



Strategies for Restoration of Soil Quality to Mitigate Land Degradation in Semi-Arid North Western Nigeria

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Abstract: Soil degradation alone was reportedly estimated to affect approximately 485 million Africans, with annual long-term costs of between US \$ 95-279 billion. Increasing agricultural productivity in Nigeria, with its over 70% marginal/problem land and a decreasing per capital arable land (PCAL), would, therefore, need sound and adequate information on soil quality enhancement. Soil organic carbon (SOC) plays a crucial role in influencing physical, chemical and biological properties and the overall soil quality. Some common strategies for restoration of SOC include conservation tillage which reduces decomposition, fallow, agroforestry, improved pasture and optimal fertilization which improves C levels through enhanced biomass production. After 6 years of natural fallow, the un-amended soils in the Samaru experiment recorded slight decrease in soil organic matter (SOC) content from 7.04 t C ha⁻¹ to 6.83 t C ha⁻¹ representing about 3% reduction. This result shows that the resilient power of the un-amended soils (degraded) to self-restoration is low under natural fallow. The potential for carbon sequestration by the use of eucalyptus (*Eucalyptus globulus*) and neem (*Azadirachta indica*) trees in afforestation in NW Nigeria is about 23 g C m⁻² yr⁻¹ to 305 g C m⁻² yr⁻¹ over rates in unstabilized sand dune (control). These values would increase substantially if management practices such as fertilization are introduced. The use of NPK between 1977 and 1995, a period of 18 years in the Samaru experiment, improved SOC content from 4.95 t C ha⁻¹ to 7.30 t C ha⁻¹, reflecting a rate of 13 g C m⁻² yr⁻¹. This rate is about 50% less the rate using manure alone and 75% less using manure with NPK. The use of N fertilization alone for 18 years also resulted in an increase of about 2.83 t C ha⁻¹ or 16 g C m⁻² yr⁻¹. In the NE Nigeria, the use of manure along with the selected restorative strategies gave the fastest options for restoring soil quality and productivity.

Key words: Land degradation, soil organic matter, soil quality, biomass production.

Land degradation is defined as the loss of resilience of land, that is, the loss of the ability of land under a particular form of land use to withstand, or recover from shock or stress by itself, without external assistance (FAO, 1991). Land degradation involves the degradation of three commonly and closely interrelated resources: soil, water and vegetation, with a consequent loss of soil through erosion. Darkoh (2003) identified land degradation as the most important environmental problem facing Africa, both in terms of economic significance and the area of land and number of people potentially affected. Soil degradation alone was reportedly estimated to affect approximately 485 million Africans, about 46% of the total population with annual long-term costs of between 95 and 279 US billion (UNEP, 2015).

Degraded or marginal lands are areas where low and variable rainfall, low temperatures

and/or steep slopes severely limit natural biological productivity. They are called 'marginal' as intensive agriculture is not possible. Drylands in Africa, excluding the hyper-arid deserts, comprise 1,277 million ha of potentially productive marginal lands (Darkoh, 2003). They support about one-third of the world's rural population who earn their living mainly by livestock grazing and subsistent farming. In Nigeria, about 17 million ha of drylands exists (FAO, 1969). Because marginal lands are ecologically very fragile, they require careful management in particular. In the past, when human population was less, man established a harmonious partnership with nature and marginal lands were never cultivated. Today, with increasing population pressure, marginal lands are often used in ways that are ecologically unsound. For example, in arid zones overgrazing can set off a chain of events leading to irreparable soil degradation. To satisfy human needs without damaging the

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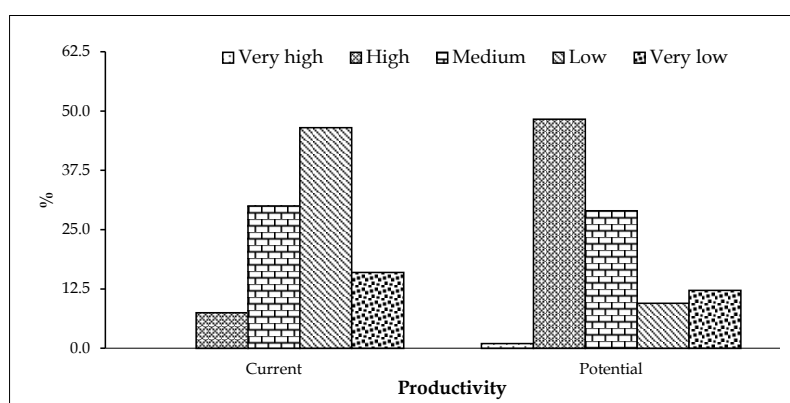


Fig. 1. Land productivity and potentialities in Nigeria (Extracted from Riquier *et al.*, 1970).

environment, new management systems must be developed for these areas to restore good soil quality.

