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BEST MANAGEMENT PRACTICES ON SOIL ORGANIC MATTER CONSERVATION AND RAINFALL RUNOFF REDUCTION: A TECHNICAL NOTE

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Abstract: The loss of soil degrades arable land and eventually renders it unproductive. Appropriate land management is very important in an area like Uyo, South-South Nigeria, which is characterized by frequent rainfall and high intensity of rainfall in order to reduce the impact of soil erosion consequent upon runoff to a great extent. There have been numerous attempts to avert the menace of soil erosion in the agro-ecological region of Uyo, especially through the large-scale engineering projects funded by World Bank as well as the Federal and State Governments. However, little awareness has been created on the use of cheap and reliable management practices such as growing vegetation strip cropping, crop rotation and mulching, which are capable of protecting the soil surface against the direct impact of rain drop by kinetic energy. These methods also help to increase soil organic matter level and / or vegetal cover, thereby ensuring the stability of the soil aggregates (structure), increases infiltration capacity, while vegetal cover intercepts the ain drops on the soil direction, thus averting intense surface runoff and erosion. The study is intended to provide profound information on cheap and simple methods of soil conservation and erosion control, named best management practices (BMPs). These management practices are expected to be implemented by farmers, soil and water conservation engineers, soil scientists, environmental scientists, crop scientists, and environmentalists, in order to avert soil degradation and optimize agricultural production.
Keywords: soil degradation, soil organic matter, rainfall runoff, erosion control, soil conservation

INTRODUCTION

Land degradation through soil erosion is considered a natural and geologic phenomenon, and it is identified as one of the key challenges that impact on diverse sectors of human existence ranging from the depletion of top natural rich soils, lowering of agricultural productivity and volume storage depletion of reservoirs through sedimentation (Coulombo et al., 2010; Wang et al., 2013). It is therefore pertinent that the soil be protected from the natural and accelerated erosion phenomenon. It is important to state here that the most practical approach to runoff/ erosion control is preventive rather than curative. Preventing erosion by keeping the soil in place through good management techniques is termed, "Best Management Practices" (Syed et al., 2012).

The best management practices (BMP) are required to be implemented in order to control the erosion phenomenon and secure food production via agricultural productivity, enhance the water resources and promote biodiversity and carbon sequestration, as well as influence the agricultural and forestry ecosystems positively. The choice of the technique used in reducing or subsiding erosion problems must fulfil the criteria including cost effectiveness, feasibility, availability, durability, compatibility and labour and management (Jabatan, 1996).

The less the soil is covered with vegetation, mulches, crop residues, etc, the more the soil is exposed to the impact of raindrops. When a raindrop hits bares soil, the energy of the velocity detached individual soil particles from soil clods. These particles can clog surface pores and form many thin, rotten impermeable layers of sediment at the surface, referred to as surface crusts. They can range from a few millimetres to 1cm or more; and they are usually made up of sandy or silty particles. These surface crusts hinder the passage of rainwater into the profile; with the consequence that runoff increases. The breaking down of soil aggregates by raindrops into smaller particles depends on the stability of the aggregates, which largely depends on the organic matter content.

Increased soil cover can result in reduced soil erosion rates close to the regeneration rate of the soil or even lower as reported by Debarba and Amado(1997) for an oats and vetch/ maize cropping system.When the soil is protected with mulch, more water infiltrates into the soil rather than running off the surface. This causes streams to be fed more by subsurface flow rather than by surface runoff. The consequence is that the surface water is cleaner and resembles groundwater more closely compared with areas where erosion and runoff predominate. Greater infiltration should reduce flooding by increased water storage in soil and slow release to streams. Increased infiltration also improves groundwater recharge, thus increasing well supplies (Debarba and Amado, 1997).

Soil erosion fills surface water reservoirs with sediment, reducing their water storage capacity. Sedimentation also reduces the buffering and filtering capacity of wetlands and the flood-control capacity of floodplains. Sediment in surface water increases wear and tear in hydroelectric installations and pumps, resulting in greater maintenance costs and more frequent replacement of turbines. Sediments can also reach the sea, harming fish, shellfish and coral. Eroded soil contains fertilizers, pesticides and herbicides; all sources of potentially harmful offsite impacts. One of the most significant factors affecting organic matter content is erosion (Oregon, 1984). Studies in the United State have shown that OMC was the variable most closely associated with runoff from moderately sloping soils encompassing a broad range of textures.

