic matter	400 – 200
Vermiculite	150
Clay	25 – 60
Clay loam/silt clay loam	15 – 35
Silt loam	10 – 25
Sandy loam	2 – 15
Sand	1 – 5

CEC – Cation exchange capacity
Source: [3].

Nutrient Retention and Release:

Humus is a very active and plays vital role in regulating the retention and release of plant nutrients. It has a highly negatively charged soil fraction and as a result capable of holding a large swarm amounts of cations readily in exchange for plant roots. The highly charged humic fraction of the SOM acts slowly in release of nutrients just like "slow" release fertilizer [3]. Once nutrients are removed from soil cation exchange sites, they become available for plant uptake. In these ways, SOM help in soil maintenance and increase of productivity. Presently, predictions of the amount of nutrients released from SOM are not attainable as there are no generally agreed methods in use [3]. Nevertheless, the authors noted that prediction of N release to the soil from SOM is difficult but could be estimated by pre-plant soil profile nitrate (PPNT) or pre-side dress nitrate (PSNT) tests. At Abakaliki, [20] and [15] in their studies on mineralization rate constant, reported that SOM content greater than

5% would require lower fertilizer N requirement compared to a soil with less than 5% SOM. Due to low activity clays prevalent in the Abakaliki areas, SOM falls between 0.5 – 3.0%. Therefore while some areas need a lower level of fertilizer N for higher productivity others indeed require very high fertilizer N for soil fertility maintenance and for enhanced productivity. Sometimes, fertilizer N requirement of the soil is dependent on prevailing farming practices.

Soil Structure and Bulk Density:

Soil structure is the arrangement of the primary particles of soil, silt and clay to form peds [21]. Soil structure (Figure 2) is stabilized by binding or commenting agents which organic matter is a primary factor [22]. The binding agents include plant and animal materials or residues (polysaccharides, Fungal hyphae, plant roots) and inorganic cements such as exchange cations (Ca^{2+} and Mg^{2+}), charged attractions; freezing and thawing as well as wetting and drying cycles operating in the soil body. These agents are responsible for building large-stable aggregates in soils. The stable and active fractions of SOM contribute greatly to fertility in maintaining soil structure and resistance to compaction.

Fig. 2: Runoff of water on a poorly structured soil.

Water Holding:

One of the ways to increase drought resistance especially in arid environment is to increase SOM level. The negative effect of drought on crop and soil productivity is not only tied to inefficient rainfall or its irregularity but because a large proportion of this rainfall is lost from the fields through runoff and seepage. Some factors which facilitate inefficient water usage are completely out of a growers' hands, for example slope and steepness, rainfall intensity, soil texture and seepage beyond rooting depth [23]. At the same time, some factors such as buring of crop residues, continuous tillage [24], crusting and sealing reduce SOM content and consequently water infiltration and this increase water runoff. Generally, SOM affects the amount of water in a soil by influencing water infiltration and percolation, evaporation rates and increases the soil water holding capacity [21].

Factors such as crusting, sealing, lack of surface residues, poor soil structure, compaction, drastically reduce water infiltration and percolation [21] and steep slopes that permit large volume of water runoff. Lateral movement of water often results to erosion [21] which carries away valuable topsoil. Practices that encourage leaving surface residues on soil is plausible as it impedes water runoff, resulting in reduced velocity of water movement. Reduced movement of water encourages and facilitates downward movement of water into the soil profile rather than across soil surface. Increasing SOM and leaving residue on the soil surface is panacea to increased water infiltration into the soil.

Crusting and sealing (Figure 3) is common in Abakaliki areas when tillage is carried out during dry season before onset of rainfall. When eventually heavy rainfall occurs, pounding effect of the rainfall drop impact on the disturbed soils create soil crust and sealing which prevent adequate water infiltration and can physically constitute a barrier for seedling emergence and potentially reduce optimum plant population [21]. However, surface residue can reverse this negative effect by slowing rate of water evaporation and improving soil structure. This helps to prevent soil crusting and sealing propensity.