Riquier *et al.* (1970) classified lands in Nigeria according to their present productivity and potentialities under adequate land management practices (Fig. 1). Of the total land area, over 60% are considered of low productivity or problem/marginal land but with adequate management, there could be a three-fold reduction in the extent of problematic lands (FDLAR, 1991). The average per capita

arable land (PCAL) in Nigeria, according to Shuaib *et al.* (1997), reduced from 0.77 ha in 1991 to about 0.35 ha by 2010, only slightly above the world average of 0.33 ha. Raji and Owootomo (2007) in a review of soil survey reports in NW Nigeria identified about 150 soil series, but only 126 could be documented after eliminating duplications. Of these, over 70% of the soil series were dominated by well-drained sandy soils; acidic, low fertility, low organic matter content and inherently of low productivity (Fig. 2). These are diagnostic

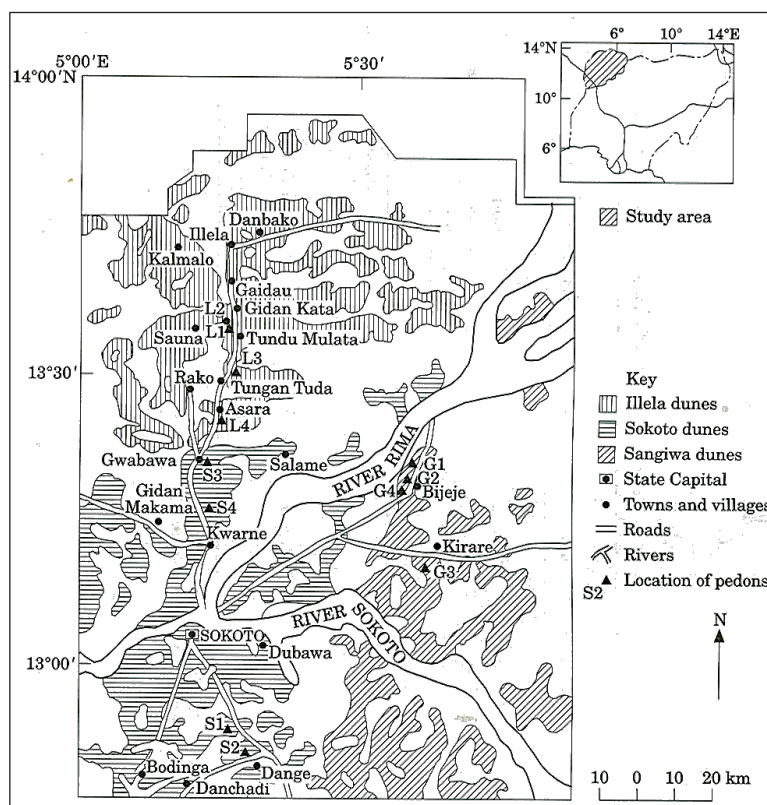


Fig. 2. Distribution of sand dunes in the Sokoto Basin, NW Nigeria.

characteristics of poor soil quality. To prevent further environmental degradation, efforts must be made to improve the soil quality. There are basically two options, one involves the intensification of agriculture on existing land while other option entails extension of agriculture into new lands. It is important to note that intensification and extension of agriculture to marginal or problem lands have created severe ecological problems of deforestation, soil degradation, environmental pollution and further decreased agricultural productivity. Increasing agricultural productivity in Nigeria, with its over 70% marginal/problem land and a decreasing PCAL, would, therefore, need sound and adequate soil information on soil quality enhancement.