CLIMATIC CONDITION OF THE STUDY AREA

In humid tropical area like Uyo, rainfall characteristic is one major factor that influences erosion. In Uyo, south-south Nigeria, the rains are of high intensity and of bimodal pattern with two peaks in July and September, and period of 2 – 3 week of little or no rain called August break in between. The dry season gives rise to the pose-season characteristics of a maximum rainfall regime in which the months with the heaviest rainfall are June and July for the first rainfall maximum and September for the second maximum. The annual rainfall ranges from 2000mm on the northern fringe to over 3000mm along the coast (Essien, 2012).

Research reveals that at least 40% of vegetation cover is appropriate to gain considerable protection from rainfall (Jabatan, 1996), but in most regions of Uyo, the native vegetation has been completely replaced by secondary forest of predominantly oil palms and woody shrubs such as grasses. The forest is noticeable around hamlets, watercourses, tree crop plantations and forest reserves. The state lies north of the equator and within the humid tropical and has a mean annual temperature between 26 – 27^{o} and two distinct seasons: the wet season (April to October) and the dry season (November - March). In the south and central parts of the state, the rainy season lasts for about 7 or 8 months but, towards the far north of the state, it reduces to about 6 months (SLUK-AK, 1989).

The geological formation in Uyo is coastal plain sand, which occupies more than 75%of Akwa Ibom State soils (SLUK-AK, 1989). The soils are derived from the parent material and are highly weathered and dominated by low activity clays; the dominant soils in Uyo are of inter-fluvial slope with a pattern of increase in clay content down the profile and are generally of low organic matter cover (OMC), low water storage capacity, and low CEC and highly susceptible to erosion. The dominant forest types in Uyo include the saline water swamp, fresh water swamp forest and the rainforest (Essien, 2012).

It is an established fact that organic matter content increases the stability of soils, thereby reducing its susceptibility to erosion (Gupta et al., 2010; Udoumoh eta l., 2020). The organic content of Uyo soils are low (Udoumoh et al., 2020). Many researchers including (Brady and Weil, 2012; Toy et al., 2002), observed that soils with relatively low organic matter are very vulnerable to water erosion since organic matter increases the stability of the soil. Organic matter binds the soil particles together and creates forces between particles and thus creating stability (Brady and Weil, 2012).

ENHANCING ORGANIC MATTER ACCUMULATION IN THE SOIL

Soil organic matter is the fraction of the soil that consists of plant or animal tissue in various stages of breakdown (decomposition). Most of our productive agricultural soils have between 3 and 6 % organic matter. Organic matter is made up of different components that can be grouped into three major types, namely: plant residues and living microbial biomass, active soil organic matter also referred to as detritus, and stable soil organic matter, often referred to as humus (Cornell, 2006).

The living microbial biomass includes the micro-organisms responsible for decomposition (breakdown) of both plant residues and active soil organic matter or detritus. Humus is stable fraction of the organic matter that is formed from decomposed plant and animal tissue. It is the final product of decomposition. Over time, the application and incorporation of organic materials can result in an increase in stable soil organic matter levels. Sources of organic materials include; crop residues, animal manure, compost (see figure 1), cover crops (green manure), perennial grasses and legumes (Cornell, 2006).

Figure 1: Compost application aimed at increasing soil organic matter levels and promoting aggregate stability Source: FAO (2005).

Soil organic matter (SOM) level depends on both uncontrollable factors ie weather conditions, and controllable factors, that is, soil management. Managing SOM is a balancing act of additions; crop residues, manure, and compost and losses; decomposition plus erosion. Addition of organic materials including animal manure, compost, cover crops (green manure), and some off-farm materials such as municipal leaves and food residues will increase SOM (Umass, 2020). SOM improves many physical, chemical, and biological characteristics of the soil, including water holding capacity, cation exchange capacity (see figure 2), pH buffering capacity, and chelating of micronutrients.

Furthermore, well decomposed SOM improves soil structure by increasing aggregation, enhances biological activities in the soil, slowly releases nutrients, and suppresses some diseases. A loss of SOM can lead to soil erosion, loss of fertility, compaction and general land degradation (Umass, 2020; Doran and Parkin, 1994; Karlen et al., 2001; Dexter, 2004a). The accumulation of SOM within soil is a balance between the return or addition of plant and animal residues and their subsequent loss due to the decay of these residues by microorganisms and mismanagement of soil (U)to plant loss due to the decay of these residues by microorganisms and mismanagement of soil (Umass, 2020).

For the study area, the relative proportion of the organic matter fraction is small compared to the clay fraction on a dry weight basis (Udoumoh et al., 2020). Humic materials (humus) along with clay particles would provide cation exchange sites in soils that hold the positively charged plant nutrients improving the soil's ability to reduce nutrient losses by leaching.