Close observation or common experience may have shown that soils with higher SOM have better "tilth" or "spongy" than soils with less SOM. Reason being that SOM is less dense than the mineral soil particles per unit volume and as such provides greater pore space for water and air to be held. The positive effect of increased

SOM is greater soil space which provides enough area for water to be stored during drought periods. Pores are characterized as "macro", "meso" and "micro". [21]. Macro pores do not hold water tightly and drains rapidly. The meso and micro pores hold water more tightly and for a longer period of time so that during drought period the soil retains moisture and release same for plant uptake. The benefit of leaving residue on the soil surface and increasing SOM is that water infiltration is increased, soil crusting and sealing decreased and the soil can hold more water that infiltrates into the soil that is eventually made available for the plant use.

Fig. 3: crusted soil

Biological Activity:

Perhaps, the importance of activities of microorganisms in the study of soil is captured by [25], a father of soil pedology that a natural body of degraded mineral or organic material cannot be considered a "soil" without soil organisms. Microorganisms evaluated as "life" in soils include vast array of bacteria, fungi, algae actinomycetes, virus, protozoa, plants and fauna such as nematodes, springtails, mites, earthworms and insects. Although microorganisms only make up a small portion of SOM (practically less than 5%) but they are very significant in the formation, transformation and functioning of the soil. They are largely involved in decomposition, nutrient cycling, degradation of toxic materials, N fixation, symbiotic plant relationships and pathogen control [3]. [25] noted that microorganisms break up plant materials, expose organic surface areas to microbes, move fragments up and down, and function as homogenizer of soil strata. Soil fauna play an important role in the initial breakdown of complex and large pieces of organic matter, making it easier for soil microorganisms to release carbon and plant nutrients from the material as they continue the process of decomposition.

Effect of Farming Practices on Soil:

Loss of SOM from farmland has been one of the most extensively studied and documented evidence of agro-ecological consequences of our farming activities on soil. Indeed, farming has affected the quantity and quality of SOM in many ways. For instance, greatest loss of soil organic carbon (SOC) associated with farming occurs during the first 25years of cultivation [26] which 50% losses are common. At Abakaliki, most of the soils converted from natural to farming systems have lost between 30–60% of the original SOC level. Farming practices contribute to the depletion of SOC through deforestation and biomass burning, drainage of wetlands, tillage, crop residue removal, cultivation and over use of pesticides and other chemicals [27]. Generally farming lands store less SOC than grazing lands because crop land has greater disturbance from cultivation and lack of manure not being returned to the system, has caused less root biomass or less biomass returned to the soil surface [27]. Many factors related to farming management can affect the rate and amount of C lost from the soil system [3]. [26] pointed out that factors which affected soil C loss from agricultural soils were climate and soil type, tillage intensity and depth, crop rotation decisions, amount of organic inputs, amount of plant residue on the soil surface, quality of plant residues returned to the soil, soil biological activity, depth and time of fallow and erosion.

Carbon Sequestration:

Farming is known to have evolved many years ago but since the development, it has changed the face of the planet in a slow but relentless transformation [3]. Present day researchers have uncommon interests and concerns for events that happen on our earth. One of these areas is the study of soil organic matter which plays a critical role in global C cycle [3]. According to the authors, the importance of soil in the C cycle is due to its role as both a major source and sink for C in the biosphere. The total soil C pool is three times greater than the atmospheric C pool and 3.8 times greater than the biotic C pool [19]. The soil C pool contains about

$1.7x10^{12}$tons of organic C and about 8.3 x 10^{11}tons of inorganic C to a depth of 120cm [27]. Although the soil C cycle is complex, the concept of C sequestration for mitigating the release of greenhouse gases is unambiguous [3]. They noted that carbon stored in soils ties up C that would otherwise be released to the atmosphere as C – containing greenhouse gases for example carbon IV oxide (Co_2) and methane (CH_4). A lot of researches are geared towards determining the extent to which atmospheric carbon can be diminished by storing C in soils.