Soil quality, defined as the capacity of a specific kind of soil to function (Karlen *et al.*, 1997), is a manifestation of the inherent and dynamic properties of the soils. While the inherent properties such as soil texture, drainage class and depth are unlikely to change with management practices, the dynamic properties can change with time as a result of human intervention. The quality of any soil depends in part on the soil's natural or inherent composition (inherent soil quality), which is a function of soil formation factors (e.g., parent material and topography) and also to changes related to human use and management (dynamic soil quality) (Larson and Pierce, 1991). Because dynamic properties change fast as a result of intensive input-based agricultural practices, they are keys to soil quality assessment, serving as soil quality indicators. Historically, assessment of soil fertility indicators, such as soil organic carbon (SOC), available N and pH, have been emphasized, thereby supporting the concept of the importance of dynamic soil properties and water retention-release behavior in soil quality. High-quality soils will not only be better producers of food and fiber for the world's growing population but will also play a major role in stabilizing natural ecosystems and in enhancing air and water quality.

The importance of organic matter in improving soil properties and processes has widely been documented (Zebbarth *et al.*, 1999; Madari *et al.*, 2005). Soil organic carbon (SOC) plays a crucial role in influencing physical, chemical and biological properties and the overall soil quality (Gregorich *et al.*,

1998). Restoration of SOC in arable lands also represents a potential sink of atmospheric CO₂ (Banger *et al.*, 2009). Therefore, the amount and quality of SOC in agricultural soils is quite critical in influencing both soil productivity and environmental quality (Lal, 2015). Some common strategies for restoration of SOC include conservation tillage which reduces decomposition (Chen *et al.*, 2011) fallow, agroforestry and improved pasture and optimal fertilization which increases C input by enhancing biomass production.

Properties of Soils of NW Nigeria

The marginal and degraded soils of northwestern Nigeria had similar soil properties. Morphologically, most of the soils had similar properties, especially in the surface horizons. They were deep to very deep, well-drained and all had a color hue of 7.5YR and sandy texture in the Ap horizons. They had moderate medium sub-angular blocky peds of friable to very friable consistence. Many fine quartz grains occur throughout the depth of the pedons while few ants and termite holes and nests indicated limited faunal pedoturbation within the soils. Texturally, the marginal soils are sand in the surface horizon with sand content generally greater than 90% and decreased with soil depth. The clay content was also generally less than 5% while the porosity was also generally low with high bulk densities that were greater than 1.5 mg m⁻³ in virtually all the soils (Table 1). The marginal soils are therefore, generally low in the water and nutrient holding capacity and because of the fairly high bulk density, root generation would likely be sub-optimum (Raji and Jimba, 1999; Raji and Obidike, 2011; Raji *et al.* 1995, 1996, 2008).

All the soils have been reported to be low in nutrient nitrogen, phosphorus, exchangeable bases and organic matter, usually below critical limits. It is however desirable that the vast marginal lands be adequately characterized and if possible, differentiated for proper fertility management at farmer's level. In the studies of the chemical properties, Raji and Jimba (1999), Raji and Obidike (2011), Raji *et al.* (1995, 1996, 2004) indicated similar fertility levels in all the dunes. The pH values, were generally very strongly acidic in the surface horizons with acidity increasing with depth. The acidic nature of the soils could be attributed to the

Table 1. Mean values of physical properties of selected sand dune soils

Soil properties	Illela		Sokoto		Sangiwa		Wurno	
	Surface	Subsoil	Surface	Subsoil	Surface	Subsoil	Surface	Subsoil
Sand (%)	94.00	90.70	91.50	81.90	89.00	83.40	64.00	72.00
Silt (%)	1.50	1.70	2.50	5.00	7.50	6.00	20.00	16.00
Clay (%)	4.50	7.60	6.00	13.00	4.00	10.50	16.00	12.00
Texture	Sand	Sand	Sand	Loamy sand	Sand	Loamy sand	Sandy loam	Sandy loam
Porosity (%)	33.21	39.32	39.62	42.71	39.87	46.53	41.50	39.60
Bulk density (Mg M ⁻³)	1.77	1.61	1.60	1.52	1.59	1.41	1.55	1.60

acidic parent material, which was siliceous in all the soils and also to the leaching of bases out of the solum.