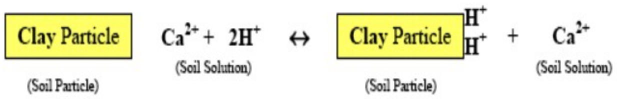

Figure 2: Cation exchange mechanism. Source: Oregan (1998)

Some plant nutrients and metals exist as positively charged ions, or "cations", in the soil environment. Among the more common cations found in soils are hydrogen (H^+), aluminium (Al^{3+}), calcium (Ca^{2}+), magnesium (Mg^{2+}), and potassium (K^+). Most heavy metals also exist as cations in the soil environment. Clay and organic matter particles are predominantly negatively charged (anions), and have the ability to hold cations from being "leached" or washed away. The adsorbed cations are subject to replacement by other cations in a rapid, reversible process called "cation exchange".

Cations leaving the exchange sites enter the soil solution, where they can be taken up by plants, react with other soil constituents, or be carried away with drainage water. The "cation exchange capacity", or "CEC", of a soil is a measurement of the magnitude of the negative charge per unit weight of soil, or the amount of cations a particular sample of soil can hold in an exchangeable form. The greater the clay and organic matter content, the greater the CEC should be, although different types of clay minerals and organic matter can vary in CEC.Cation exchange is an important mechanism in soils for retaining and supplying plant nutrients, and for adsorbing contaminants. It plays an important role in wastewater treatment in soils. Sandy soils with a low CEC are generally unsuited for septic systems since they have little adsorptive ability and there is potential for groundwater (NRCS, 2014).

The CEC of soils varies according to the clay %, the type of clay, soil pH and amount of organic matter. Pure sand has a very low CEC (Moore et al., 1998). Microorganism supported by the rich food substrate of soil organic matter would stabilise soil particles through encouragement of aggregation, which would result in better water holing capacity in the sandy soils and consequently improve soil drainage in clay soils by promoting large sized pores.

Improved soil structure would improve drainage and also decrease the erosion potential of the previous top soil by reducing the runoff. Many studies have revealed that repeated use of organic amendments will improve the organic matter level (Bauer and Black, 1992; Esu, 2005). Other factors which influence the activity of SOM include organic soil pH and temperature.

EFFECTS OF RUNOFF AND INCIDENCE OF SOIL EROSION

There is pronounced relationship between rate of runoff and incidence of erosion. Runoff water has the energy to detach soil particles by scour and to transport entrained soil materials either in suspension or by pushing or rolling larger particles. In this way overland flow causes erosion. Erosion by scouring accounts for less than 10% of the erosion process, the rest being causes by raindrop impact. Secondary forms of erosion resulting from the transporting effects of runoff are more damaging and are usually classifies as rill, gully and stream channel erosion according to increasing concentration of runoff and the degree of damage caused to land. Runoff erosive capacity is a function of its volume and velocity; as the volume and velocity increase, so do the energy to scour away soil particles and the load-carrying capacity or transport ability. Doubling the velocity of runoff increases its scouring capacity and transportability to the fifth and sixth powers, respectively (Gupta et al., 2010).

Gully erosion is a characteristic feature on the landscape of Uyo agro-ecological/climatic zone, and is attributed to land use and management, especially continuous cropping with the associated shortened or lack of natural fallow and loss of the protective vegetal cover (Ukpong, 1997; Udoumoh et al., 2020). Gully erosion is an advanced stage of rill erosion. Rills are localised washes or channels created when water concentrates into small rivulets in the field. The little streams or rills carry more soil as they pick up speed or grow in size. The abrasive particles they carry scour the sides and bottom of the channels. Rills are relatively small and can be obliterated by conventional tillage equipment. However, total soil loss, even in a single storm can be great because rill and sheet erosion occur simultaneously. Rills when neglected develop in size and become gullies. Rills can be upto 0.3m deep. If they become any deeper than 0.3m they are referred to as gully erosion. Thus, rill erosion is often described as the intermediate stage between sheet and gully erosion. Sheet erosion is the planar removal of surface soil by the action of either raindrop splash, shallow flows of surface of water, or even by wind. Another name for rill erosion is inter-rill erosion (Suresh, 2006; Aina, 2020).

Gully could also be caused by runoff concentrating at a point on agricultural land. In this case, water concentrates in depression caused by localized weakening of the vegetation cover by grazing or bush burning and enlarges until several depressions coalesce and an incipient channel is formed. Erosion is concentrated at the heads of the depressions where near-vertical scarps develop over which supercritical flow occurs. Some soil properties are detached from the scarp which results in deepening of the channel and undermining of the headwall, leading to collapse and retreat of the scarp up slope (Suresh, 2006).