Tillage:

Tillage results in loss of SOM through three major mechanisms of soil aggregates deterioration, changes in temperature as well as moisture regimes and leaching of organic C [24] and accelerated rates of erosion [27]. Even in cropping systems such as "slash and burn" and many other practices that do not return residues to the soil, reducing tillage intensity can result in maintaining soil fertility and productivity through increasing the soil organic fraction that is most easily degradable [28]; [29]; [16]. Tillage facilitates loss of carbon from the soil in form of carbon IV oxide (Co_2). The deeper and more aggressive the tillage the more Co_2 is released to the atmosphere [3]. As documented by USDA-ARS and reported in [30], measurement of Co_2 loss from three tillage systems in a continuous corn system showed that mould board plough (Figure 4) which is the most aggressive system lost 579Gtha^{-1} of Co_2 in a 24 hour period. Comparatively, disc plough, strip tillage and strip till lost 47, 30 and 18% lower CO_2 relative to mould board plough system respectively.

Fig. 4: Moldboard Ploughing reduces soil organic matter compared to other tillage systems.

Crop Rotations:

Crop rotation enhances the productivity of both soil and crop. Advantages of a well-managed crop rotation are improved yields, breaking plant pest cycles, maintaining soil fertility and reducing fertilizer inputs and controlling erosion [3]. Cover crops are integrated with green manures as part of the crop rotation in well designed sustainable land management system. Cover crops are generally crops grown to provide soil cover and sometimes may not be incorporated into the soil [3]. Cover crops may serve as means to prevent soil erosion. It is known as "catch crop" if it is grown to reduce nutrient leaching or retrieve nutrients deep in the soil profile. On the other hand, a green manure is a crop primarily grown to improve soil fertility and often incorporated after planting while it is still green or before flowering.

Cover crops, perennial grass and legumes in crop rotations including reduced tillage are important factors in maintaining SOM in a sustainable cropping system. Furthermore, crop rotations affect biological diversity of an agro-ecosystem [3]. The authors also pointed out that biological diversity is important for maintaining a high-functioning, disease-resistant, and stable ecological system. Crop rotations that maximize soil C inputs and maintain a high proportion of active C are important factors in establishing a sustainable cropping system for higher productivity [3].

Fertilization:

There was a new era in crop production after the world war II which saw the advent of production through affordable N fertilizers [3]. Marginal lands were improved and profitably cropped with ammonium and nitrate-based fertilizers [3]. Incidentally the authors noted that there was no answer to elucidate how fertilization affected SOM since many other factors such as present vegetation, soil type and prevailing climate must also be considered. Besides, SOM fractions for example active and stable are affected differently by fertilization [3].

Fertilization could affect the soil microbial community either directly or indirectly by supplying mineral nutrients for microbial use and allows for proliferation of plant biomass to serve as a microbial food source.

According to [3], a large microbial community can result in either a net C increase or decrease to the soil system and depending on how much C stays in the soil system as microbial biomass and how much is lost as respired gases, nevertheless, a greater microbial community results in a greater amount of soil respiration. Of all the factors, vegetation, harvested biomass, microbial community biomass and plant and microbial respiration are factors that must be considered when determining if adding fertilizer would result in SOM accumulation or degradation. This is important for assessment of soil quality, fertility maintenance and for increased productivity.

Conclusion:

This review has shown that soil organic matter has profound impact on soil fertility maintenance, quality assurance, crop and soil productivity. Though understanding of functions of SOM is complex given the varied responses of soil organisms to their environment and to our management efforts, nevertheless increasing SOM in all ramifications has a host of benefits from both an agricultural and environmental point of view [3]. Empirical studies indicate that soil organic matter optimize CEC, nutrient retention and supply, moisture availability, structural stabilization, aeration and biological activities. These culminate in fertility and productivity optimization. Practices such as deforestation, over-grazing, deep tillage, continuous cultivation, slash and burn and over-fertilization should be avoided in view of their negative impacts on soil fertility and productivity. This study would contribute to increasing awareness of soil scientist, land users such as farmers and other critical stake-holders on the importance of SOM and its role in building sustainable fertility and productivity. Generally, it is recommended that enhancing factors that result in SOM accumulation in the soil and avoidance or moderation of those engendering losses are veritable steps toward good management to ensure soil sustainable fertility maintenance and productivity in our farming system.

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