Organic matter, the key index to soil quality and related properties were extremely low reflecting the low biomass of the Sudano-Sahelian ecosystem. Organic matter is “life” to the soil like blood is to human. The organic carbon values were generally less than 2 g kg⁻¹ in all the soils while the available phosphorus

ranged from 1.78 to 20.19 mg kg⁻¹. There were similar levels of exchangeable bases, that was essentially very low in all the soils but occurred in the order Ca > Mg > K > Na as also reported by other workers for the Nigerian savanna (Ogunwale *et al.*, 1975; Esu, 1986). The exchangeable Ca content was generally less than 2 cmol kg⁻¹ but occupied over 50% of the adsorption complex. Exchangeable Mg was below 1 cmol kg⁻¹ while exchangeable K

Table 2. Mean values of fertility properties of the surface horizon of selected sand dune soils

Soil properties	Illela		Sokoto		Sangiwa		Wurno	
	Surface	Subsoil	Surface	Subsoil	Surface	Subsoil	Surface	Subsoil
pH	5.80	6.20	5.90	5.00	5.40	4.50	5.00	5.00
Organic carbon	0.90	0.36	1.10	0.65	1.10	0.33	1.19	1.19
Available phosphorus	25.33	60.21	12.05	8.76	4.24	3.15	2.68	4.48
Exch. Ca	0.90	1.19	0.86	0.80	0.71	0.89	0.01	0.02
Exch. Mg	0.30	0.32	0.33	0.32	0.21	0.31	0.03	0.05
Exch. K	0.07	0.04	0.06	0.05	0.12	0.10	1.10	0.05
Exch. Na	0.04	0.04	0.03	0.03	0.03	0.05	0.09	0.01
Exch. Acidity	0.38	0.44	0.40	1.15	0.60	0.98	1.00	0.80
Total bases	1.32	1.59	1.28	1.20	1.07	1.34	1.23	0.93
CEC	1.75	2.77	2.20	3.12	1.48	2.53	2.81	2.50
ECEC	1.70	2.02	1.68	2.36	1.67	2.33	2.23	1.73
Base saturation	69.00	51.00	61.00	41.00	73.00	51.00	44.00	37.00
Electrical conductivity	0.11	0.07	0.13	0.09	0.09	0.07	0.60	0.17
Exch sodium percentage	2.25	1.62	1.50	1.15	2.25	1.92	3.20	0.40
CaCO ₃ equivalent	7.75	6.69	3.50	2.15	5.75	5.92	Nd	Nd
Available Cu	2.35	2.40	2.39	2.46	1.46	1.99	4.00	6.00
Available Zn	7.13	8.10	6.60	5.55	6.11	5.85	0.60	1.00
Available Mn	20.33	9.51	28.13	21.18	21.60	25.73	2.50	1.50
Available Fe	33.41	36.57	35.05	37.10	24.83	18.69	9.00	4.10
Extractable Fed	0.48	0.48	0.54	1.09	0.18	0.34	Nd	Nd
Extractable Feox	0.11	0.11	0.19	0.22	0.06	0.08	Nd	Nd
Extractable Ald	0.73	0.73	1.12	1.11	0.81	0.87	Nd	Nd
Extractable Alox	0.60	0.60	0.82	0.71	0.66	0.68	Nd	Nd

was also less than 0.2 cmol kg^{-1} and constituted about 15 and 5% of the adsorption sites, respectively (Raji *et al.*, 2004). The values of the DTPA extractable cationic micronutrients (Cu, Zn, Mn, Fe), on the other hand, were all above the critical limits of 0.2, 0.8, 1.0 and 4.5 mg kg^{-1} respectively (Lindsay and Norvell, 1978). Extractable Cu ranged from 0.46 to 1.27 mg kg^{-1} , Zn ranged from 1.10 to 3.50 mg kg^{-1} , Mn ranged from 1.6 to 38.8 mg kg^{-1} while Fe also ranged from 4.0 to 16.0 mg kg^{-1} in the soils (Table 2). Thus all the soils were adequately endowed with micronutrients (Raji *et al.*, 2008). The high levels of the micronutrients could most probably be traced to the soil parent material since all the soils have been reported to originate from a common parent material (Sombroek and Zonneveld, 1971).

X-ray diffraction analyses of the sand and silt fractions indicated that the soils were composed almost entirely of quartz (Fig. 3) with some quantity of kaolinite (0.718 and 0.356 nm peaks) and magnetite (0.370, 0.293 and 0.256 nm peaks). The dominance of the sand and silt fractions by quartz reflects the siliceous nature of the parent material. X-ray diffraction analyses of the clay fractions (Fig. 3c and d) indicated that kaolinite was the dominant mineral. Kaolinite was indicated by the sharp 0.718, 0.448 and 0.358 nm peaks and also by 0.259 and 0.235 nm peaks. Quartz was the next dominant mineral after kaolinite as shown by the 0.426, 0.334, 0.229, 0.213 nm peaks.