RAINFALL RUNOFF MANAGEMENT TECHNIQUES FOR EROSION CONTROL

It will not be an overstatement to assert that runoff is perhaps the greatest water management problem on rain-fed crop lands, probably because not only is it the loss of potential water resources but it also causes damaging soil erosion. Runoff occurs when rainfall intensity exceeds the infiltration capacity of the soil which is a measure of the ability of the soil to absorb and transmit rain water. Runoff is limited on soils with a high infiltration capacity. This in turn depends on the water transmission characteristics and structural stability of the soil and its ability to maintain continuous pores. The transmission pores may exist in the soil as a result of coarse texture, good aggregation, or from the burrowing activities of the soil fauna, particularly certain species of earthworms. The rate and amount of runoff are also influences by the intensity and amount of rainfall received, the previous soil moisture content, the degree of relief, slope steepness and aspect. These factors manifest themselves in a wide range of runoff management problems and conservation needs (Aina, 2020).

Runoff is best minimized by ensuring high infiltration of rainwater into the soil through biological conservation measures. Where this cannot be done to full effect, particularly in areas of high-intensity storms or where there are periods of poor crop cover, earth works (physical control measures) can provide surface protection by holding water to give it time to soak through the surface. Such physical conservation measure involves land shaping, the construction of contour bunds, terraces and ridges. These require considerable technical design, supervision, proper construction and maintenance. In contrast, the biological methods include some soil management and agronomic cultural practices that are normally the companion of profitable agriculture such as appropriate land use and preparation, fertility maintenance, crop residue management, the use of cover crops and appropriate crop husbandry (Aina, 2020).

Below are some of the best management practices on erosion control due to runoff:

Mulching

Mulch farming is an efficient method of conserving water and soil by maintaining a protective cover of vegetative residues. One way to improve the condition of the soil is to mulch the area requiring amelioration (FAO, 1995). The beneficial effects of mulching include protection of the soil surface against raindrop impact, decrease in flow velocity by imparting roughness, and improve infiltration capacity. It also enhances burrowing activities of some species of earthworms (e.g. *Hyperiodrilus* spp. and *Eudrilumspp*) which improves transmission of water through the soil profile and reduces surface crushing and runoff and improves soil moisture storage in the root zone (Lal, 1976a). Crop residue mulching is a system of maintaining a protective cover of vegetation residues such as straw, maize stalks, palm fronds and stubble on the soil surface. The system is particularly valuable where a satisfactory plant cover cannot be established rapidly when erosion risk is greatest (FAO, 1993).

Mulching adds organic matter to the soil, reduces weed growth, and virtually eliminates erosion during the period when the ground is covered with mulch. The two principal mulching systems are: in situ mulching system (i.e. a system where plant residue remains where they fall on the grown), and cut-and-carry mulching system (a system where plant residues are brought from elsewhere and used as mulch) (FAO, 2005). Lal (1976a) reports an annual saving of 32% of rainfall in water runoff from mulching in humid western Nigeria. The quantity of mulch required for maintenance of favourable filtration capacity and structural stability depends on the rate of residue decomposition, climate, soil properties, relief and rainfall characteristics.

Vegetation Cover (Cover crops)

Growing cover crops is one of the best management practices for improving organic matter levels of soils and, hence, soil quality. Cover crops help to reduce evaporation, runoff and erosion. The vegetation cover provides shelter to the soil surface by intercepting rain drops which hamper erosion process (Zuazo, 2011). A range of crops which can be used as vegetation cover include grains, oil crops, legumes such as *Mucuna pruriens utilis, Centrosema pubescens, Glycine spp, Setaria spp, Stylosenthes spp*. These are the cover crops which can provide in situ mulch to the soil.

Depending on the land topography, climatic region and other related features it is preferred to use native grass species to alleviate rain drop impacts which therefore reduces runoff an increases rate of infiltration.

Figure 3: A gully in Uyo (near old dumpsite along Uyo village road), gradually becoming stabilized by vegetation cover. Source: Researcher.