Based on the criteria of the USDA Soil Taxonomy (1999) and because of the absence of any discernible B-horizon and morphological, physicochemical similarities, most of the soil were classified at the Order level as Entisols and at the family level as Ustic Quartzipsamments, isohyperthermic. However, few pedons were classified as Kanhaplic Haplustults at the Subgroup level, because of their low base saturation and simple profile arrangement that lacked plinthite and mottles but had argillic horizons.

Strategies for Restoration of Soil Quality

Several agricultural technologies have been proven to be effective in remedying the constraints listed and identified for the soils. Some of them are the use of fallow,

agroforestry, improved pasture, fertilization and afforestation.

Fallow

Fallow as a restorative strategy has long been used and considered as a traditional method (Fig. 3). We utilized the opportunity of the Long-term DNPK trial in the Institute for Agricultural Research (IAR) at Ahmadu Bello University, Zaria, to study the impact of fallow on soil quality. The DNPK plots in Samaru have been under natural fallow since 1995 after 45 years of continuous cultivation. In 2001, after 6 years of natural fallow, the un-amended soils experienced a slight decrease in soil organic matter (SOC) content from 7.04 t C ha^{-1} to 6.83 t C ha^{-1} representing about 3% reduction. This result shows that the resilient power of the un-amended soils (degraded) to self-restoration is low under natural fallow. Research reports have shown varied roles that fallow plays in carbon sequestration in soils. Juo *et al.* (1995) reported that 12-13 years of bush fallow restored the natural fertility on a farm following forest clearance. However, Rasmussen (1998) identified the frequency of summer fallow to negatively influence the SOC content in the United States. In fallow plots which had received manure under cultivation, in the DNPK plots, SOC content increased from $13.17 \text{ t C ha}^{-1}$ to $19.64 \text{ t C ha}^{-1}$ in 6 years or $108 \text{ g C m}^{-2} \text{ yr}^{-1}$. The highest increase in SOC content was obtained on plots previously fertilized with NPK. Increase in SOC of such plots was about 150% of the pre-fallow levels. Additionally, plots receiving manure with NPK fertilizer sequestered up to $24.62 \text{ t C ha}^{-1}$ against $15.12 \text{ t C ha}^{-1}$ prior to the fallow period (ie $158 \text{ g C m}^{-2} \text{ yr}^{-1}$). Generally, the rate of SOC sequestration during the fallow period is approximately 400% more than the rates under continuous cultivation. Very high rates during the fallow periods could be attributed to the highly degraded nature of the soils initially since organic matter (crop residue) is normally harvested annually from the DNPK plots under continuous cultivation. The non-degraded soils receiving either inorganic fertilizers or manure or a combination of these were more resilient in self-restoration under bush fallow. The results of our work also revealed that the resilient power for self-restoration of degraded lands decreases with the number of fallow and that

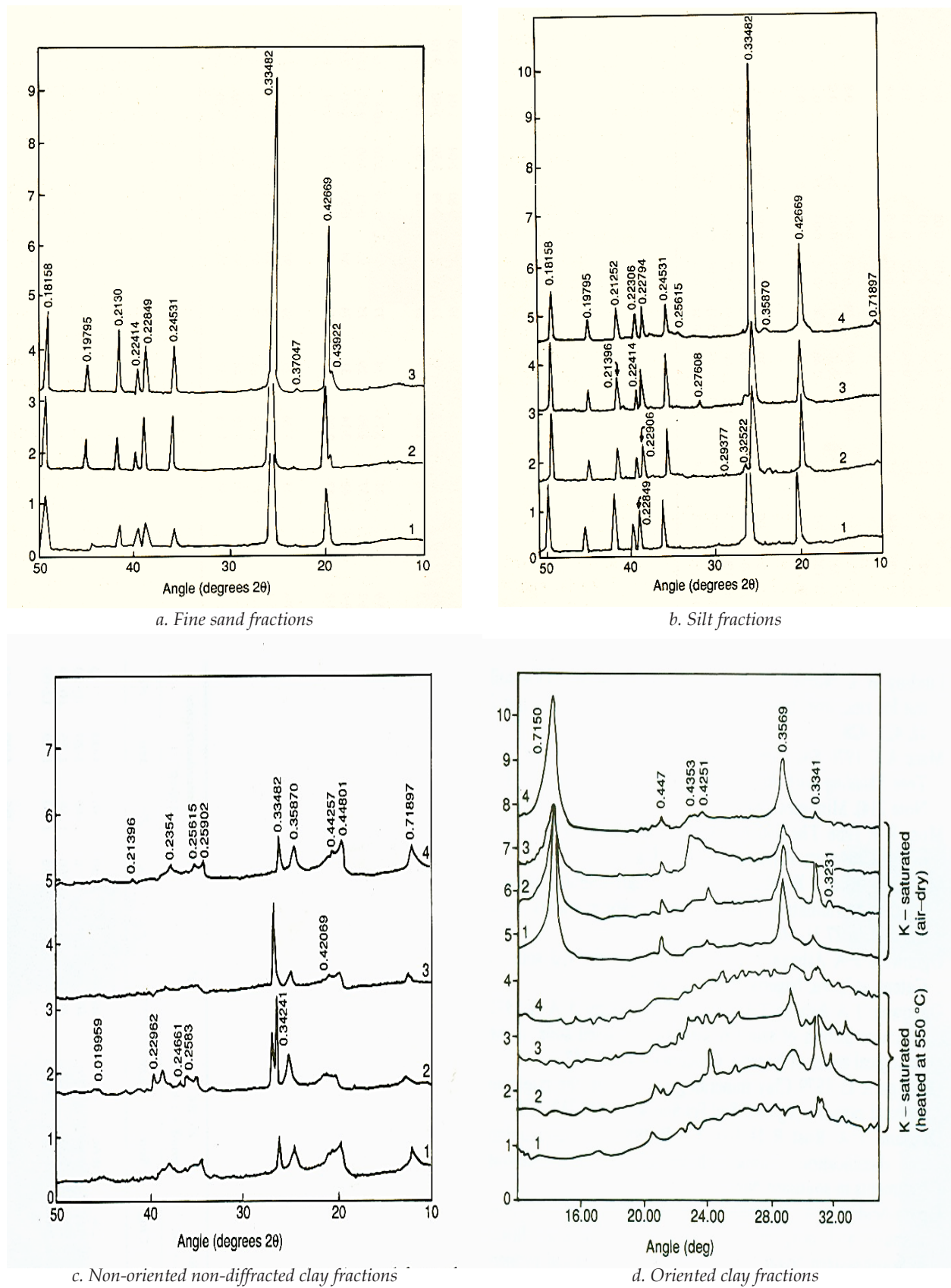


Fig. 3. X-Ray diffractograms of the sand dune soils.

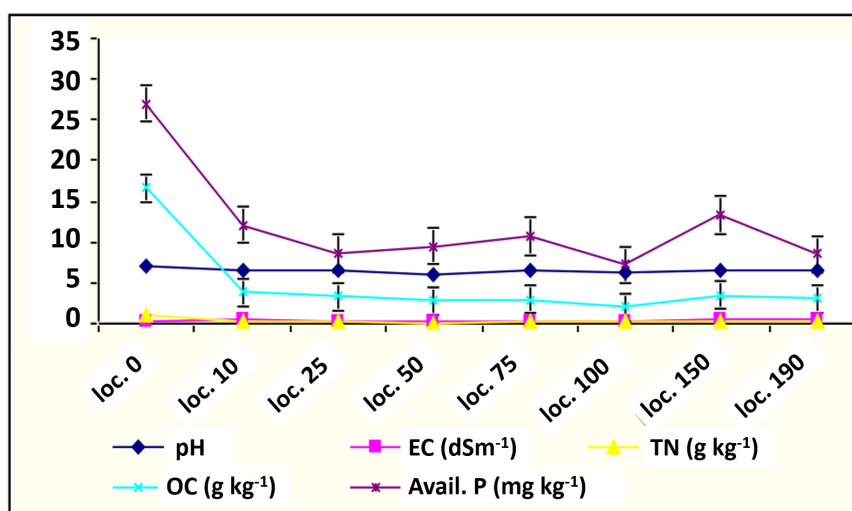


Fig. 4. Agroforestry practice on the sand dune in NW Nigeria.

fallow shorter than six years may be optimum to fully restore highly degraded tropical soils.