For the rainfall intensity of 45mm/h, runoff rate from the grass cover was found to be 4.2 mm/h whereas for shrubs cover it was found to be 9.3 mm/h whereas soil loss remained relatively constant for both the grass and shrub covered plots under the same intensity which reveals the efficiency of grass cover (Xiao et al., 2011). Increasing the grass cover decreases surface runoff (Li, 2011). Moreover, in most areas, grasses have produces desired and intended results for erosion control as they grow rapidly and provide complete protection layer for the ground surface (De, 2006). The most effective way to restore degraded soil is by improving natural vegetation (Garcia-Esringana, 2010). Furthermore, studies by Lal (1988) shows that fallowing for one or two years with the above-named cover crops has been reported to improve soil structure and infiltration capacity.

Conservation Tillage Practices (e.g. zero tillage or no tillage)

Several studies have revealed that conventional plowing and disking breaks down natural (composite) soil aggregates thus creating an avenue for wind and water erosion. In most conservation tillage practices, the number of field operations and soil disturbances are minimised, mulch is used and herbicides are used for weed control. Different types of conservation tillage include: mulch tillage, sub-surface tillage, zero tillage (Onwualu et al., 2006). Repetitive tillage degrades the soil structure and its potential to hold moisture, reduces the amount of organic matter in the soil, breaks up aggregates and reduces the population of soil fauna such as earthworms that contribute to nutrient recycling and soil structure. Avoiding mechanical soil disturbance implies growing crops without mechanical seedbed preparation or soil disturbance since the harvest of the previous crop. The term zero tillage is used for this practice synonymously with terms such as no-till farming, no tillage, direct drilling, and direct seeding (FAO, 2005).

Whereas conventional tillage practices accelerates soil carbon losses and speed up organic matter decomposition; conservation (or reduced) tillage minimize soil carbon losses and thus slow down organic matter decomposition processes. In other words, conventional tillage exposes the organic matter to air and sunlight, and the resultant effect is the lowering of the stable organic matter. As much as a 5-fold reduction in runoff has been reported under no-tillage compared to conventional tillage (Lal, 1976a). The effectiveness of no-tillage farming in soil and water conservation is improved when used in association with planted cover crops. The pulverising effect of conventional tillage can be minimized by reducing the number of operations on the land. This can be achieved by cultivating only the small strips of land required for seedbeds thus leaving wide untilled zones (strip zone tillage); by carrying out tillage with a mulch retained on the ground (mulch tillage) or completing as many activities as possible in one pass (minimum tillage) as with plough-plant operations (Aina, 2020).

Repeated application of organic amendment (manure)

Saying that organic matter is the key to health and contributes to soil productivity is saying the obvious. Many studies have revealed that a single manure application will not increase the percentage organic matter significantly. In other words, it takes ample time to improve the soil organic matter level. It is unlikely that a single incorporation of manure or cover crops will noticeably increase the percentage of organic matter. Repeated application of an organic amendment in continuation with reduced tillage will improve the organic matter level (Umass, 2020), thereby producing more biomass.

The use of organic inputs such as crop residues and manure have great potential for improving soil productivity and crop yield through improvement of the soil physical, chemical, microbiological and nutrient supply (Abassi et al., 2009). Ofori and Santana (1990) noted that cow dung improves the productivity of soil more than inorganic fertilizer owing to its slow release of nutrient. Poultry manure (PM), swine waste (SW), cow dung (CD), and sewage sludge (SS) were added to a hydromorphic utisol and it influenced the physical properties of soil (Okenmuo et al., 2018). Physical properties of soil influenced by animal wastes were bulk density, total porosity, hydraulic conductivity, gravimetric moisture constants, aggregate stability, and rheological characteristics. Organic manures can also increase water infiltration, water holding capacity, water content and aeration (McCauley, 2017). Erosion will be reduced and root penetration and tillage operation will be enhanced when the soil is well aggregated (USDA, 2003). Addition of soil organic matter is also an important soil conservation measure that accomplishes soil carbon sequestration and mitigation of climate change (McCauley, 2017; NDSU, 2020).

Crop Rotation

Another technique of improving the soil organic matter content as a result of the decomposition of the root mass, as well as the reduction of erosion is he rotation of annual row crops with perennial grass or legume sods. The perennial grasses will sure add biomass above the ground as well as below-the-ground, thus maintaining adequate stability of the aggregate (Syed et al., 2012; Okafor et al., 2017).

CONCLUSION AND RECOMMENDATIONS

Soil, as the most important component of an ecosystem, can secure the food production, enhance the water resources and promote the biodiversity and carbon sequestration if it is well managed. Soil erosion can be managed and controlled through cultivation of vegetation cover, application of proper soil and water conservation practices, proper crop management techniques, reduced human interference on the environment, government assistance and public awareness activities/ campaigns through agricultural extension workers.

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ISSN: 2067-3809