Agroforestry

Several authors (Lal, 1999; Batjes, 2001) have reported the use of agro-forestry and or alley cropping (Fig. 4) in the rehabilitation of degraded lands in several climates with resounding success. In our study of the use of Afforestation/Agroforestry/alley cropping as a management option, Raji *et al.* (2004) and Samndi *et al.* (2007) studied the sand dune stabilization trial at Gidan Kaura, north of Illela, Sokoto State and also took advantage of the well-established teak plantation at Nibia Forest in Kaduna State respectively. Afforestation is recognized not only as a major sink for soil carbon but as well as accumulating carbon above ground. It can also make significant contributions to soil carbon even in drylands (Silver *et al.*, 2000; Lal *et al.*, 2003). However, management practices such as fertilization, liming, harvesting and site preparation besides choice of appropriate species have a beneficial impact on SOC sequestration (Lal *et al.*, 2003).

Sand dune stabilization trials in Gidan Kaura, wherein besides the screening for appropriate tree species, no other management practice was followed, it was revealed that SOC under eucalyptus in shelter belt was sequestered up to 39.09 t C ha⁻¹ in 12 years of the trial. This value is about 16 times the SOC in the unstabilized sand dune (control) and gives SOC rate of accumulation of about 305 g C m⁻² yr⁻¹. Post and Kwon (2000) also reported rates of up to 300 g C m⁻² yr⁻¹ in a subtropical wet forest

plantation. The rate of SOC accumulation in this semi-arid environment is, however, greater than 1150 g C m⁻² in the top 10 cm of soil under the same fast-growing eucalyptus trees after 12-13 years of growth in a wet tropical forest that was previously under sugar cane field (Bashkin and Binkley, 1998).

The rate of SOC mineralization is, however, higher under wetter tropical conditions than dry semi-arid regions because of increased biological activities (Post and Kwon 2000). The use of live fencing, a common practice around residential compounds in the semi-arid regions resulted in over 110% increase in SOC over their control. However, when direct tree re-vegetation is facilitated by the use of a polymer that absorbs water many times its own mass, the increase in SOC sequestration rate was 141% over the control. The potential for SOC sequestration by the use of eucalyptus (*Eucalyptus globulus*) and neem (*Azadirachta indica*) trees in afforestation in NW Nigeria is about 23 g C m⁻² yr⁻¹ to 305 g C m⁻² yr⁻¹ over the control. These values would increase substantially if management practices such as fertilization are introduced. Fertilization is particularly important because most forest (s) are N-limiting (Magill and Aber, 2000; Post and Kwon, 2000).

The use of afforestation, however, may also immobilizes plant nutrients from the soil into the above ground mass and thus may lead to further degradation of such soils as removal of Ca, Mg, K and other micronutrients by teak in Nigeria reported by Samndi *et al.* (2007).

Improved Pasture

Pasture, especially the planting of improved leguminous grasses has been reported to maximize the benefit of natural fallow several folds. In this context, use of improved pasture in the rehabilitation of the marginal lands of NW Nigeria, the long-term pasture land at National Animal Production Research Institute (NAPRI), Shika was evaluated. Improved pasture, *Brachiaria decumbens* (BD), had the greatest potential of SOC sequestration of the three species screened in the sub-humid savanna of Nigeria.

It sequestered about 20 t C ha⁻¹ in 35 years or about 825 g C m⁻² yr⁻¹ over the control. This rate is several times more than the rate under natural fallow and that (110 g C m⁻² yr⁻¹) reported by Post and Kwon (2000) for the Grassland Conservation Reserve program of the United States. However, Fisher *et al.* (1994) also reported between 800 and 1300 g C m⁻² yr⁻¹ increases in SOC when a native tropical savanna was replaced with productive, deep-rooting exotic grasses in the first 3-6 years. These facts suggest that improved or exotic grasses sequester SOC faster than natural fallow and that longer time periods are required for pronounced increases in SOC under the condition of low grass productivity. The change in SOC may be due to increased inputs obtained from increased production and as a result of fertilizer application. High carbon contributions have been reported from input from plant roots at grassland sites (Farage *et al.*, 2003) that provides the potential to increase SOC in pastures.

Generally, the soils under pasture exhibited significantly higher contents of available phosphorus, acidity and micronutrient Cu, Zn and Mn than the control. The levels of exchangeable Ca, K, Na, soil pH and micronutrient Fe were all significantly higher under pastures when compared with soils under continuous cultivation. Under the pastures, soils under *Brachiaria decumbens* (BD) produced the highest organic matter and recorded favourable soil properties studied followed by a mixture of BD with *Digitaria smutsii* (DS) while DS alone produced the least. The better performance of *Brachiaria decumbens* may be ascribed to the fact that it thrives better than *Digitaria smutsii* in well-drained drought-prone soils as

observed in the Nigerian savanna. It, therefore, produced the highest organic matter build-up that encouraged higher biological activity and nutrient recycling. *Brachiaria decumbens* is therefore recommended for reclamation of degraded lands, especially in the Nigerian savanna.

Fertilization

Application of fertilizer, no doubt is universally agreed to be the most reliable and fastest means of providing nutrients to the crops. A well-planned fertility program could provide a "balanced diet" of nutrients to plants and replace any plant uptake. A 45 years long-term DNPK trial at IAR, Samaru highlights the impact of long-term fertilizer application on the quality of soils in the savanna agroecosystems. Important among the recommended management practices for SOC sequestration on cropland is residue incorporation. Soil organic carbon among the DNPK treatments ranged from 4.95 t C ha⁻¹ to 8.64 t C ha⁻¹ in 1977. When compared with the control, this represents a decrease of 0.28 t C ha⁻¹ after 27 years of continuous N fertilization but about 68% increase under continuous manure application (3.55 t C ha⁻¹). This means that the addition of manure as a soil fertility restoration practice for increased crop production leads to increased sequestration of carbon. However, the addition of mineral NPK fertilizer to manure did not improve soil C sequestration in these soils. In Versailles experiment in France where a 50% decline in SOC was observed in 50 years (FAO, 2001). However, in the same period of 45 years, the use of continuous NPK application resulted in an only slight increase in SOC (3%) over the un-amended soil while manure with NPK gave 115% more SOC in the DNPK trial at Samaru, Nigeria. However, Halvorson *et al.* (1999) reported an increase in SOC from 15 Mg ha⁻¹ for zero N fertilizer use to 17 Mg ha⁻¹ for a 134 kg N ha⁻¹ (13% increase) after eleven crops in Akron, Colorado. Application of farmyard manure resulted in doubling the SOC content in the Rothamsted long-term agronomic experiment. Also in contrast, continuous application of only N fertilizer also resulted in an increase of 1.26 t C ha⁻¹ over the control (FAO, 2001).

The use of NPK between 1977 and 1995, a period of 18 years, improved SOC content

from 4.95 t C ha⁻¹ to 7.30 t C ha⁻¹, i.e. at rate of 13 g C m⁻² yr⁻¹. This rate is about 50% less than the rate using manure alone and 75% less using manure with NPK. Drinkwater *et al.* (1998) obtained slightly lower values of 2.2 t C ha⁻¹ in Pennsylvania in 15 years using chemical nitrogenous fertilizers. Crop residue management is another important method of sequestering C in soil and increasing the soil organic matter content. However, Drinkwater *et al.* (1998) have shown that manure application resulted in 5.5 times more SOC over rates from nitrogenous fertilizers compared with the 3 times SOC under legume-based rotation. This is because manure is a valuable source of SOC and it promotes the formation and stabilization of soil macro-aggregates and particulate organic matter. In addition to this, manure is more resistant to microbial decomposition than plant residues. Gregorich *et al.* (1998) found that soils receiving manure had large quantities of soluble carbon with a slower turnover rate than in control or fertilized plots. There is no doubt that the use of manure, on a long-term basis, improve soil C content when compared with other management options practiced within the sub-humid savanna of Nigeria. Results from the un-amended soil also tend to indicate that the removal of crop residue for livestock feeding, a common practice in the study area, drive the system to a new steady state of about 6 t C ha⁻¹. Using manure alone also resulted in doubling the SOC content when compared with the control and the use of NPK fertilization gives results similar to those obtained from the Rothamsted experiments (FAO, 2001). These results have shown that practices like manure application that enhances soil carbon sequestration (SCS) improves soil quality and reduce agricultural contribution to carbon dioxide emissions.

Conclusion and Management Implications

Soil organic carbon (SOC) plays a crucial role in influencing physical, chemical and biological properties and the overall soil quality. In the degraded lands, the use of manure along with selected restorative strategies such as fertilization, agroforestry, improved pasture and fallow were the fastest options for restoring soil quality and productivity. Fertilization alone gave restorative rate of about 50% less than the rate utilizing manure alone and 75% less using manure with NPK. The result of this

study showed that the resilient power of the un-amended soils (degraded) to self-restoration is low under natural fallow. For optimum and efficient restoration of degraded lands, it is therefore, recommended that incorporation of manure be part of any restorative strategy to obtain maximum effect.

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